
**A bi-level system dynamics modeling framework to evaluate costs
and benefits of implementing Controller Pilot Data Link Communications and
Decision Support Tools in a non-integrated and integrated scenario**

by

Debayan Sen

Thesis submitted to the Faculty of the Virginia Polytechnic Institute
and State University in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil Engineering

APPROVED BY:

Dr. Antonio A. Trani, Chairman

Dr. Hojong Baik

Dr. Dusan Teodorovic

December, 2003
Blacksburg, Virginia

Keywords: Systems dynamic, Air traffic management, URET, TMA, CPDLC, PFAST,
Data link, Simulation, Modeling, Benefit cost analysis.

Copyright 2003, Debayan Sen.

A bi-level system dynamics modeling framework to evaluate costs and benefits of implementing Controller Pilot Data Link Communications and Decision Support Tools in a non-integrated and integrated scenario
(Debayan Sen)

ABSTRACT

A modeling framework to evaluate the costs and benefits of implementation of Controller Pilot Data Link Communication (CPDLC), and Air Traffic Management (ATM) decision support tools is proposed in this paper. The benefit/cost evaluation is carried out for four key alternatives namely alternative A: Do nothing scenario (only voice channel), alternative B: Voice channel supplemented with CPDLC, alternative C: Alternative B with ATM tools in a non-integrated scenario and finally alternative D: Alternative B with ATM tools in an integrated scenario. It is a bi-level model that captures the linkages between various technologies at a lower microscopic level using a daily microscopic model (DATSIM) and transfers the measures of effectiveness to a higher macroscopic level. DATSIM stands for Data Link and Air Traffic Technologies SIMulation and it simulates air traffic in the enroute sector and terminal airspace for a single day and captures the measures of effectiveness at a microscopic level and feeds its output to the macroscopic annual model which then runs over the entire life cycle of the system. Airspace dwell time benefit data from the microscopic model is regressed into three dimensional benefit surfaces as a function of the equipage level of aircraft and aircraft density and embedded into the macroscopic model. The main function of the annual model is to ascertain economic viability of any deployment schedule or alternative over the entire life cycle of the system. The life cycle cost model is composed of four modules namely: Operational benefits module, Safety benefit module,

Technology cost module and Training cost module.

Analysis using the model showed that an enroute sector gets congested at aircraft densities greater 630 per day. This is mainly because the controller workload gets saturated at that traffic volume per day. Benefits realized in alternatives B, C and D as compared to alternative A increased exponentially at traffic densities greater than 630 i.e. when controller workload for alternative A becomes saturated.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Dr. Antonio Trani for his valuable guidance and help rendered in the last three years that I have known him. He has not only been an inspirational figure acting as a guiding light in this research effort but also a wonderful person, a kind of human being I have always aspired to become. I will always be greatly indebted to him for all the understanding and support that he has shown to me during the hardest times of my life. I would also like to thank my committee members, Dr. Dusan Teodorovic and Dr. Hojong Baik for all the help rendered as part of this research effort.

I would like to dedicate this thesis to my parents without whose love, understanding and support this thesis would not have been possible. Thank you mom and dad for always being there for me and for just being such wonderful parents.

I would also like to thank my dearest buddies back in India- Kaizad, Rupesh and Raj who stood by me in the face of adversity and showed what true friends are all about. Thank you dudes, without you guys I wouldn't have made it through.

A special thanks to Deepak for all the conversations that we had on life, death, love, karma, perception, reality and god knows what else. It definitely made my stay in Blacksburg much more interesting. I would also like to thank all the dudes of Blacksburg – Madav, Sandipan, Das, Ritu, Arya, Krishna, Kane, Pittu and everybody else who made my stay in Blacksburg an amazing experience, one that I will cherish throughout my life. Finally, above all, my deepest gratitude to Sai Baba for his guiding grace and blessings.

Table of Contents

ABSTRACT ii

ACKNOWLEDGEMENTS iv

Table of Contents v

LIST OF FIGURES ix

LIST OF TABLES xix

CHAPTER 1: INTRODUCTION 1

1.1 Problem Definition 1

1.2 Need and Evolution of Data Link 2

1.3 Need for Decision Support Tools 5

1.4 Concept of Free Flight 6

1.5 Research Scope, Objective, and Approach 7

1.6 Outline of Thesis 8

CHAPTER 2: DATA LINK & DECISION SUPPORT TOOLS DESCRIPTION 10

- 2.1 Description and functioning of Controller Pilot Data Link Communication 10
- 2.2 Controller Pilot Data Link Communication Implementation Schedule 16
- 2.3 Description of User Request Evaluation Tool 18
- 2.4 Description of the Traffic Management Advisor 24
- 2.5 Description of Passive Final Approach Spacing Tool 27

CHAPTER 3: LITERATURE REVIEW 35

- 3.1 Introduction 35
- 3.2 Studies on Controller Pilot Data Link Communication 36
- 3.3 Operational Evaluation of URET 52
- 3.4 Operational Evaluation of Traffic Management Advisor 53
- 3.5 Operational Evaluation of Passive Final Approach Spacing Tool 53

CHAPTER 4: METHODOLOGY 55

- 4.1 Introduction 55
- 4.2 System Dynamics 56
- 4.3 Description of STELLA 7.02 56
 - 4.3.1 Interface Layer 58*
 - 4.3.2 Map/Model Layer 59*
 - 4.3.3 Equation Layer 61*
- 4.4 Methodology 61
 - 4.4.1 Alternative A 63*
 - 4.4.2 Alternative B 63*
 - 4.4.3 Alternative C 64*
 - 4.4.4 Alternative D 64*

CHAPTER 5: DESCRIPTION OF MICROSCOPIC MODEL 65

- 5.1 Modeling framework 65
- 5.2 Microscopic Daily Model (DATSIM) 68
 - 5.2.1 *Simulation Parameters of microscopic daily model* 70
 - 5.2.2 *Aircraft Demand Generator module* 71
 - 5.2.3 *Basic Structure of the Enroute Sector Module* 73
 - 5.2.4 *Basic Structure of the Terminal Airspace Module* 77
 - 5.2.5 *Routine Communication Parameters* 97
 - 5.2.6 *Conflict Communication Parameters* 102
 - 5.2.7 *Conflicts in enroute sector* 107
 - 5.2.8 *Conflicts in tracon airspace* 113
 - 5.2.9 *Concept of Transit Time (TT)* 114
 - 5.2.10 *Free Flow Time (FFT)* 117
 - 5.2.11 *Routine Task Diversion Time (RTDT)* 120
 - 5.2.12 *Conflict Diversion Time (CDT)* 124
 - 5.2.13 *Controller Workload* 127
 - 5.2.14 *Airspace Occupation Times* 135
 - 5.2.15 *Communication Channel Utilization* 137
 - 5.2.16 *Pilot Workload* 138
 - 5.2.17 *Interface level of microscopic daily model* 139

CHAPTER 6: MICROSCOPIC MODEL RESULTS 142

- 6.1 Overview 142
- 6.2 Enroute Sector Model 143
 - 6.2.1 *Airspace Occupation Metrics* 143

6.2.2 *Controller Workload Metrics* 236

6.2.3 *Communication Channel Utilization* 246

CHAPTER 7: MACROSCOPIC MODEL DESCRIPTION 249

7.1 Outline of the model 249

7.1.1 *Simulation Parameters* 251

7.1.2 *Airline Benefits module* 251

7.1.3 *Safety Benefit Module* 265

7.1.4 *Training Cost module* 269

7.1.5 *Technology cost module* 277

7.1.6 *Net Benefits module* 291

7.1.7 *Interface layer of macroscopic annual model* 292

CHAPTER 8: CONCLUSIONS 295

8.1 Final Review 295

8.2 Scope for further research 296

BIBLIOGRAPHY 297

APPENDIX A: MICROSCOPIC MODEL INPUT EQUATIONS 301

APPENDIX B: MACROSCOPIC MODEL INPUT EQUATIONS 397

LIST OF FIGURES

- Fig. 1.1 Forecast of ACARS Spectrum Use (C/AFT, 1999). 4*
- Fig. 1.2 Free Flight Phase 1 Core Capabilities [ffp1.nasa.gov] 6*
- Fig. 2.1 Example Boeing 747 FMS FANS-1 Cockpit Display. 12*
- Fig. 2.2 CPDLC Implementation Schedule. 16*
- Fig. 2.3 URET CCLD System Interface [ffp1.nasa.gov] 20*
- Fig. 2.4 Conflict Probe System Block Diagram [Celio, 2000] 21*
- Fig. 2.5 R & D positions showing DSR and URET [Kirk, 2000] 22*
- Fig. 2.6 URET FFP1 Implementation sites [Celio, 2000] 23*
- Fig. 2.7 TMA Display suite at Ft. Worth ARTCC 25*
- Fig. 2.8 TMA hardware/software diagram [Swenson, 1997] 26*
- Fig. 2.9 FAST Data Flow [Mueller, 1998] 29*
- Fig. 2.10 Example of Runway Allocation Decision Tree [ctas.nasa.gov] 33*
- Fig. 4.1 Three Layer Operating Environment in STELLA 57*
- Fig. 4.2 Interface Layer Devices 59*
- Fig. 4.3 Basic Building Blocks at the Map/Model Layer 60*
- Fig. 4.4 Two level model system 62*
- Fig. 4.5 Alternative scenarios 63*
- Fig. 5.1 Two Level Model System 67*
- Fig. 5.2 Outline of Microscopic Daily Model 68*
- Fig. 5.3 Classification of Terminal Airspace Module into types of airport 69*
- Fig. 5.4 Output from Microscopic Daily Model 70*
- Fig. 5.5 Basic structure of the enroute module 74*
- Fig. 5.6 Flow chart outlining the QDR logic 76*

-
- Fig. 5.7 Four corner post system of a hub airport 78*
- Fig. 5.8 Basic Structure of single feeder post of Terminal Airspace 78*
- Fig. 5.9 Basic structure of single arrival stream at single post 79*
- Fig. 5.10 Basic structure of single feeder post 80*
- Fig. 5.11 Flow chart explaining logic of injection of aircraft in tracon airspace 81*
- Fig. 5.12 Flow chart describing the logic of QSR 83*
- Fig. 5.13 Wake vortex 86*
- Fig. 5.14 TMA and ASP statistical delay comparison at metering fix [Swenson, 1997] 87*
- Fig. 5.15 Delay reduction per aircraft in TMA scenario 88*
- Fig. 5.16 Excess in-trail separation [ctas.arc.nasa.gov] 89*
- Fig. 5.17 Excess in-trail separation as a function of aircraft rate 91*
- Fig. 5.18 Merging from two arrival streams into a feeder post 93*
- Fig. 5.19 Flow chart explaining the logic of Queue Merging Rate 94*
- Fig. 5.20 Conflict Time Breakdown 104*
- Fig. 5.21 Regressed conflict equations 109*
- Fig. 5.22 3-fold modification of conflicts due to uret implementation 112*
- Fig. 5.23 Components of Transit Time 116*
- Fig. 5.24 Free Flow Route 117*
- Fig. 5.25 Histogram of Free flow transit time data 118*
- Fig. 5.26 Routine Task Diversion Time Classification 120*
- Fig. 5.27 Diverted Route 121*
- Fig. 5.28 Outline of the interface layer of microscopic model 140*
- Fig. 5.29 Snapshot of the navigation menu at the interface layer 141*
- Fig. 6.1 Mean sector traversal times per aircraft for Alternative A (Uncongested Case)*

144

Fig. 6.2 Sector Traversal Time difference per aircraft for CPDLC Build I v/s ADS (Uncongested Case) 145

Fig. 6.3 Power fit between delta and aircraft density for CPDLC Build I at 100 percent Equipage (Uncongested) 146

Fig. 6.4 Sector Traversal Time difference per aircraft for CPDLC Build I v/s Equipage Level (Uncongested) 147

Fig. 6.5 Linear fit between delta and Equipage level for CPDLC Build I at ADS = 86 (Uncongested) 148

Fig. 6.6 Regression Surface for CPDLC Build I (Uncongested) 149

Fig. 6.7 Sector Traversal Time difference per aircraft for CPDLC Build I and non integrated URET v/s ADS (Uncongested) 150

Fig. 6.8 Power fit between delta and aircraft density for CPDLC Build I with non integrated URET at 25 percent Equipage (Uncongested) 151

Fig. 6.9 Sector time difference per aircraft for CPDLC Build I with non integrated URET v/s Equipage Level (Uncongested) 152

Fig. 6.10 Linear fit between delta and equipage level for CPDLC Build I with non integrated URET at ADS = 86 (Uncongested) 153

Fig. 6.11 Regression Surface for CPDLC Build I with non integrated URET (Uncongested Case) 154

Fig. 6.12 Sector time difference per aircraft for CPDLC Build I and integrated URET (Uncongested) 155

Fig. 6.13 Power fit between delta and aircraft density for CPDLC Build I with integrated URET at 100 percent Equipage (Uncongested) 156

Fig. 6.14 Sector time difference per aircraft for CPDLC Build I with integrated URET

v/s Equipage Level (Uncongested) 157

Fig. 6.15 Linear fit between delta and equipage level for CPDLC Build I with integrated URET at ADS = 86 (Uncongested) 158

Fig. 6.16 Regression surface for CPDLC Build I with integrated URET (Uncongested Case) 159

Fig. 6.17 Sector time difference per aircraft for CPDLC Build IA (Uncongested) 160

Fig. 6.18 Power fit between delta and aircraft density for CPDLC Build IA at 100 percent Equipage (Uncongested) 161

Fig. 6.19 Sector time difference per aircraft for CPDLC Build IA v/s Equipage Level (Uncongested) 161

Fig. 6.20 Linear fit between delta and equipage level for CPDLC Build IA at ADS = 86 (Uncongested) 162

Fig. 6.21 Regression Surface for CPDLC Build IA (Uncongested) 163

Fig. 6.22 Sector time difference per aircraft for CPDLC Build IA and non integrated URET (Uncongested) 164

Fig. 6.23 Power fit between delta and aircraft density for CPDLC Build IA with non integrated URET at 100 percent Equipage (Uncongested) 165

Fig. 6.24 Sector time difference per aircraft for CPDLC Build IA with non integrated URET v/s Equipage Level (Uncongested) 166

Fig. 6.25 Linear fit between delta and equipage level for CPDLC Build IA with non integrated URET at ADS = 86 (Uncongested) 167

Fig. 6.26 Regression Surface for CPDLC Build IA with non integrated URET (Uncongested Case) 168

Fig. 6.27 Sector time difference per aircraft for CPDLC Build IA and integrated URET (Uncongested) 169

Fig. 6.28 Power fit between delta and aircraft density for CPDLC Build IA with integrated URET at 100 percent Equipage (Uncongested) 170

Fig. 6.29 Sector time difference per aircraft for CPDLC Build IA with integrated URET v/s Equipage Level (Uncongested) 171

Fig. 6.30 Linear fit between delta and equipage level for CPDLC Build IA with integrated URET at ADS = 86 (Uncongested) 172

Fig. 6.31 Regression Surface for CPDLC Build IA with integrated URET (Uncongested Case) 173

Fig. 6.32 Sector time difference per aircraft for CPDLC Build II (Uncongested) 174

Fig. 6.33 Power fit between delta and aircraft density for CPDLC Build II at 100 percent Equipage (Uncongested) 175

Fig. 6.34 Sector time difference per aircraft for CPDLC Build II v/s Equipage level (Uncongested) 176

Fig. 6.35 Linear fit between delta and equipage level for CPDLC Build II at ADS = 86 (Uncongested) 177

Fig. 6.36 Regression Surface for CPDLC Build II (Uncongested Case) 178

Fig. 6.37 Sector time difference per aircraft for CPDLC Build II and non integrated URET (Uncongested) 179

Fig. 6.38 Power fit between delta and aircraft density for CPDLC Build II with non integrated URET at 100 percent Equipage (Uncongested) 180

Fig. 6.39 Sector time difference per aircraft for CPDLC Build II with non integrated URET v/s Equipage level (Uncongested) 181

Fig. 6.40 Linear fit between delta and equipage level for CPDLC Build II with non integrated URET at ADS = 86 (Uncongested) 182

Fig. 6.41 Regression surface for CPDLC Build II with non integrated URET (Uncon-

gested case) 183

Fig. 6.42 Sector time difference per aircraft for CPDLC Build II and integrated URET (Uncongested) 184

Fig. 6.43 Power fit between delta and aircraft density for CPDLC Build II with integrated URET at 100 percent Equipage (Uncongested) 185

Fig. 6.44 Sector time difference per aircraft for CPDLC Build II with integrated URET v/s Equipage level (Uncongested) 186

Fig. 6.45 Linear fit between delta and equipage level for CPDLC Build II with integrated URET at ADS = 86 (Uncongested) 187

Fig. 6.46 Regression Surface for CPDLC Build II with integrated URET (Uncongested) 188

Fig. 6.47 Mean Sector Traverse Times for Alternative A (Congested) 190

Fig. 6.48 Sector time difference per aircraft for CPDLC Build I v/s ADS (Congested) 191

Fig. 6.49 Non Linear fit between delta and aircraft density for CPDLC Build I at 100 percent equipage level (Congested) 192

Fig. 6.50 Sector time difference per aircraft for CPDLC Build I v/s Equipage Level (Congested) 193

Fig. 6.51 Exponential fit between delta and equipage level for CPDLC Build I at ADS = 880 (Congested) 194

Fig. 6.52 Regression Surface for CPDLC Build I (Congested) 195

Fig. 6.53 Sector traversal time difference per aircraft for CPDLC Build I and non integrated URET v/s ADS (Congested) 196

Fig. 6.54 Non Linear fit between delta and aircraft density for CPDLC Build I with non integrated URET at 100 percent equipage level (Congested) 197

Fig. 6.55 Sector time difference per aircraft for CPDLC Build I with non integrated URET v/s Equipage Level (Congested) 198

Fig. 6.56 Exponential fit between delta and equipage level for CPDLC Build I with non integrated URET at ADS = 880 (Congested) 199

Fig. 6.57 Regression surface for CPDLC Build I with non integrated URET (Congested) 200

Fig. 6.58 Sector time difference per aircraft for CPDLC Build I and integrated URET (Congested) 201

Fig. 6.59 Non Linear fit between delta and aircraft density for CPDLC Build I with integrated URET at 100 percent equipage level (Congested) 202

Fig. 6.60 Sector time difference per aircraft for CPDLC Build I with integrated URET v/s Equipage Level (Congested) 203

Fig. 6.61 Exponential fit between delta and equipage level for CPDLC Build I with integrated URET at ADS = 880 (Congested) 204

Fig. 6.62 Regression surface for CPDLC Build I with integrated URET (Congested) 205

Fig. 6.63 Sector time difference per aircraft for CPDLC Build IA (Congested) 206

Fig. 6.64 Non Linear fit between delta and aircraft density for CPDLC Build IA at 100 percent equipage level (Congested) 207

Fig. 6.65 Sector time difference per aircraft for CPDLC Build IA v/s Equipage Level (Uncongested) 208

Fig. 6.66 Exponential fit between delta and equipage level for CPDLC Build IA at ADS = 880 (Congested) 209

Fig. 6.67 Regression Surface for CPDLC Build IA (Congested) 210

Fig. 6.68 Sector traversal time difference per aircraft for CPDLC Build IA and non in-

egrated URET (Uncongested) 211

Fig. 6.69 Non Linear fit between delta and aircraft density for CPDLC Build IA with non integrated URET at 100 percent equipage level (Congested) 212

Fig. 6.70 Sector time difference per aircraft for CPDLC Build IA with non integrated URET v/s Equipage Level (Congested) 213

Fig. 6.71 Exponential fit between delta and equipage level for CPDLC Build IA with non integrated URET at ADS = 880 (Congested) 214

Fig. 6.72 Regression surface for CPDLC Build IA with non integrated URET (Congested) 215

Fig. 6.73 Sector time difference per aircraft for CPDLC Build IA and integrated URET (Congested) 216

Fig. 6.74 Non Linear fit between delta and aircraft density for CPDLC Build IA with integrated URET at 100 percent equipage level (Congested) 217

Fig. 6.75 Sector time difference per aircraft for CPDLC Build IA with integrated URET v/s Equipage Level (Uncongested) 218

Fig. 6.76 Exponential fit between delta and equipage level for CPDLC Build IA with integrated URET at ADS = 1304 (Congested) 219

Fig. 6.77 Regression surface for CPDLC Build IA with integrated URET (Congested) 220

Fig. 6.78 Sector time difference per aircraft for CPDLC Build II (Uncongested) 221

Fig. 6.79 Non Linear fit between delta and aircraft density for CPDLC Build II at 100 percent equipage level (Congested) 222

Fig. 6.80 Sector time difference per aircraft for CPDLC Build II v/s Equipage level (Uncongested) 223

Fig. 6.81 Exponential fit between delta and equipage level for CPDLC Build II at ADS

= 880 (Congested) 224

Fig. 6.82 Regression Surface for CPDLC Build II (Congested) 225

Fig. 6.83 Sector traversal time difference per aircraft for CPDLC Build II and non integrated URET (Congested) 226

Fig. 6.84 Non Linear fit between delta and aircraft density for CPDLC Build II with non integrated URET at 100 percent equipage level (Congested) 227

Fig. 6.85 Sector time difference per aircraft for CPDLC Build II with non integrated URET v/s Equipage level (Congested) 228

Fig. 6.86 Exponential fit between delta and equipage level for CPDLC Build II with non integrated URET at ADS = 880 (Congested) 229

Fig. 6.87 Regression Surface for CPDLC Build II with non integrated URET (Congested) 230

Fig. 6.88 Sector time difference per aircraft for CPDLC Build II and integrated URET (Congested) 231

Fig. 6.89 Non Linear fit between delta and aircraft density for CPDLC Build II with integrated URET at 100 percent equipage level (Congested) 232

Fig. 6.90 Sector time difference per aircraft for CPDLC Build II with integrated URET v/s Equipage level (Congested) 233

Fig. 6.91 Exponential fit between delta and equipage level for CPDLC Build II with integrated URET at ADS = 880 (Congested) 234

Fig. 6.92 Regression surface for CPDLC Build II with integrated URET (Congested) 235

Fig. 6.93 Controller utilization versus aircraft density for alternative A 237

Fig. 6.94 Reduction in controller utilization for 100 percent equipage level of aircraft 238

-
- Fig. 6.95 Reduction in controller utilization for ADS = 745 239*
- Fig. 6.96 Controller activity level for period A for 100 percent equipage level 240*
- Fig. 6.97 Controller activity level for period B for 100 percent equipage level 241*
- Fig. 6.98 Controller activity level for period C for 100 percent equipage level 242*
- Fig. 6.99 Controller activity level for period D for 100 percent equipage level 243*
- Fig. 6.100 Controller activity level for period A for ADS = 418 244*
- Fig. 6.101 Controller activity level for period B for ADS = 418 244*
- Fig. 6.102 Controller activity level for period C for ADS = 418 245*
- Fig. 6.103 Controller activity level for period D for ADS = 418 246*
- Fig. 6.104 Voice channel utilization for alternative A 247*
- Fig. 6.105 Reduction in voice channel utilization for 100 percent equipage level of aircraft 248*
- Fig. 6.106 Reduction in voice channel utilization for ADS = 745 248*
- Fig. 7.1 Basic structure of the macroscopic annual model 250*
- Fig. 7.2 Flow chart denoting logic of calculation of enroute savings 261*
- Fig. 7.3 Schematic Outline of the Interface layer 293*
- Fig. 7.4 Snapshot of the navigation menu 294*

LIST OF TABLES

Table 2.1 Uplink Messages 16

Table 5.1 Simulation Parameters of microscopic daily model 71

Table 5.2 Inter Arrival times for base year 72

Table 5.3 Proportion of aircraft entering Tracon Airspace 81

Table 5.4 Descent Speed [BADA] and Proportion for each category of aircraft [AT-ADS] 85

Table 5.5 Intrail Separation in nautical miles 86

Table 5.6 Capacity of terminal airspace 97

Table 5.7 Number of routine communications [Cote, 1999] 98

Table 5.8 Sample Conflict Times 107

Table 5.9 Cumulative Probability of Free Flow Time 119

Table 5.10 Message lag time parameters via datalink 123

Table 6.1 Regression coefficients and confidence intervals (Uncongested) 189

Table 6.2 Regression coefficients and confidence intervals (Congested) 236

Table 7.1 Simulation Parameters of Macroscopic Annual Model 251

Table 7.2 Categorizing flights according to the stage length 252

Table 7.3 Cost per kbit of message [C/AFT, 1999] 289

Table 7.4 ATC VDL Mode 2 parameters [FAA JRC Charts] 290

1.1 Problem Definition

As air traffic density in airspace grows the congestion in the enroute and terminal airspace has become more severe. Part of this congestion is due to the saturation of the voice communication channel between controllers and pilots. Data link is advocated as a supplemental communication channel to voice and promises to ease the congestion in the airspace. Over the past few years, a number of simulation experiments have been carried out (including the development of models) to ascertain the benefits of using data link as a supplemental channel of communication between controllers and pilots. Two such ‘man in the loop’ simulation experiments [FAA Data Link Study Team; 1995, 1996] have been carried out by the Federal Aviation Administration (FAA) at the William J. Hughes Technical Center in Atlantic City.

Apart from the delays caused due to saturation of voice channel, a high proportion of delays in the enroute and terminal areas are caused by aircraft flying rigid, non optimal routes. The rigidity of the route structure ensures a high level of safety by keeping the controller workload low or atleast within manageable limits. The trade off for a higher level of safety is a less efficient air route structure resulting in higher operational costs to users (airline) and service provider (FAA). Decision Support tools have

been developed with the aim to help controllers monitor and process air traffic in a more efficient manner without any significant increase in workload and prototypes of these tools have been evaluated at Indianapolis, Memphis and Dallas Ft. Worth Air Route Traffic Control Centers (ARTCC).

With the advent of data link and decision support tools into the air traffic control system, there are several important questions which this thesis aims to provide a framework to answer. The first question is what would be true benefits of the data link system as a supplement to the existing voice communication channel? The second question is what are the benefits when data link is used in conjunction with decision support tools in a non integrated scenario? The third question what are the additional benefits of integration of decision support tools with data link and do the additional benefits justify the additional cost required for the integration? Each of these research questions constitutes an alternative by itself, the viability of which is to be ascertained. Hence there are four alternatives where:

- Alternative A - Baseline or 'do nothing' scenario
- Alternative B- Implementation of only Controller Pilot Data Link Communication System.
- Alternative C- Implementation of Controller Pilot Data Link Communication System along with Decision Support Tools in a non integrated scenario.
- Alternative D- Implementation of Controller Pilot Data Link Communication System along with Decision Support Tools in an integrated scenario.

Apart from providing a framework to answer the three main questions, this thesis also aims to provide a framework to answer certain secondary questions such as what would be best equipage rate for various ARTCC and aircraft with the necessary Air Traffic Control (ATC) infrastructure to achieve benefits, including a break even point analysis in the investment.

1.2 Need and Evolution of Data Link

Up to a few years ago, flight crews relied exclusively in voice communication channel to relay any data

to their companies or controllers on the ground. Data transmissions related to a emergency or routine data reports like flight number, fuel data, engine performance data etc. the voice channel was the only mean of communicating this information. As the number of flights in the enroute airspace began to increase, the voice channel has become more and more congested leading to delays in the airspace. One of the primary reasons for the development of data link communications has been the growing utilization of voice radio frequencies in NAS. Since the voice channel is available to only one speaker at a time, increases in traffic volume leads rapidly to frequency congestion. When the channel becomes saturated, system performance suffers as clearances become less timely and exchange of information is reduced. Physical constraints of the system rather than information processing resources of the controller limit the system performance. In addition to frequency congestion problems, ATC communications errors degrade efficiency and can affect flight safety. In 1988, the FAA noted that 23 percent of all operational errors (aircraft minimum separation violations) were caused either directly or indirectly by communication errors [C/AFT, 1999].

Congestion in the voice channel, delays and operational errors led to the development and implementation of a data link system called Aircraft Communication Addressing and Reporting System (ACARS). ACARS was developed to support airline-related communications. ACARS is a 2400 bits per second (bps) packet-like system used by civilian aircraft for on-board flight-deck computer interconnections into ground stations. The data is transmitted via Very High Frequency (VHF) and High Frequency (HF) radio, which allows airline flight operations departments to communicate with aircraft in their fleet. The data transmitted usually contains routine items like departure clearances, passenger loads, arrival reports, fuel data, engine performance data, etc. A typical ACARS message consists of the aircraft registration number, flight number and text of the message, the actual length of which is limited to a maximum of 220 characters. ACARS use has grown tremendously in the past ten years. More frequencies have been added to deal with the increased message traffic but the time is fast approaching when the spectrum capacity will be exceeded. Assuming conservative Airline Operational Control (AOC) traffic growth projections and maximum ACARS frequency capacity (8 frequencies) parts of the US will run out of the spectrum as early as 2003 [C/AFT, 1999].

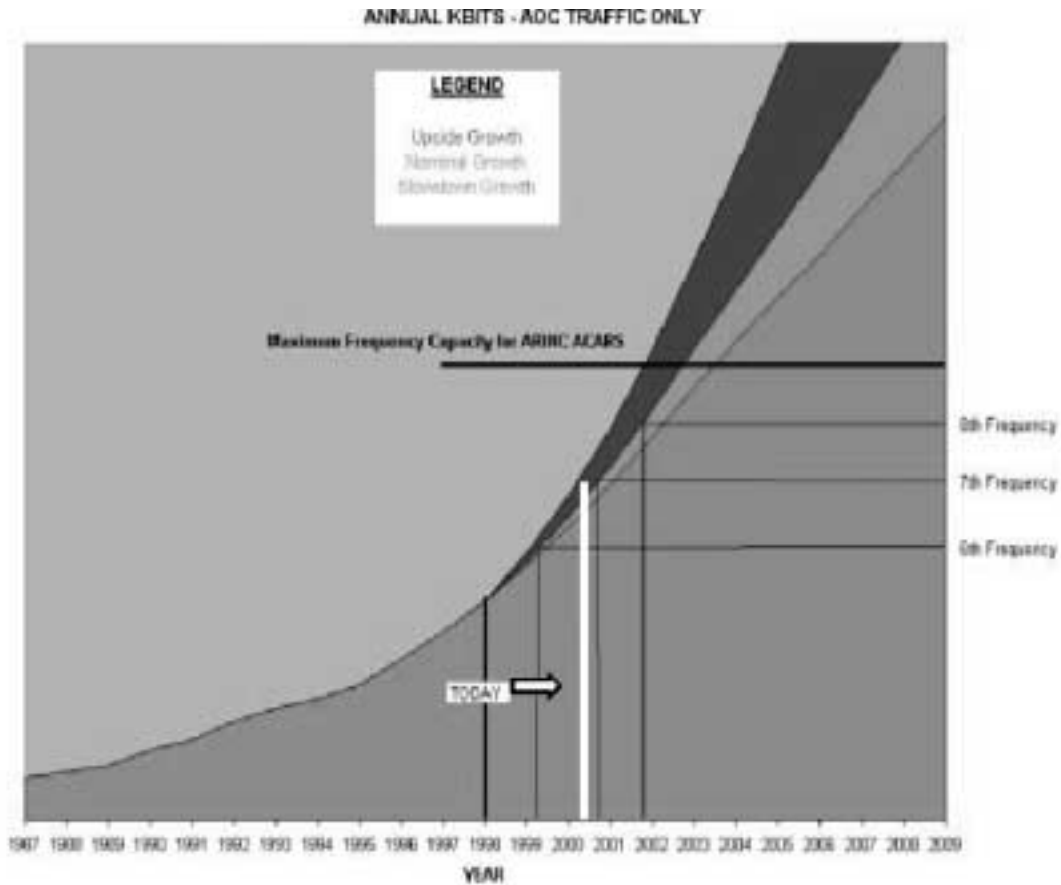


Figure 1.1 Forecast of ACARS Spectrum Use (C/AFT, 1999).

Over the past several years, FAA has developed a comprehensive plan for building an air traffic management (ATM) system. A key asset of this ATM is the use of digital data link communications as a primary means for exchanging aeronautical information and delivering ATC services. Preliminary applications of data link have included pre-departure clearance (PDC), Digital Automatic Terminal Information Service (D-ATIS), Flight Information Services (FIS) and oceanic ATC services. Tower Data Link Services (TDLS) such as Digital Automatic Terminal Information System and Pre-Departure Clearance (PDC) applications have been implemented at 57 airports where voice frequency congestion was considered a serious problem. The next step in the FAA plan currently calls for the implementation

of domestic, in-flight data link ATC services. In the initial stage, controllers will have the capability to uplink a variety of clearance and advisory messages to equipped aircraft and the aircrew will be able to downlink reports and ATC requests. These services are referred to as Controller-Pilot Data Link Communications (CPDLC). At a later stage, CPDLC will expand to a broad range of automated information exchanges including integration with other applications that will optimize traffic flow and permit long-range conflict detection and resolution.

1.3 Need for Decision Support Tools

Over the years, traffic density has increased with a corresponding increase in delays in the terminal area and in the enroute system. This coupled with the “hub and spoke” strategy used by major carriers and marketing requirements to land and take off at specific times has prompted needed improvements to the Air Traffic Control (ATC) system. Some major “hub” airports like Atlanta Hartsfield and Chicago O Hare are so congested during peak traffic that delays of over 60 minutes for individual flights haven’t been an uncommon occurrence. Since the world’s airline passenger traffic is expected to grow at an average rate of 5.5% per year, the congestion problem in most “hub” airports would only get worse [Gervais, 1994].

There are several alternatives to alleviate the congestion, one is to build more runways, the economic, geographical and political reasons make this an undesirable solution for most airports and communities. Another alternative is to reduce delays and manage the current airspace and airport capacity in a more efficient manner [Swenson, 1997].

However, even in today’s structured air traffic control environment, human limitations in workload and the accuracy to determine and project aircraft positions can result in late or unnecessary ATC interventions to resolve conflicts. To meet the additional demands to be placed on controllers operating in an unstructured routing environment introduced (i.e Free Flight), the FAA and MITRE’s Center for Advanced Aviation System Development (CAASD) have developed a strategic conflict probe capability for the enroute air traffic control system called the User Request Evaluation Tool (URET). NASA Ames Research Center has also developed a suite of decision support tools called Center Tracon Au-

tomation System (CTAS). The Traffic Management Advisor (TMA) and Passive Final Approach Spacing Tool (PFAST) are two of the several components that make up CTAS.

This lead to the development of prototype of decision support tools like User Request and Evaluation Tool (URET), Traffic Management Advisor (TMA) and Passive Final Approach Spacing (pFAST) to aid controllers to carry out various Air Traffic Control (ATC) in a more efficient manner.

1.4 Concept of Free Flight

Free Flight is the concept of air traffic management that permits pilots and controllers to share information and work together to manage air traffic from pre-flight through arrival without compromising safety. Free Flight will permit pilots to fly cost effective optimum flight paths between takeoff and landing.

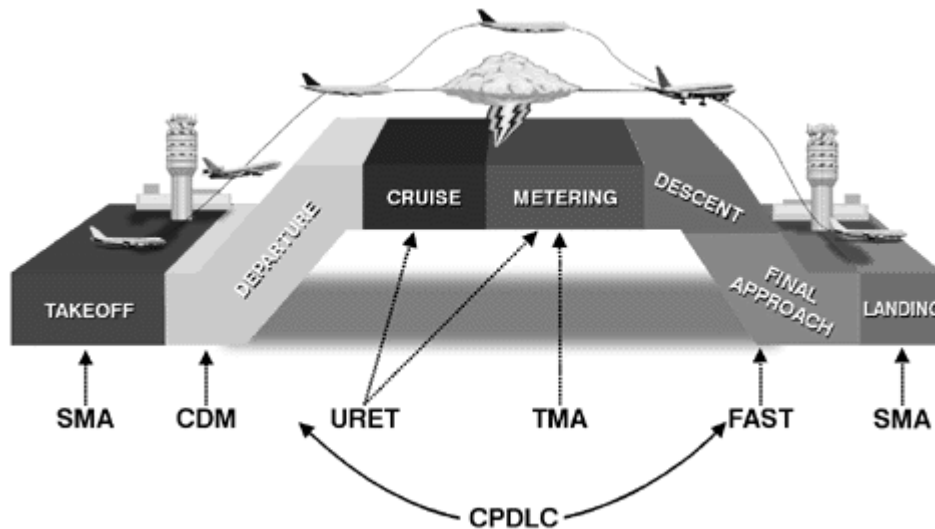


Figure 1.2 Free Flight Phase 1 Core Capabilities [ffp1.nasa.gov]

Free Flight Phase 1 (FFP1) is the limited deployment of the core capabilities of several decision support systems. The goal of FFP1 is to provide Air Traffic Management capabilities that can provide early benefits to service providers and NAS users. Air traffic controllers currently rely on structured routes and traffic organization for managing separation problems.

The core capabilities of Free Flight Phase 1 are:

- Final Approach Spacing Tool (FAST) -- Allows better sequencing and runway assignment of aircraft on final approach to congested airports.
- Traffic Management Advisor (TMA) -- Provides ARTCC controller and traffic managers with arrival scheduling tools to optimize delay allocation.
- Controller Pilot Data Link Communication (CPDLC) Build I-- Allows the exchange of selected non-time-critical data messages between controllers and pilots.
- User Request and Evaluation Tool (URET) -- Helps controllers manage en route traffic with an awareness of future conflict situations and to grant user requests or resolve conflicts through the use of trail planning capability.
- Collaborative Decision Making (CDM) -- Provides the FAA and participating airlines with electronically exchanged flight information and NAS capacity and status information.
- Surface Management Advisor (SMA) -- Provides terminal and airport surface data to participating airlines; exchanges data in a manner that supports efficient movement of aircraft on the airport surface.

It is the FAA's goal to have all of the FFP1 core capabilities operational by the end of 2002. National implementation to remaining sites is targeted for 2004.

1.5 Research Scope, Objective, and Approach

The main objective of the thesis is to develop a framework to evaluate the benefits and costs of implementation of new technologies like Controller Pilot Data Link Communication (CPDLC), User Request Evaluation Tool (URET), Traffic Management Advisor (TMA) and Passive Final Approach Spacing Tool (pFAST) in an integrated and a non-integrated scenario. The approach or framework adopted is to develop a model that will be able to accurately capture casual relationships between various technologies and measures of effectiveness to quantify benefits and costs over the entire life cycle of the system. A two level (bi-level) model system is proposed for this research endeavour. A lower

level microscopic model simulates air traffic in an enroute sector and terminal airspace for a day and quantifies operational benefits.

The high level or mesoscopic model is a life cycle model would be fed by the daily results from a microscopic simulation model and runs over a life cycle period quantifying benefits and costs. Both models consider integrated and non-integrated scenario to assess the deployment of Air Traffic Control (ATC) and airplane infrastructure. Benefits are quantified and separated in terms of applicability to the user (airline), the service provider (FAA), or both. To achieve this all variables and factors known to significantly affect benefits and costs are modeled using mathematical relationships between these variables.

1.6 Outline of Thesis

The thesis first presents a description of data link and decision support tools which is followed by a comprehensive literature review on all past studies in the field of data link and decision support tools. After that the methodology of the research effort is described which is followed by a complete description of the model. Finally the results of the model and conclusions and recommendations and scope for future research is outlined.

Chapter 2 deals with the description of data link and its functioning. This is followed by the deployment schedule of CPDLC in various builds that the FAA wishes to implement. Lastly the chapter ends with a complete description of decision support tools like URET, TMA and pFAST.

Chapter 3 contains the literature review and provides comprehensive information on all studies and simulation experiments done using data link. It also reviews the studies and operational evaluation results of URET, TMA and pFAST in Indianapolis, Memphis and Dallas Ft. Worth ARTCC.

Chapter 4 deals with methodology adopted in reaching the three main research objectives. A detailed description of system dynamics and STELLA software is also provided.

Chapter 5 provides a detailed description of the microscopic simulation model. All the modules that feed into the microscopic model are also described. The mathematical relationships between various

elements in the model are described and all assumptions made are outlined.

Chapter 6 provides a detailed discussion of the findings and results of the enroute module of the microscopic model and Chapter 7 describes in detail the macroscopic annual life cycle model. Finally Chapter 8 discusses the conclusions and recommendations for further research.

Data Link & Decision Support Tools Description

2.1 Description and functioning of Controller Pilot Data Link Communication

CPDLC is a data link application that allows a direct exchange of text-based messages between a controller and a pilot. CPDLC greatly improves communication capabilities in oceanic areas, especially in situations where controllers and pilots have previously had to rely on a third-party HF communications relay.

Apart from the direct link, CPDLC adds a number of other capabilities to the Air Traffic Services (ATS) system. The following are some example capabilities:

- Allowing the flight crew to print messages.
- Allowing the auto load of specific uplink messages into the Flight Management System (FMS). This reduces crew-input errors.
- Allowing the crew to downlink a complex route clearance request, which the controller can re-send when approved without having to type a long string of coordinates.
- Specific uplink messages arm the FMS to automatically downlink a report when an event, such as crossing a waypoint, occurs. This automation assists with workload management for the flight crew and the controller.
- Specific downlink messages, and the response to some uplink messages automatically update the Flight Data Record in some ground systems.

CPDLC uses the concept of Data Authority (DA). There can be only two DA's and therefore a maximum of two ATS units can be connected to the aircraft for CPDLC at any time. Only one of these connections can be active at any one time. The ATS unit able to exchange CPDLC messages with the aircraft is known as the current DA. The connection between the aircraft and the Current Data Authority is known as the active connection.

The next (adjacent) ATS unit to communicate with the aircraft via CPDLC is known as the Next Data Authority (NDA). The connection established between the aircraft and the Next Data Authority following the Address Forwarding process is known as an in-active connection. From the avionics aspect, the next unit does not become the Next Data Authority until nominated by the Current Data Authority in the NDA message. If the NDA message is not received by the aircraft, a Next Data Authority does not exist and termination of the connection with the current Data Authority will leave the aircraft without CPDLC connectivity. Similarly, if the next ATS unit is not data link equipped, an NDA message is not sent to the aircraft. The End Service message sent by the Current Data Authority will terminate the active connection, and the aircraft will not be CPDLC connected with any ATS unit until an initial logon is performed prior to the boundary of the next data link equipped unit. The initial logon to the next unit is a pilot responsibility.

When the pilot performs an initial logon to an ATS unit, that unit automatically becomes the Current Data Authority because it is the only unit connected. The CPDLC connection is active, however, in the Future Air Navigation System (FANS) -1/A environment, the ground system can not determine that it is the Current Data Authority until a downlink message is received from the aircraft. Some CPDLC units consist of only one sector. A logon and a subsequent active CPDLC connection with that ATS unit allows the sector to exchange CPDLC messages with the relevant aircraft.

In a multi-sector environment, an individual sector is generally never the current data authority. If this were the case, a full connection transfer would be necessary at every sector boundary. In the multi-sector environment the data authority designation is generally held by the ATS unit itself.

Figure 2.1 shows a simplified diagram of the B747-400 FMS Human Machine Interface (HMI). The page currently being displayed is called the ATC page and is accessed by selecting the ATC button if

no connections currently exist.

Below the buttons there is an alphanumeric keypad. To perform an initial logon manually the pilot types the four-letter ICAO designator for the ATS unit. The flight number entered must be exactly the same as that submitted in the flight plan. This text will appear on a line below INDEX. The pilot then selects the LOGON TO button to move the designator to where the four boxes are displayed.

The pilot then enters the flight number and selects the FLT NO button. This action moves the flight number into the appropriate position and then activates a SEND button at the top right of the display. On selection, the pilot will see LOGON SENDING then LOGON SENT and finally LOGON ACCEPTED.



Figure 2.1 Example Boeing 747 FMSFANS-1Cockpit Display.

Individual entries in the message set are known as message elements. A CPDLC message can be created from a single message element, or a combination of up to five message elements. Messages may

be constructed solely from pre-formatted message elements, solely from free text message elements, or from a combination of pre-formatted and free text message elements. Pre-formatted message elements can be purely text-based, such as DUE TO AIRSPACE RESTRICTION, or can be a combination of text and variables, such as CLIMB TO [level]. The text of the message element is shown in upper case characters and the variable field is shown with the variable name displayed in lower case characters enclosed in square brackets. Each pre-formatted message element is assigned a unique identification number. For example, the element CLIMB TO AND MAINTAIN [level] is always uplink element number 20. Depending on the urgency attribute, an uplink free text element is either number 169 or 170 without regard to the content. An uplink message consisting of 5 different free text elements will be constructed of 5 message elements assigned number 169, whereas a message consisting of 5 pre-formatted elements will be made up of five elements each assigned their own unique identification number.

Each message element is also assigned a number of attributes within the code. The attributes include urgency, alert and response requirements. The response attribute determines the type of response required to close each message dialogue.

For Uplink messages:

- The attribute W/U means that a WILCO or UNABLE response is required to close the dialogue.
- The A/N attribute requires either the AFFIRM or NEGATIVE response,
- The R attribute requires a ROGER response, and
- The NE attribute means that the message does not technically require a response and is considered by the ground system as a self-closing message.

For downlink messages:

- The Y attribute requires a response from the controller, and
- The N attribute does not require a response.

Each full message, whether consisting of one element or five, is assigned a Message Identification Number (MIN) by the originating system. The MIN is a number between 0 and 63 and its purpose is to allow a CPDLC dialogue to be tracked so that uplink and downlink messages belonging to the same dialogue are correctly paired and closed off. The networks, over which the messages travel, can some-

times lose synchronization, which means that a response to an earlier message can arrive later than the response to a subsequent message. It is important that controllers and flight crew are aware of which response relates to which message. For any system receiving a message with an attribute requiring a response, the MIN of that message becomes the Message Reference Number (MRN) for the purposes of the response. There are three uplink messages that arm the avionics to perform functions automatically. These messages are: REPORT REACHING [level], REPORT PASSING [position], and REPORT LEVEL [level]. When one of these messages is received by the avionics, the flight crew is presented with an ARM prompt on the UPLINK and VERIFY REPORT pages of the FMS. Selecting the ARM prompt on either page will arm the report for transmission.

When the specified flight level is reached, the specified position is passed, or if the specified level is being maintained, the avionics will automatically send the appropriate downlink report message (e.g. REACHING FL310). The flight crew can load specific uplink message elements into the FMS. The crew is presented with a LOAD prompt when a message containing one or more of these elements is received, provided that there is not a pending modification in the FMS flight plan. Loading one of these elements will either modify or replace details in the active FMS flight plan. This functionality allows flight crew to load long or complex route clearances received from an ATS Unit directly into the FMS without having to manually enter waypoints, reducing the possibility of errors. There are some important differences between pre-formatted and free text message elements. These are:

- Some pre-formatted uplink elements arm the avionics to automatically send a downlink report when a specific event occurs (e.g. passing a waypoint),
- Some pre-formatted uplink elements can be auto-loaded into the FMS (e.g. route clearances), and
- Some pre-formatted uplink elements automatically update the Flight Data Record (FDR) of some systems on receipt of a WILCO response from the crew (e.g. vertical clearances).

Free text messages do not perform any of these functions. Another major difference between pre-formatted message elements and free text elements is in the delivery of the message. For a message constructed of pre-formatted elements, only the message number and any variable contained in the element are transmitted. The message number is then decoded by a file of message elements stored in the re-

2.1 Description and functioning of Controller Pilot Data Link Communication

ceiving system. In contrast, the entire free text message is sent to the receiving system. The procedures for the sending of uplink messages state that free text shall only be used when an appropriate pre-formatted message element does not exist, or as an additional amplification of a pre-formatted element.

A clearance delivered by CPDLC requires no specific read back by the crew. It is all due to the last four characters tacked onto the end of the coded message. This code is a check sum of the message header, the message contents and the sending time-stamp expressed as bits and is known as a Cyclic Redundancy Check (CRC) and each CRC is analyzed by the receiving system. If the CRC is intact, then the message and its contents have not been corrupted during transmission. The CRC check ensures that CPDLC has one of the highest integrity ratings of any aviation system, especially when compared with voice communications.

The following table presents a selection of uplink message elements with their individual element numbers, the defined intent and individual response attributes.

UL	Message Element	Intent	Response
0	UNABLE	Indicates that ATS cannot comply with the request.	NE
166	DUE TO TRAFFIC	The associated instruction is issued due to traffic considerations.	NE
164	WHEN READY	The associated instruction may be complied with at any future time.	NE
20	CLIMB TO [level]	Instruction that a climb to the specified level is to commence and the level is to be maintained when reached.	W/U
23	DESCEND TO [level]		W/U
175	REPORT REACHING [level]		R

2.2 Controller Pilot Data Link Communication Implementation Schedule

UL	Message Element	Intent	Response
128	REPORT LEAVING [level]	Instruction to report when the aircraft has left the specified level. Either a level that has been maintained, or a level passed through on climb or descent.	R
181	REPORT DISTANCE [to/from] [position]	Instruction to report the present distance to or from the specified position	NE

TABLE 2.1 Uplink Messages

2.2 Controller Pilot Data Link Communication Implementation Schedule

The implementation of the CPDLCFAA ground system will be accomplished as a multi-build development.

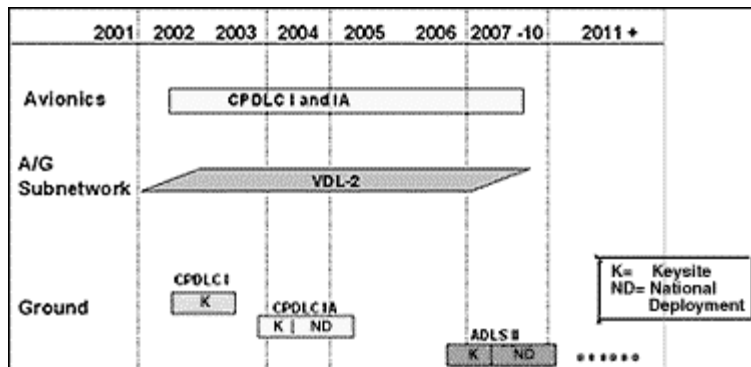


Figure 2.2 CPDLC Implementation Schedule.

Build I

Domestic U.S. service only, using a small message set that provides four services, utilizing ARINC's VDL-2 Air/Ground sub network and planned for Key Site implementation at the Miami Air Route Traffic Control Center (ARTCC) in June 2002.

Build IA

Domestic U.S. service only, with five additional message services being supported, and will use the VDL-2 as the Air/Ground sub network and is planned for late 2003 for Key Site implementation. National deployment at all 20 ARTCCs is planned during 2004 - 2005.

The Aeronautical Data Link System (ADLS) Build II is the next evolutionary step after CPDLC Build IA. ADLS Build II (CPDLC Build II) continues the evolution toward the common aeronautical data communications network from existing capabilities already achieved in previous data link builds. ADLS Build II includes the integration of flight deck systems with air/ground data exchange, enabling more advanced coordination.

The RTCA Special Committee has proposed the following evolution sequence:

Build II A

- Data link functions in ground automation integrated with decision support tools (e.g., User Request Evaluation Tool (URET), Traffic Management Advisor (TMA)). This enables, for example, controllers to develop trial plans on URET and upon their authorization, send the new route clearance to the pilot directly without reentering data.
- A component of the FAA ground system, the Data Link Applications Processor (DLAP) has full Baseline 1 CPDLC message set enabling expansion of the “vocabulary” for CPDLC to include additional applications.
- End-to-end system complies with ATN Standards and Recommended Practices (SARPs) edition 3 security requirements impacting ground and airborne ATN end system implementations creating a more robust and secure infrastructure

Build II B

- Operational capability extended to major Terminal Radar Approach Control (TRACON) facilities for non-time-critical communications, expanding the benefits of CPDLC to the terminal domain.

2.3 Description of User Request Evaluation Tool

- Data link functions in ground automation integrated with TRACON-oriented decision support tools (e.g., passive Final Approach Spacing Tool (pFAST)) to facilitate the efficient communication and execution of control decisions.

Build II C

- Operational capability extended to Oceanic centers and upgrades to Air Route Traffic Control Centers (ARTCCs) and TRACONs to accommodate the seamless control of air traffic across domains.
- Automatic Dependent Surveillance (ADS) functionality required to support non-radar operations. Interface to the flight management system required to support ADS functions, to include auto-load of CPDLC
- Integration of additional sub networks is required to support non-line-of-sight operations
- Upgrade Communications Management Unit (CMU) to include ATN Baseline 2 to further expand CPDLC capabilities and enhance inter-operability with other ATC systems.

Build II D/E

- Re-host approach/departure functionality in Standard Terminal Automation Replacement System (STARS) automation platform (need to decide when to go from Automated Radar Tracking System (ARTS) to STARS)
- Operational capability extended to surface operations to support gate-to-gate ATC communications and control
- Data link functions in ground automation integrated with surface decision support tools to increase the efficiency of ground operations
- Approach/departure operations necessitate enhanced crew display capability to reduce crew response times and facilitate more rapid communications responses.
- Approach/departure operations necessitate display in the forward field of view to help maintain situational awareness and reduce the workload associated with CPDLC communications.

2.3 Description of User Request Evaluation Tool

In order to respond to rising demands for services from the National Airspace System (NAS), the Federal Aviation Administration (FAA) and The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) developed and evaluated a set of enroute air traffic control (ATC) decision support capabilities based on many of years of earlier work on the Advanced En Route ATC (AERA) program. The component capabilities—embodied in a prototype referred to as the User Request Eval-

uation Tool (URET)—include a conflict probe that continuously checks current flight plan trajectories for strategic conflicts, and a Trial Planning function that allows a controller to expeditiously evaluate problem resolutions before they are issued as clearances. These capabilities are intended to provide the flexibility and decision support needed to allow more user preferences to be met while continuing to maintain or enhance today's level of safety.

URET is a decision support tool that supports strategic planning by the sector team and is a potential enabler for free flight. URET combines real-time flight plan and radar track data with site adaptation, aircraft performance characteristics, and winds and temperatures aloft to construct four-dimensional flight profiles, or trajectories, for pre-departure and active flights. For active flights, it also adapts itself to the observed behavior of the aircraft, dynamically adjusting predicted speeds, climb rates, and descent rates based on the performance of each individual flight as it is tracked through en route airspace.

URET uses its predicted trajectories to continuously detect potential aircraft conflicts up to 20 minutes into the future and to provide strategic notification to the appropriate sector. Trajectories are also the basis for the system's trial planning capability. Trial planning allows the controller to check a desired flight plan amendment for potential conflicts before a clearance is issued. The controller can then construct the amendment from that trial plan with the click of a button. The system enables expeditious coordination of these plans and amendments among sectors and facilities with its auto-coordination function.

The controller interface to these detection and resolution capabilities supports flight data management and task prioritization using both text and graphic displays. The text-based Aircraft List and Plans Display help manage current flight plan information, trial plan information, and conflict data. The Graphic Plan Display provides for a graphic view of aircraft routes and altitudes, predicted conflicts, and results of trial plan resolutions. The point-and-click interface enables quick access to system functions and entry of flight plan amendments.

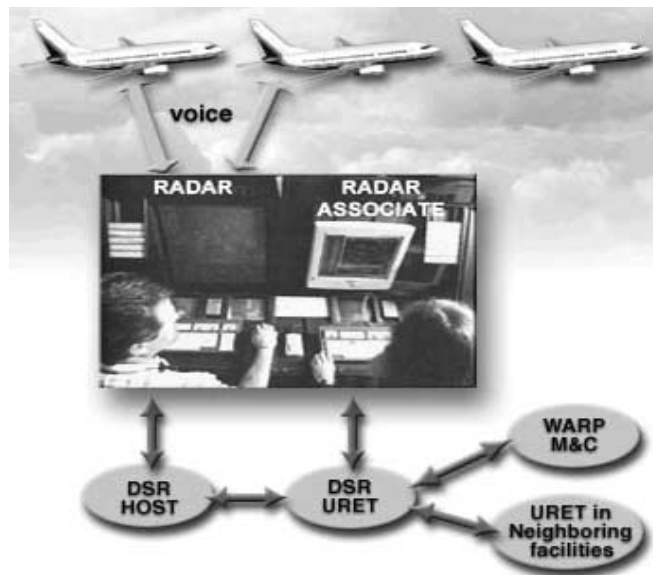


Figure 2.3 URET CCLD System Interface [ffp1.nasa.gov]

These capabilities are packaged within a Computer Human Interface (CHI) that includes text and graphic information. The text-based Aircraft List and Plans Display manage the presentation of current plans, trial plans, and conflict probe results for each sector. The Graphic Plan Display provides a graphical capability to view aircraft routes and altitudes, predicted conflicts, and trial plan results. In addition, the point-and-click interface enables quick entry and evaluation of trial plan route, altitude, or speed changes. Finally, the Wind Grid display provides a visual representation of forecast winds and temperatures at selected altitudes.

A key part of the URET infrastructure is its Interfacility, or IFA, capability. In an IFA mode of operation, the systems in neighboring en route facilities exchange critical flight and track data. This interfacility data exchange significantly improves the quality of the information used by each individual system, thus reducing uncertainties in its predictions, enhancing its look-ahead, and improving overall controller situational awareness at the sector.

2.3 Description of User Request Evaluation Tool

Since the first URET system was installed at the Indianapolis ARTCC in January 1996, it has been upgraded and evaluated several times. In June 1997, the system was installed in a second facility, the Memphis ARTCC. And by November 1997, both facilities began to use the system on a daily basis.

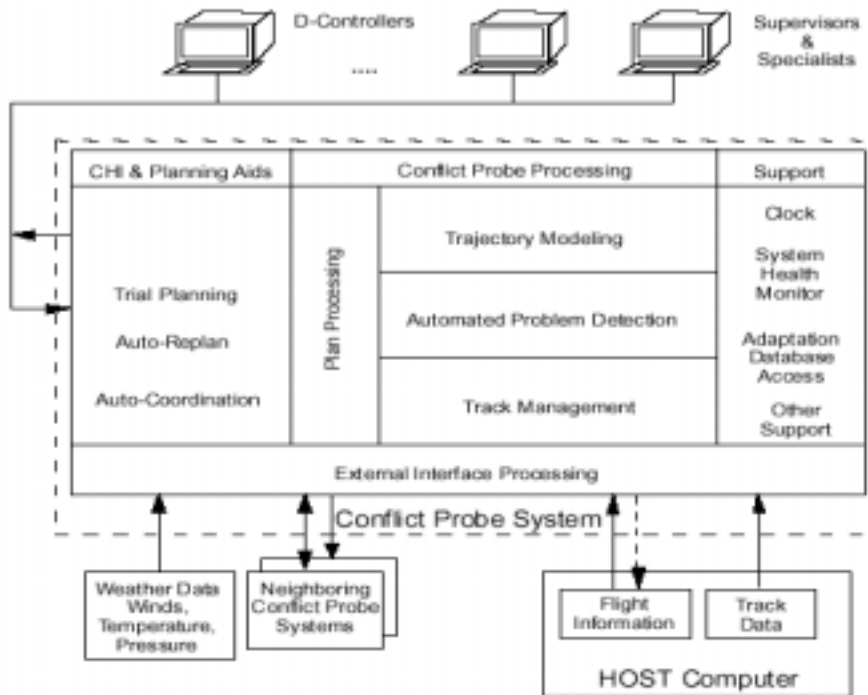


Figure 2.4 Conflict Probe System Block Diagram [Celio, 2000]

System capabilities are developed using an evolutionary model. At each step of its evolution, enhanced capabilities are introduced to a team of controllers at each facility and evaluated under simulated and live traffic conditions. If the capabilities are found to be operationally useful and acceptable, the daily-use system is upgraded. A process is also in place for the facilities to provide feedback from daily-use operations. The system evolves as feedback from its use is received and understood in the context of the operational concept upon which it is based—updates are planned and implemented accordingly.

URET continues in daily use at the Indianapolis and Memphis ARTCCs to evaluate the Conflict Probe

2.3 Description of User Request Evaluation Tool

capabilities for operational acceptability and suitability. Over 800 operational personnel (controllers, supervisors, traffic management specialists, etc.) are trained in the use of URET at the Indianapolis and Memphis ARTCCs. Both facilities are operating 22 hours a day, 7 days a week. In early May 2001, URET reached a combined sector operational use at the two facilities of 1,000,000 hours.

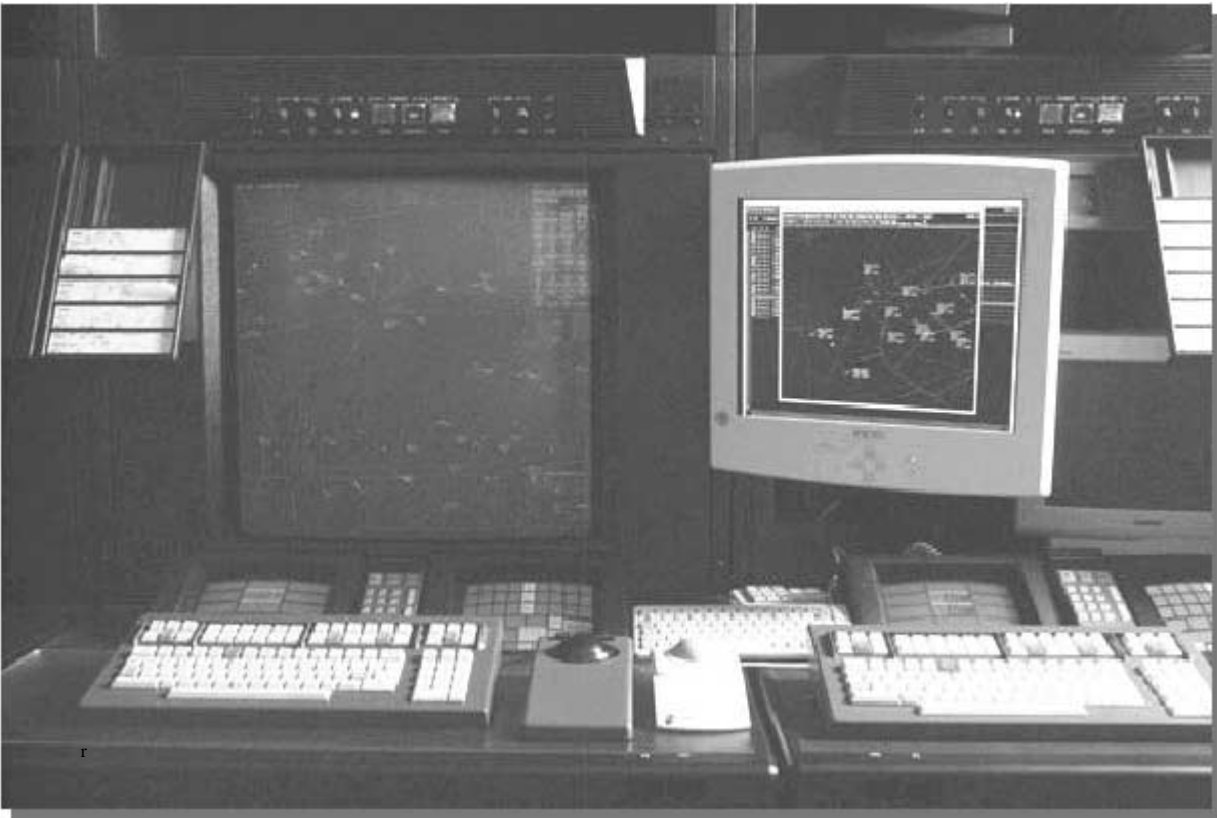


Figure 2.5 R & D positions showing DSR and URET [Kirk, 2000]

The use of URET at the two facilities has achieved some near-term benefits. More than 20 altitude restrictions have been lifted allowing aircraft to fly higher, more efficient altitudes longer. It is estimated that lifting these restrictions will save almost 1 million gallons of fuel annually. URET has allowed the facilities to grant more direct clearances to flights in their airspace. The overall analysis to date shows an average savings of more than 0.5 mile per flight for every flight going through ZID and ZME air-

space. This translates into a monthly economic benefit of approximately \$1.5 million for both ARTCCs combined URET FFP1 Deployment [ffp1.nasa.gov].

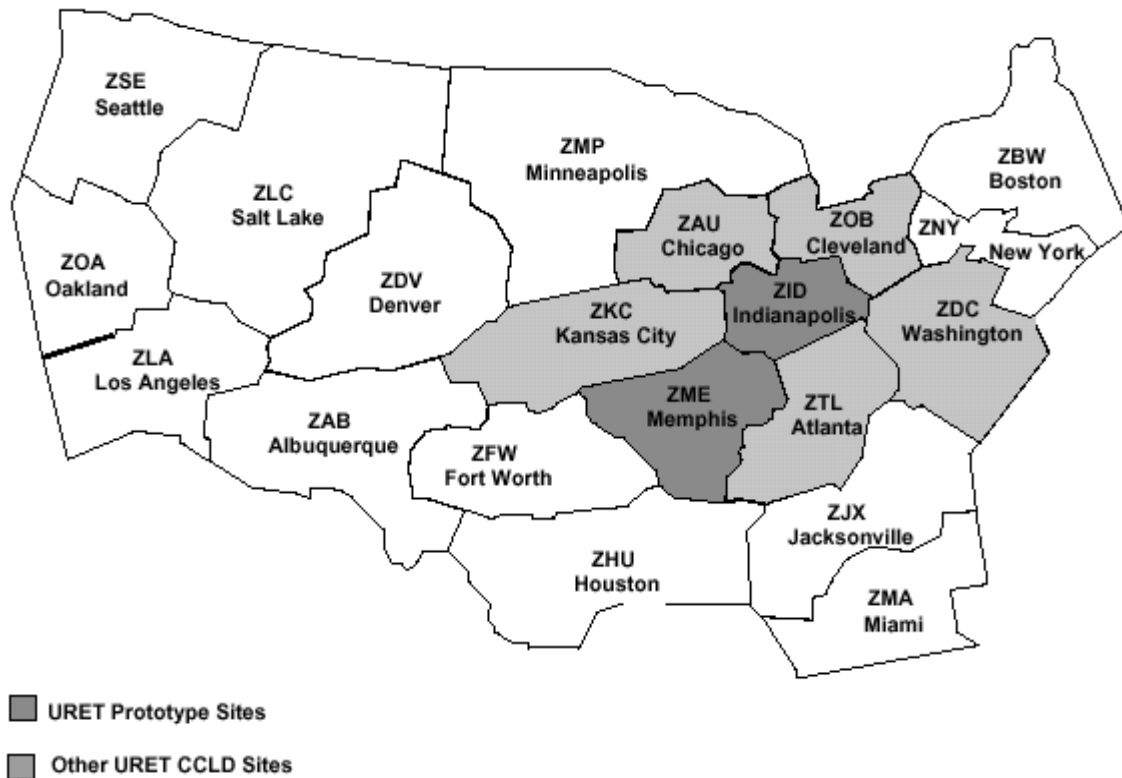


Figure 2.6 URET FFP1 Implementation sites [Celio, 2000]

The NAS Modernization Task Force, at their January 1998 meeting, suggested a way to evolve the early Free Flight capabilities and called it Core Capability Limited Deployment (CCLD). The first step in the evolution of capabilities is called Free Flight Phase 1 (FFP1). The prototype of URET is currently being operated at ZID and ZME 22 hours a day, 7 days a week. For FFP1, URET is expected to be implemented at five more ARTCCs namely ZTL, ZDC, ZKC, ZAU and ZOB.

URET is to be implemented in two Builds. Build 1 includes the basic functions in the URET prototype

being used at Indianapolis and Memphis at the end of 1999. Build 2 contains the functions deemed necessary for operational acceptability at all seven FFP1 facilities.

2.4 Description of the Traffic Management Advisor

The growth of commercial air travel in the United States has put a severe strain on the nation's air capacity. Lot of delays has been attributed to the inefficient management of airspace in the enroute scenario. The TMA was developed to alleviate congestion and help Traffic Management Controllers (TMC) efficiently manage and control traffic on an Air Route Traffic Control Center (ARTCC) level.

The TMA is a time-based strategic planning tool that provides Traffic Management Coordinators (TMCs) and En Route Air Traffic Controllers the ability to efficiently optimize the capacity of a demand-impacted airport. The TMA consists of trajectory prediction, constraint-based runway scheduling, traffic flow visualization and controller advisories. TMA is one tool from the set of decision support tools called Center Traccon Automation System (CTAS). CTAS is an integrated set of three automation tools, Traffic Management Advisor, Passive Final Approach Spacing Tool and Descent Advisor.

The primary users of TMA are TMCs whose primary function is predict the demand of air traffic and capacity of their facility. The TMC's key responsibility is to ensure the demand in excess of the facility's capacity is safely and efficiently absorbed throughout the airspace.

Figure 2.7 is a typical display for Traffic Management Advisor which is currently operational at the Dallas/Fort Worth ARTCC.



Figure 2.7 TMA Display suite at Ft. Worth ARTCC

The TMA software components are hosted on a network of modern UNIX workstations. A simple hardware/software diagram is shown in figure 2.8. On the left side is the operational air traffic control system from which the TMA receives aircraft track data, flight plans and various controller entries. These data are passed to the communications manager (CM) for distribution to the prediction, scheduling and visualization processes. The CM also transfers the atmospheric data to the prediction and visualization algorithms. The time prediction process generates estimated times of arrival (ETA) for all aircraft to the meter fixes and all eligible runways. This is the most computationally intensive process and is a function of the number of aircraft in the system. It was thus designed to be scaleable with more

computers. The ETA data are used with ATC constraints to generate scheduled time of arrivals (STA). The ETA, STA and other information of interest are displayed in various graphic formats on the TMA displays. The CM also transmits STA and ETA information back to the operational ATC HOST computer in the form of aircraft sequence, scheduled meter fix and outer metering arc crossing times and delay advisories to be presented on the controllers Planview Displays (PVD).

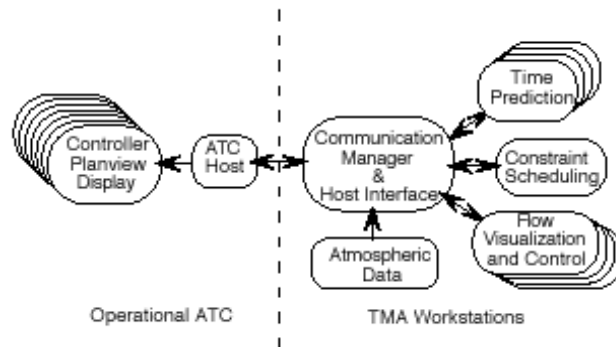


Figure 2.8 TMA hardware/software diagram [Swenson, 1997]

The time prediction algorithms are the foundation of TMA. The fundamental basis of the time prediction process are algorithms designed for flight management systems of modern commercial aircraft. The time prediction is separated into two modules: the route analyzer (RA) and trajectory synthesis (TS). The RA generates, based upon user generated site specific adaptation logic and heuristics, a two-dimensional path from the aircraft's current position to its final destination. The complexity of this path is determined via the necessary adaptation. This two-dimensional path is coupled by the TS with the aircraft's current energy state and atmospheric data to calculate a fuel optimal four-dimensional trajectory using aircraft specific mathematical performance models. ETAs are extracted from this trajectory for specific points of interest. The TS trajectories include all modes of flight including ascent, cruise and decent.

The functional logic for the scheduling algorithm is a modified first-come-first-serve (FCFS) algo-

2.5 Description of Passive Final Approach Spacing Tool

rithm. The scheduling constraints used to modify the FCFS schedule are the factors associated with the separation safety requirements specified by FAA regulations. The FCFS algorithm is coupled with delay reduction runway allocation logic and a Center/TRACON delay distribution function (DDF). The scheduling algorithms ensure conflict-free schedules simultaneously at both the meter fix and runway threshold or the final approach fix (FAF) during visual meteorological conditions.

TMA generates controller advisories which are transmitted to the operational ATC Host computer. The advisories are displayed superimposed on the sector controller PVD as a list of aircraft designators in a time ordered sequence. The aircraft identifier is displayed adjacent to the scheduled crossing time and delay to be absorbed. These advisories are referenced to both the meter fix and outer metering arc for jet aircraft and only the meter fix for low altitude turbo prop and prop aircraft. Only the advisories relevant to a specific sector are displayed on that controller's PVD. The delays are distributed between the sector controllers working the jet traffic in both high (above 24,000 ft.) and low altitude. The high altitude controller absorbs all but an adapted minimum amount of the center required delay where jet aircraft are most fuel efficient. The delay distributed to low altitude controllers is for both workload distribution and to maintain pressure on the TRACON meter fixes to ensure a volume of aircraft are available in the event that the TRACON determines that capacity can be increased. The low altitude controllers are also required to absorb delays associated with all other traffic.

TMA was evaluated extensively at the Dallas/Fort Worth ARTCC. The tool generated minimal delay advisories that distributed delay efficiently between Center and TRACON operations. The tool was used to achieve delay reductions of an average of 70 seconds per aircraft when compared with current operations during periods when ATC demand exceeded capacity. The TMA also allowed the TRACON to increase the average airport acceptance rate by 5%.

2.5 Description of Passive Final Approach Spacing Tool

The development of decision support tools for aiding air traffic controllers in managing and controlling air traffic has long been the subject of extensive research. The continued growth of air traffic throughout the world has caused increases in air traffic delays and has put considerable stress on both existing

air traffic control (ATC) systems and on the air traffic controllers. Early work in the automation of terminal air traffic control was presented in the late 1960's [Martin and Willet, 1968]. Martin and Willet described a system that provided speed and heading advisories to controllers to help increase spacing efficiency on final approach. Although tests of the system showed an increase in landing rate, controllers found that their workload was increased and rejected the system. An examination of the concept suggested that while some aspects of the design were sound, its acceptance was limited by the technology of the time period, especially the lack of an adequate controller interface. More recently, several automation systems have found their way into operational use in Europe due in large part to the introduction of modern computer processing and interfaces, and because of more careful design approaches [Volckers, 1990; Garcia, 1990]. While these systems provide significant decision support functions for the overall management of arrival air traffic, they do not contain detailed modeling of complex terminal area procedures and runway operations.

Passive Final Approach Spacing Tool (PFAST) is one of the tools from the Center Tracon Automation System (CTAS) host of tools which assists air traffic controllers in the terminal airspace. PFAST is a passive decision support tool for management and control of terminal area traffic that combines detailed models of aircraft performance and ATC procedures. The main function of PFAST is to provide landing sequence and runway assignments to achieve an accurately spaced flow of traffic and balancing of traffic into different runways so as to optimize the arrival rate for the airport where it is being deployed. PFAST was evaluated in operation with live traffic at the Dallas/Fort Worth, Texas airport in 1996. It is also providing benefits at the Southern California TRACON through the use of auxiliary displays at the controller position and large screen displays at the Traffic Management Unit [ffpl.faa.gov].

Passive FAST is a decision aid to the air traffic controller which consists of two modules. The first is the Trajectory Synthesizer (TS) which is used to predict the aircraft trajectory history to the runway threshold based on the current time, position and speed. The second module Scheduling Logic (SL) which determines the air traffic controller preferred sequencing of aircraft within a flight segment or merging of aircraft onto a common flight segment. This is accomplished by examining the trajectory variables from two aircraft at a time, for all aircraft in the Terminal Radar Approach Control (TRA-

CON) and by evaluating a set of fuzzy logic propositions to determine the preferred choice.

Figure 2.9 illustrates the data flow surrounding and through FAST. The aircraft horizontal position and velocity estimates are obtained from the ARTS radar and its tracking software. This data is combined

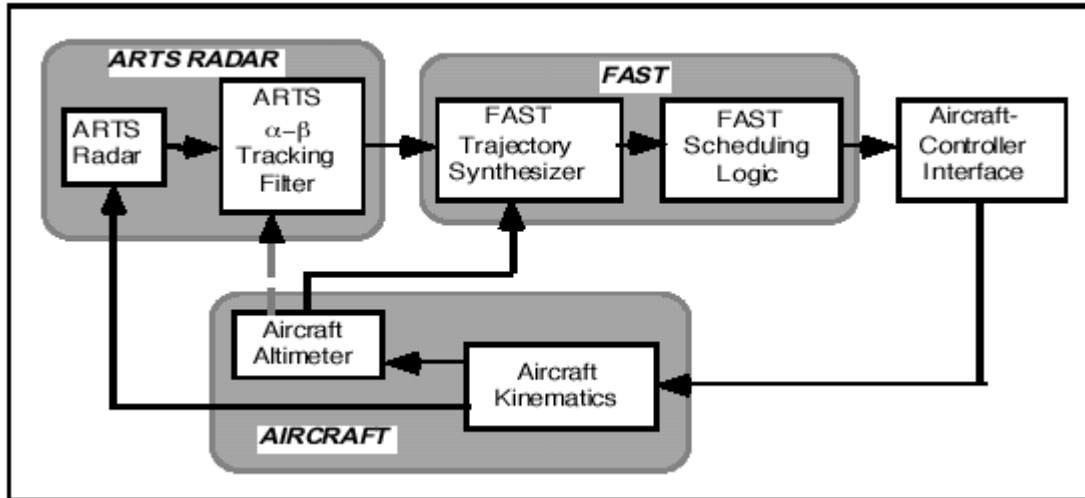


Figure 2.9 FAST Data Flow [Mueller, 1998]

by the FAST TS with altitude information, provided by the aircraft barometric altimeter, to obtain predicted aircraft flight path trajectories. FAST uses these predicted trajectories to determine the preferred sequencing or merging of aircraft in the TRACON.

FAST depends on the accurate estimates of arrival times for all aircraft. These arrival times are used by FAST for sequencing and scheduling aircraft to the runway threshold. CTAS's Route Analyzer (RA) and Trajectory Synthesizer (TS) provide the rapid update and accurate calculation of Estimated Times of Arrival (ETAs) based on radar track or flight plan data.

The set of ETAs that the RA/TS computes represents ranges of possible arrival times given an aircraft's predicted route of flight combined with possible variations in degrees of freedom along those routes. Typical degrees of freedom include speed, horizontal maneuvers, and vertical maneuvers. Upon receipt

of a flight plan or radar track data update (x-coordinate, y-coordinate, altitude, ground speed), the RA categorizes each aircraft's situation for each potential landing runway in terms of destination airport, airport configuration, geographical sections of airspace, engine type (jet, turbo-prop, or piston), approach segment (downwind, final, base, etc.), and aircraft states (x-coordinate, y-coordinate, altitude, heading, speed). Each situation category has a name and a complete description of route/degree of freedom combinations that are possible for that aircraft. The RA uses this site-adaptable data for each situational category to build a series of one or more routes for each aircraft, apply degrees of freedom to those routes, and finally request the TS to compute ETAs for each route/degree of freedom combination.

The inputs to the TS are the aircraft state, winds aloft, temperature and pressure profiles, a series of waypoints depicting the expected route of flight for an aircraft, and vertical and speed constraints on the predicted route. The outputs from the TS include a complete time-based (4D) trajectory along the expected path including all data pertinent for resolving conflicts and estimating times of arrival at points along the path.

As the aircraft flies through the arrival airspace and descends to the runway, it will change situation categories as it transitions from one flight segment to the next, producing stable sets of ETAs. These sets of ETAs form the basis for the sequencing and scheduling process. Once the sequencing and scheduling process is completed, the same set of RA/TS trajectories will be used for conflict resolution. Finally, they will be used as a reference in computing expected delay for aircraft in the runway allocation process.

All trajectory segments for an aircraft are checked for conflicts with other aircraft within the same segments. If there is no conflict for an aircraft, it will be assigned its nominal trajectory. When a conflict is predicted, one or both aircraft trajectories must be manipulated to resolve the conflict. Because the aircraft have already been ordered, PFS knows which aircraft is ahead and which aircraft is behind. PFS will add delay to the trailing aircraft in order to resolve the conflict. The PFS accomplishes this by searching the trajectory for degrees of freedom which will help to resolve the conflict. The magnitude of the conflict is measured and translated into a required delay for the aircraft before it reaches the conflict point. Because the PFS knows which degrees of freedom will help to resolve the conflict,

it can combine this knowledge with the route/degree of freedom/ETA values it received from the RA/Ts to bound and then begin the iterative process for resolving the conflict.

In general, aircraft are vectored from Center airspace into a TRACON over a feeder gate or metering fix. Aircraft engine types (e.g. turbo-jets, turbo-props, piston) and feeder gate assignment map to a preferred runway which is typically the closest runway to that feeder gate. Depending on the procedures at a given TRACON, an aircraft may be eligible to change to secondary or alternate runways. Situations which would influence a controller-initiated runway change include excessive or unbalanced delay buildup on the preferred runway, controller workload for a given runway, and airline or control tower preferences for ease of ground traffic movement. A controller will select which aircraft to change to an alternate runway based on a number of considerations such as separating aircraft of a dissimilar engine type or weight class from the other aircraft in a busy stream of traffic, avoiding potential conflicts in current streams of traffic, or avoiding potential conflicts in merging streams of traffic. Ideally, a controller would like to change the runway early in the traffic flow (i.e. near the feeder gates), but because of the uncertainties of making such a decision early in the flow, changes are commonly held off until the last possible moment. This can cause an undesirable increase in workload for the pilots of arriving aircraft because of the late changes in selecting navigation frequencies and configuring the aircraft for an approach.

The strength of an automation system such as FAST is its ability to assign runways based on accurate estimations of delay savings and workload benefits at an early stage of the arrival process. The runway allocation algorithm employed in FAST attempts to meet three primary objectives:

- making an early and accurate decision,
- reducing overall system delay and
- reducing controller workload.

The algorithm is heuristically-based and site-adaptable. The approach is to define the preferred runway for all aircraft in the landing sequence and then to select the set of all aircraft which are eligible for reassignment, apply criteria to narrow this set to a most likely aircraft to be reassigned, to test the aircraft's new runway in a full sequencing and conflict resolution cycle with all other aircraft, and finally to apply detailed criteria to this solution set for all aircraft.

The set of aircraft eligible for runway reassignment is defined by a runway allocation time window for each runway. The time window begins with a “start testing runway allocation time horizon” measured in expected flight minutes from a given runway and ends with a “freeze runway allocation time horizon” also measured in expected flight minutes from the runway. Any aircraft with an estimated time of arrival for a runway which falls within the runway allocation time window are deemed eligible for allocation to that runway. Once the set of eligible aircraft are determined for all arrival runways, the system builds an estimated schedule and its associated delays for each aircraft to their currently assigned runway and to any available alternate runways. The system then selects those eligible aircraft which pass a set of runway allocation heuristics. This selection process is based on a site adaptable decision tree file which incorporates facility procedures, delay reduction, and controller heuristics.

A simplified example of a runway allocation decision tree is shown in Figure 2.10. In this example, only one thread through a series of branches on the decision tree is shown. The tree first branches on runway pair, followed by arrival feeder gate, followed by a criterion labeled “Odd Aircraft Type”. This criterion examines the aircraft together with all aircraft meeting the previous criteria (runway pair and feeder gate), and determines if the aircraft currently traversing the decision tree is an odd type (e.g. the only turbo prop in a stream of jet traffic). If this is true, then the system examines a system-wide or global delay reduction criterion. Because the aircraft in this example is an odd engine type in its stream, the delay reduction criterion is small (0 minutes). If we examined the branch on the “No” answer for “Odd Aircraft Type,” we would find that the global delay reduction criterion would require a larger value (typically 2-4 minutes). The reason for the difference in delay reduction requirements on these two branches is to force FAST to favor pulling a dissimilar engine or weight class aircraft out of the traffic stream. This serves to reduce workload for the controller.

After all eligible aircraft have passed through this decision tree and thus narrowing the list of all eligible aircraft to a smaller set, FAST then selects a single aircraft which appears to have the greatest delay benefits to the overall arrival system. In some cases, there may not be any aircraft which pass these criteria and in this case, the runway allocation algorithm will not consider any aircraft for that update cycle. Once an aircraft is selected, it is then placed in an alternate runway sequencing and conflict resolution cycle. The entire arrival airspace sequencing problem is solved with this aircraft placed on its

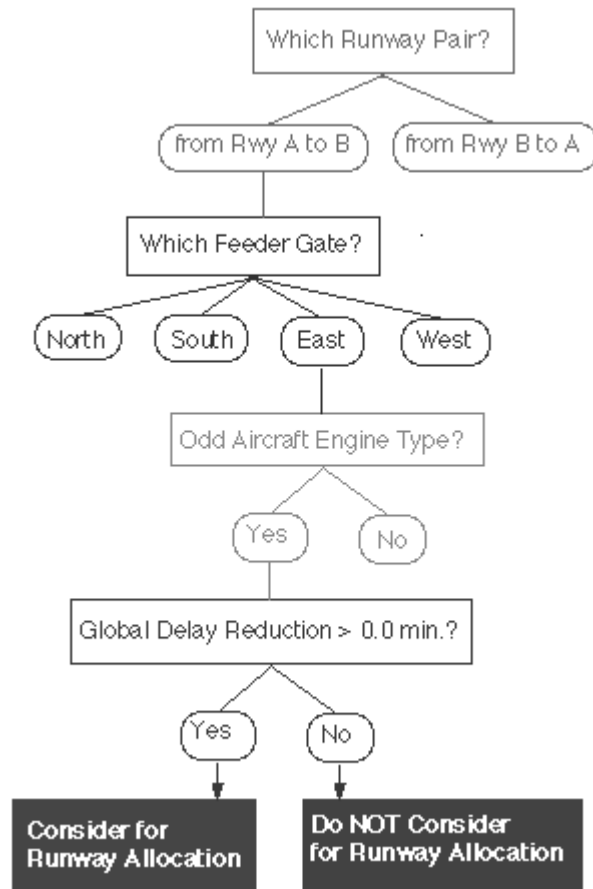


Figure 2.10 Example of Runway Allocation Decision Tree [ctas.nasa.gov]

alternate runway. This allows the software to evaluate all aspects of the particular runway allocation. Full trajectory solutions are obtained for each aircraft which in turn give accurate sequences, expected delay, and conflict detection for the entire airspace. At this point, a new and more detailed set of criteria are applied. These criteria examine trajectory based issues such as potential conflict resolution problems and exhaustion of critical degree of freedom limits. They are applied to the alternate solution set in order to make the final determination as to whether or not to change the aircraft to the alternate runway.

Once an aircraft has been switched away from a given runway, that runway is blocked off from further consideration for that aircraft. A more optimal solution would be to allow allocation of this aircraft back to its original runway if a situation warrants, but this was found to be unacceptable to controllers. Controllers always have the final authority in the runway assignment, and if a controller directs FAST to assign a given aircraft to a runway through a keyboard entry, the system will freeze that decision and no longer consider that aircraft for any other runway. Finally, once an aircraft's ETA falls below a runway's freeze time horizon, that runway will be blocked off from further consideration. After all but one runway has been blocked off, the runway assignment advisory is frozen for the remainder of the flight. In nearly all cases, the aircraft has a frozen runway assignment before twelve minutes of flight time from the runway [ctas.nasa.gov].

CHAPTER 3 Literature Review

3.1 Introduction

The objective of this literature review is to provide comprehensive and complete information on Controller-Pilot Data Link Communication (CPDLC) System and Decision Support Tools (DST) like User Request and Evaluation Tool (URET) and Center-TRACON Automation System (CTAS) suite of automation tools like Traffic Management Advisor (TMA).

This literature review provides information on all the studies that have been done in the past on CPDLC like estimation of benefits to the airline and controllers have been summarized.

The literature review also focuses on various enroute DSTs like URET and TMA. Various Air Route Traffic Control Centers (ARTCCs) and are currently using the prototypes of some of these tools. Studies that have been conducted on the operational analysis on the prototype of these tools have been summarized.

3.2 Studies on Controller Pilot Data Link Communication

A 'man in the loop' simulation study [Federal Aviation Administration Data Link Benefits Study Team, 1995] using two-way Data Link ATC communications was conducted by the Federal Aviation Administration (FAA) at the William J. Hughes FAA technical center in Atlantic City, which addressed two operational en route ATC problems that have been attributed to limitations of the communications capability of controllers using the existing voice radio system. Air traffic controllers, ATC supervisors and professional pilots participated in these high fidelity simulation tests in which a combined Data Link and voice radio communication system was used to control traffic in en route airspace. Baseline Data Link test scenarios were built to precisely duplicate air traffic sample days taken from two air-space sectors within the Atlanta ARTCC. Two separate experiments were carried out to address two separate operational en route ATC problems, one for the arrival sector and the other for the departure sector. In both the departure and the arrival cases, data on the delay experienced by the traffic on the sample day were derived from the System Analysis Recording (SAR) tapes. In both experiments additional test runs were done with increased traffic levels representative of future demand. For all the cases comparison was made between using only voice radio communication and using both Data Link and voice radio communication.

The airplanes that enter a departure airspace sector are separated by a miles-in-trail (MIT) restriction which usually contribute to a major extent to ground delays. The first experiment was designed to determine whether the MIT restrictions can be relaxed with the introduction of Data Link communications and tested the ability of Two-way Data Link ATC communications to reduce airport departure delays that are caused by capacity problems in a high altitude en route departure sector. The test scenarios for experiment 1 were based on sample of air traffic derived from sector 32 of the Atlanta ARTCC. First the baseline scenario was run using the routine 20 MIT restriction for departures entering the sector using the same air traffic as those on a sample day SAR tape. Consequently further runs were made after decreasing the MIT restriction to 15, 10 and finally without any restriction (minimum 5 mile separation). A final test run was made with no MIT restriction but with a 10 percent increase in traffic demand to simulate future demand. Aircraft arrival times and positions at the sector boundary

for each of the above scenarios were obtained using SIMMOD. SIMMOD was primarily used for calculation of benefits like ground delay and was also used to assess the impact on total delays of increasing the departure traffic demand. Some of the findings of the experiment were that the controllers and ATC supervisors were able to handle the air traffic safely and effectively at each reduced MIT restriction and also with a 10 percent increase in air traffic using a combination of Data Link and voice radio communication. No aircraft separation violations were detected hence indicating that safety of ATC operations was in no way compromised. Total delays for all departing aircraft decreased from 1,795 minutes with 20 MIT restriction imposed at Atlanta to 687 minutes when the use of Data Link permitted the elimination of restrictions. Comparable savings were also obtained with a 10 percent increase in traffic.

Sometimes it is seen that in an en route sector, the voice communication gets saturated causing delay to airplanes passing through the sector and hence the arrival of these planes to an airport gets delayed. Due to voice frequency congestion, controllers are often unable to consistently supply at a rate which meets minimum restrictions for airport arrivals. The second experiment tested the ability of the Data Link to improve air traffic throughput in an en route sector where saturation is responsible for inefficient processing of aircraft arriving at an airport. The scenario for this experiment was based on sample of air traffic derived from sector 09 in area 5 of the Atlanta ARTCC. First test run was made using the arrival and over flight traffic demand recorded on sample day morning rush period for sector 09 at the Atlanta ARTCC. Four more runs were made, each time increasing the traffic demand by about 10 percent. SIMMOD was used to provide estimates of throughput and efficiency for the baseline case as well as for the increased traffic demand using only voice radio communications and was compared against the data produced by live simulation with Data Link.

Some of the conclusions of the FAA Data Link study for the en route scenario were: -

- Data Link permitted the elimination of spacing restrictions that are enforced to prevent saturation in a departure sector. This resulted in a 62 percent reduction in ground delays for departing aircraft.

- Average flight times and distances were reduced by approximately 20 percent in both departure and arrival sectors.
- Data Link alleviated frequency congestion making the voice radio more available for time critical clearance delivery.
- Benefit estimated at the NAS level annually was approximated to be about \$337 million with the introduction of two-way Data LinkATC communications.

Partly due to the success of the first simulation study at the William J. Hughes FAA technical center in Atlantic City, a second ‘man in the loop’ simulation study [Federal Aviation Administration Data Link Benefits Study Team, 1996] was conducted to identify and quantify some of the benefits of CPDLC in terminal airspace. The study examined operational ATC performance within the Newark area of the New York Terminal Radar Approach Control (TRACON). Three experiments were conducted separately and all were conducted using a case study methodology. Test scenarios were built to duplicate air traffic data sample periods taken from the Newark area.

In experiment 1 operational baseline data was compared to data from live simulation of ATC operations using a combined voice and Data Link communication system. For experiment 2 the no of flights were increased by 10 from the original 55 flight scenario to increase the demand on ATC resources. Experiment 3 examined Data Link’s impact on the Newark area satellite arrival position (MUGZY). The experiment was conducted on complex airspace because of crossing traffic with a variety of aircraft types and multiple destinations and tested whether the addition of Data Link communications would improve the processing of both commuter and business arrivals.

Results of experiment 1 showed that the average flight arrived at the airspace boundary 1.98 minutes sooner and mean flight distance and times within the terminal airspace reduced by an average of 6 miles and 3 minutes respectively. No holding of aircraft was required that had occurred on the operational baseline day. The productivity of the sector improved as the average number of flights handled by controllers during the test period increased by two and average number of arrivals increased by four.

For experiment 2 entry sector times reduced by an average of 1.36 minutes and the mean flight distance and times reduced by 1.7 miles and 0.7 minutes respectively. Holding was required but to a much lesser extent as compared to the operational baseline day. Experiment 3 failed to yield any significant benefits of CPDLC. Small improvements in sector performance were obtained in some test runs while, as others showed no benefit.

Some of the conclusions of the FAA Data Link study for the terminal area were:

- CPDLC will provide significant benefits when implemented in terminal ATC environments by increasing the arrival rate, reducing flight delays, improve airspace productivity, enhance safety and reduce controller workload.
- It would reduce the number of voice messages sent by controllers by an average of 45 to 66 percent.
- Reduction in annual operational costs to NAS users would be around \$152 million.

The CNS/ATM Focused Team (C/AFT) conducted two separate cost/benefit analysis of equipping with Very High Frequency Data Link (VDL) Mode 2 for Airline Operational Control (AOC) and ATC operations. One cost/benefit analysis [CNS/ATM, 1999] was conducted for determining the cost for transitioning from ACARS to VDL Mode 2 for AOC and ATC communication in a high density Cruise/Terminal Transition environment of the US National Airspace System (NAS). Another similar cost/benefit study [CNS/ATM, 2000] was conducted of equipping airplanes currently using ACARS for AOC operations with VDL Mode 2 and for equipping airplanes not using data link AOC to VDL Mode 2 in European airspace. Both the analysis was done from an airline perspective.

The NAS study concentrated on high-density Cruise/Terminal Transition environment, which is defined as the en route transition through end of Standard Terminal Arrival Route (STAR) and from the beginning of Standard Instrument Departure (SID) through transition to en route. All the comparison was done against a baseline scenario that allows AOC frequency congestion and ATC delay to increase

under the current conditions. The data link analysis model calculated the net present value (NPV) of cash flows from the years 2000 to 2020 for the proposed data link investment. The model assumed three stages of equipage, stage 0 was tied to AOC infrastructure readiness, stage 1 to ATC infrastructure readiness and stage 2 to a more advanced ATC infrastructure like CPDLC 1A or 2 readiness. The model assumed a 7 percent increase per year in the base case throughout the 20 years. Two kinds of costs were modeled, airline equipment cost for AOC and ATC, and ATC message costs. ATM costs or training costs were not modeled since the study was done from an airline perspective.

Some of the conclusions of the study were:

- VDL Mode 2 is a strategic, long term investment
- Forward fit equipage of VDL Mode 2 for AOC application has a good return on investment (IRR = 62%, Break even Year = 2006) and should start as soon as possible to avoid high retrofit costs.
- Forward fit equipage of VDL Mode 2 for Full data link has a reasonable return on investment (IRR = 57%, Breakeven Year = 2007).
- VDL Mode 2 would provide an approximate ten-fold increase in communication capacity over VHF ACARS.

The European Study was similar to the one conducted over the US NAS, the major differences being that the European study included all airlines that did not have data link AOC functionality as well as airlines that used ACARS and the European model assumed a 25 percent delay increase in years 2001-2005, 10 percent in years 2006-2010, and no increase in delay in years 2011-2020. Some of the conclusions of the study were:

- The maximum benefit (4101 Million Euros) would occur for the Full Data Link case with an IRR of 44 percent

- For the ATC case the benefits estimated were 2672 Million Euros with an IRR of 32 percent and for the AOC case the benefits estimated were 1118 Million Euros with an IRR of 35 percent
- Results of the European model were different from the US NAS model since the delay growth assumed in the European model was higher than that of the US model

A study [Rogers et al, 1998] known as the multi-center National Airspace System Simulation (NASSIM) study was conducted to evaluate the benefits of Data Link in the en route environment and to assess the impacts of Data Link equipage rates and differences between FAA facilities on Data Link benefits. A discrete event simulation model which models the transmission of communication messages through a voice communication channel and Data Link was developed. The model was used to analyze the impacts of two different Data Link message sets and four different Data Link equipage rates (25%, 50%, 75% and 90%) against a baseline scenario of only voice radio communications. Message set A included the transfer of communications and initial contact messages being sent and received using Data Link. Message set B, expanded upon the first by adding altitude, speed and heading clearances. The model was applied at three different en route facilities namely Atlanta ARTCC (ZTL) sector 9 and 32, Denver ARTCC (ZDV) sectors 27 and 29, and Los Angeles ARTCC (ZLA) sectors 19 and 8. The study showed that with increase in equipage rate the communications utilization and voice channel occupancy would decrease (e.g. 91% voice channel occupancy reduction for Denver at 90% equipage rate). Since the benefits at Atlanta ARTCC, which is a more busy airspace, were greater than those obtained at Denver or Los Angeles ARTCC, the study concluded that for busier facilities the absolute benefit is greater.

A series of studies were conducted by the ACT-350 at the FAA William J. Hughes Technical Center to evaluate and refine the controller Human Computer Interface (HCI), air traffic procedures and training for CPDLC. The first study [Darby et al, 1999] in this series was conducted to evaluate the Display System Replacement (DSR) HCI and to obtain controller input on the design of route assignment and downlink services needed to complete the CPDLC IA package. The study involved eight Air Traffic Control Specialists (ATCS) who took part in high fidelity simulation receiving hands on practice with

the DSR and CPDLC HCI. Controllers were also exposed to designs for the downlink and route assignment services. Some of the design improvements suggested were:

- Data Link Settings HCI should be modified to permit more efficient and accurate controller interaction.
- The Data Link eligibility symbol in the Full Data Block (FDB) should be changed to a filled diamond, and the symbol used to indicate an ongoing transfer of communication should be changed to a lightning bolt.
- The location of two Data Link keyboard keys should be changed to improve accessibility.

The second study [Darby, 2000] in this series was conducted to obtain a final review of the CPDLC I HCI and an initial review of the HCI and functionality for services that would be added under CPDLC IA. Procedures for CPDLC I failures and other atypical events were also tested. Six en route ATCS were recruited from the Miami ARTCC for evaluation purposes. The study found that the HCI and functionality for CPDLC I was found acceptable by the controllers.

For CPDLC IA the controllers suggested the following changes:

- Add functionality to permit the controller to view the menu text list and status list in a fully unfiltered form
- Implement the status list and menu text lists as DSR views.

A CPDLC study [Ferra, 2000] was conducted at the FAA William J. Hughes Technical Center to evaluate the functionality and performance of the CPDLC test bed facilities like the Display System Replacement (DSR), Host Computer System (HCS), Target Generation Facility (TGF), and Engineering Research Simulator (ERS) at the Technical Center and also to examine the ATC and flight deck procedural issues for CPDLC Build I. Seven test cases which simulated realistic air traffic/flight scenarios like ‘Mistuned Frequency’ were implemented to examine the impact of selected user errors and system

induced CPDLC events. The reactions and feedback of the participating pilots, controllers, and expert observers were used to evaluate the effectiveness of procedures and the performance of the facilities. The study concluded that reliable data exchange between TGC and HCS/DSR systems and between the ERS and HCS/DSR was achieved demonstrating the adequate performance of the CPDLC test facilities. The human factors objective of evaluating the flight deck and ATC procedures was also achieved.

Operational testing of CPDLC I was conducted by ACT-350 Data Link Group at the FAA William J. Hughes Technical Center to assess the readiness and operational acceptability of the FAA automation system and the ARINC sub-network. The testing was to be carried out in two phases. The first phase [Darby, 2001] simulated the ATN and VDL-2 sub-network using a production HCS software release and a prototype DLAP release. The second phase (no study as yet on it) would update the DLAP to a production release and simulate the ATN and VDL-2 sub-network in a complete end-to-end environment. The objectives of the first phase were to resolve five Critical Operational Issues (COI) namely:

- Can CPDLC be used without disruption or degradation to ATC operations?
- Does CPDLC maintain at least the current level of efficiency and accuracy of communications between the controller and pilot?
- Does CPDLC time performance allow for effective exchange of controller and pilot communications?
- Does CPDLC HCI effectively support air traffic and air crew operations?
- Is sufficient training provided for air traffic personnel and aircrew to effectively operate the CPDLC system?

Eight ATC controllers from the Miami ARTCC took part in the exercise. After a full scale simulation testing, they performed evaluations of the CPDLC training program, HCI and CPDLC procedures. Some of the conclusions of the study were:

- CPDLC did not increase perceived controller workload or impair performance on key sector duties and there was no evidence to suggest the use of CPDLC I would degrade or disrupt ATC operations
- Controller and observer sector ratings indicated that CPDLC maintained at least the current level of accuracy and efficiency in ATC communications and the time performance of the system permitted effective exchange of information
- The HCI was found to be effective for supporting ATC however there were six areas of concern that needed to be resolved before implementation of CPDLC
- Satisfactory controller performance indicated that training was sufficient to allow controllers to operate the system effectively

A study [Prinzo, 2001] was conducted to investigate the effect of controller to pilot acknowledgment time on controller workload and operational communication. Controllers took part in moderate air traffic density simulation where each controller completed the same scenario twice. For the first simulation half the controllers received immediate response to data link messages while the other half received responses after a 11 second delay. The roles of the controllers were switched for the second simulation. NASA Task Load Index (NTIX) developed by Hart and Staveland (1988) was used for evaluating the controller workload. NTIX is a multi-dimensional subjective rating procedure and is a index of perceived workload. Some of the findings of study were:

- Controllers took longer (around 2 seconds) to formulate and transmit messages over a data link communication system as compared to voice radio but the messages via data link were more accurate and contained fewer message elements

- Increase in subjective workload overall and on individual dimensions of the NTIX with mixed responses simulation scenario as compared to immediate pilot responses
- Analysis performed on communication measures revealed that controller workload was affected by communications capability on board the aircraft and not the pilot response type of immediate or delayed response.

A piloted simulation study [Waller, 1992] was conducted to determine the operational benefits of using digital data link for transmitting ATC instructions. The ATC instructions included altitude, airspeed, heading, radio frequency and route assignment data. In the study, aircraft data link communication with ATC was integrated with flight management functions of the aircraft. The conclusion of the study were that time required to process ATC data that arrived in the flight deck from the air traffic controller was reduced (25 percent).

A study [Massimini, et al., 2000] was done which proposed a method of using Total Airspace and Airport Modeler (TAAM) to measure the voice channel occupancy in a sector by manipulating the TAAM output. This method could be applied for current scenario of only voice communications and for future scenario of using CPDLC and hence could be used for examining the benefits of CPDLC. Since TAAM generates various reports that describe aircraft movements like sector crossings etc., the method involves associating every event, which is connected to a communication between controller and pilot with a voice channel occupancy time. The next step would be to compare the voice channel occupancy time obtained from TAAM with those obtained from the ‘human in the loop’ simulation conducted at William J. Hughes Technical Center. If the voice channel occupancy obtained from TAAM would be less than that from the simulation then changes like sector restrictions would be made to the TAAM model of the sector modeled until both the values became the same. After determining the exact nature of the sector that will simulate exactly the operations with CPDLC, the model could be run to estimate the system benefits such as reduction in delays or distance traveled.

A Cockpit Data Management Study [Groce, 1987] was conducted by the Boeing Commercial Airplane

Company to investigate the problems of assimilating and managing flight related information in the air carrier flight deck. Mode-S data link was used for ATC communications. A time line analysis (TLA) was used to assess the workload based on operator task time requirements. The study suggested that substantial pilot visual tasking would increase and alternative means of data link crew interface should be considered to off load the vision channels like speech technology.

Reynolds [1990] suggested that for an effective data link system it is important to adopt a system centered design approach which considers the interactive aspects of each and every participant (pilots, controllers etc.) and where all problems should be solved from a system wide point of view. Every element including controllers and pilots must be carefully analyzed and a solution for one element should not aggravate the problems of the other elements.

Corwin and his colleagues [1990] suggested a number of human factors issues to be considered for the implementation of data link. One such issue was the loss of “party line” (party line is the term used to describe the information exchange available simultaneously to all aircraft listening in on VHF communication frequency) information which might result in some loss of situational awareness with respect to other traffic and environment since via data link only ATC information available is that directed to the aircraft. They also suggested that the information available to the crew via data link should be prioritized in such a way that the messages receive the crew’s attention in proportion to the importance of the ATC directive.

According to Murphy [1992] the most significant issue, regarding external situational awareness, due to growth of data link would be loss of “party line” information. As data link related air traffic services are introduced, “party line” information must be addressed and replaced to the degree that it supports necessary external situational awareness.

Kerns [1991] suggested that both voice communication and data link should be configured to work together as a system since the unique performance characteristics of voice communication and data link would result in an operational advantage if used in combination as compared to either one used alone.

Ryan [1992] suggested that by augmenting the voice message and command system with a combined voice/data message and command system that would rely 90 percent on data link communications and 10 percent on voice communications, the airlines and the FAA could achieve significant operational benefits. According to Mattox (1990), pilot controller communications must be improved to prevent breakdown in the safety of NAS and improve efficiencies of operation and such significant improvements can be brought about by the use of data link and he also suggests that sufficient investment must be made to develop good data link designs so as to achieve the necessary safety benefits.

A study [Riley, 1992] was conducted where the Function Allocation Issues and Trade-offs (FAIT) methodology developed at Honeywell Inc. was used to identify potential human factor issues and requirement areas associated with air to ground data link. Based on the FAIT analysis, 48 significant human factor issues and 119 significant human factor requirement areas were identified. The human factors issue areas included:

- Sources and effects of delays
- Pilot and controller situational awareness
- Crew resource management
- Pilot and controller workload
- Some of the human factors requirements areas were:
 - Human-computer interface design
 - Crew Coordination
 - Sector workload

An experiment, which included detection of flawed ATC clearances as a measure of situational awareness, was performed by Chandra [1989]. Six transport pilots participated in this experiment which focused on the effect of automation on the time required by the pilot to process clearance amendments

with workload and situational awareness as secondary measurements. The experiment indicated that automation and lack of read back significantly reduced processing time. However the experiment was unable to substantiate any trends between automation, read back and situational awareness because the number of tests was insufficient for statistical significance.

Another similar experiment was conducted by Hahn et al [1992] to investigate the relationship between automated FMS programming, read back and situational awareness. The experiment varied the mode of clearance delivery from verbal to textual to graphical. Situational awareness was primarily measured by the pilot's ability to detect erroneous clearances. Three divisions of error detection performance were used, one where the error was detected immediately second where the error was detected at a later stage and third where the error wasn't detected at all. The aggregate percentages of error detection performance in each division were used to describe the overall level of situational awareness. Some of the conclusions of the experiment were that automated FMS programming might relieve some of the cognitive loads of pilots and read back when combined with automated FMS might be beneficial to pilots.

Midkiff et al [1992] conducted an experiment to identify the important "party line" elements and determine the effect of data link on situational awareness of pilots. Surveys were conducted to identify numerous "party line" elements after which flight simulation experiments were carried out to examine some of these elements. The study concluded that the ability to assimilate and use "party line" information appeared to be dependent on cognitive workload and strategic nature of situations. Results of the survey and simulation indicated that importance of "party line" information appeared to be greatest for operations near or on the airport suggesting that caution must be exercised when implementing data link communications in these high workload, tactical areas.

Shingledecker [1992] noted that technical differences between voice radio and data link systems would require users to adapt a different time scale for conducting ATC communications. Since voice communications are instantaneous in nature, the completion of a transaction using data link would require longer time due to transmission delays inherent to the ground and airborne components of the data link

systems. Shingledecker et al [1993] suggested that since data link is medium, which transmits messages to individual addressees, it could alleviate the problems induced by human-system interaction at nearly all stages of the communication process. Message composition should be assisted by storing common messages for selection from a menu, and by employing automatic checks on controller input formats to prevent transmission of ambiguous clearances. After studying 2700 reports of communications problems, Shingledecker [1993] came to the conclusion that data link would reduce 45 percent of all reported communication incidents and these incidents would include ambiguous, incomplete and garbled messages, phonetic confusions and transposition errors. Data link would partially reduce a further 54 percent of all incidents and only 1 percent of all problems identified in the reports would be unaffected since they pertained to faulty decision-making.

Beins [1995] suggested that developing the capability to translate messages from a given language to another language of preference on board the aircraft would reduce pilot controller communication errors. According to Beins the man-machine interface should be carefully designed to ensure that automation does not increase workload or create operational confusion. Data link messaging should reduce required tasks to one or two button pushes for majority of communications. Compensatory data link features should be developed which could replace "party line" situational awareness.

Bruce et al [1993] developed a model to study the influences of ATC task parameters like traffic volume and complexity on controller workload. Data for the model was obtained in an operational ATC setting from 7 FAA ARTCCs for 65 airspace sectors within those ARTCCs. The model was designed to explore the relationships between ATC system inputs (i.e. air traffic load and location of en route facility), staffing configuration (presence of single controller or controller teams) and ATC work activities on controller work pressure. Traffic volume and complexity of traffic configuration was found to have the most dominant effect on controller workload. Out of the above two task parameters traffic complexity was found to be most outstanding predictor of controller performance pressure.

Martin Nelson [1996] suggested that data link could be used to downlink automated information to identify and resolve any problems that may arise in the aircraft. An example of this would be the downlinking of engine parameters from an engine monitoring system and this would help resolve any problems like low oil pressure in an engine. This would translate into valuable time savings and costly delays would be avoided.

A data link simulation study [Mackintosh, 1999] was conducted at the NASA Ames Research Center in which five crews flew experimental scenarios in which data link was used as the primary ATC communication medium. Crew members received data link messages, which had to be read aloud by one of the members and finally then had to confirm the messages and respond to some of the messages using the "accept", reject, or "standby" response. For a limited number of messages there was also the "load" prompt which allowed crews to auto load clearance information into some aircraft subsystems. Results showed that the mean acknowledgement time was 27.5 seconds with a standard deviation of 38.7 seconds. Messages with distractions before message access had significantly longer access time (around 10 seconds) while as distractions after message access had a much greater impact on message acknowledgement times (average of 93 seconds).

A simulation study [Hinton et al, 1988] was conducted at Langley to evaluate the effects of various levels of data link capability in simulated, general-aviation, single pilot, and Instrument Flight Rules (IFR) operations. Four different levels of data link capability were evaluated, the base level being only voice communications. The second level provided one-way data link, from controller to pilot, of heading and altitude. The third level provided the same capability as second level in addition to one-way data link of textual data. The fourth level allowed two-way data link between controller and pilot. The ATC environment that was simulated was the Stapleton International Airport (Denver) itself and the airspace around it. Some of the findings of the study were:

- The number of ATC voice transmissions decreased as the data link capability increased (by 69 percent for level 4 capability for arrivals and about 75 percent for level 4 capability for departures) suggesting that data link would relieve the average occupation time of the voice channel

- Pilots took far longer time to respond to data link messages than voice communications especially in situations when they were involved in other tasks when the data link message was received
- The total number of ATC transmissions decreased as the data link capability increased (21 percent for level 4 capability for arrivals and 31 percent for level 4 capability for departures)
- The number of pilot voice transmissions decreased as the data link capability increased (by 56 percent for level 4 capability for arrivals and about 75 percent for level 4 capability for departures) suggesting that data link might relieve pilot workload.

Another similar piloted simulation study [Waller et al, 1989] was conducted at Langley to study the effects of data link in a two-pilot operation scenario. The ATC environment was the terminal airspace around Stapleton airport where a descent into the airport was simulated. Some of the findings of the study were:

- Data link was largely accepted by the pilots and was favored for routine ATC message exchange but not for time critical messages
- Copilot's reported a perception lower workload when operating with data link while as pilot's flying the aircraft were divided according to experience level on the issue of workload. More experienced pilots reported a perception of reduced workload while as less experienced ones suggested a slight increase in workload
- Data link message exchanges took on the average 11 seconds more than voice messages to complete

A similar two pilot simulation study [Knox et al, 1991] was conducted in the NASA Transport Systems Research Vehicle (TSRV) Boeing 737 airplane to determine the pilot acceptance of data link as the primary source of communication. Three separate test flights were flown on different routes originating and terminating at the Wallops Flight Facility. Each of flights consisted of a climb phase followed by an abbreviated cruise phase and finally a descent phase. Some of the conclusions of study were:

- The number of communication repeats and error were far greater with voice only communication as compared to data link with voice backup
- Pilots suggested data link with voice backup for ATC tactical clearances was acceptable to use from takeoff until operating in the terminal area for landing
- Copilots perceived that their workload was greatly reduced mainly because of the single-button entry of route modifications and barometric altimeter settings into the FMS

3.3 Operational Evaluation of URET

URET has been operational in Indianapolis and Memphis ARTCC since 1997. Both these facilities extended their hours of operation to 22 hours a day, 7 days a week early in 2000. Some of the conclusions of the operational evaluation were: [Celio, 2000]

- The number of operational errors in ZID and ZME decreased drastically and URET provided an average of 7 minutes of warning time for the 21 cases where the Host provided reliable data
- URET can realize from 30 to 50 percent of maximum benefits (corresponding to relaxation of all altitude and horizontal restrictions) using full conflict probe and resolution capability
- URET would provide reduction in sector workload to controller and create opportunity to carry out strategic planning tasks

A restriction relaxation experiment [Burski, 2000] was carried out at ZID and ZME to review all altitude and horizontal restrictions in effect at each site and to identify all possible candidates for relaxation evaluation and possible elimination.

There are about 190 static altitude restrictions in ZME airspace and about 370 in ZID airspace. Three different relaxation evaluations were carried out and for each restriction relaxed, the fuel saving varied between 1 to 2 percent of total fuel.

3.4 Operational Evaluation of Traffic Management Advisor

Traffic Management Advisor was used and operationally evaluated [Swenson, 1997] for thirty-nine rush traffic periods during a one month period in the Summer of 1996 at the Fort Worth Air Route Traffic Control Center (ARTCC). The evaluations included all shifts of air traffic operations as well as periods of inclement weather. Performance data were collected for engineering and human factor analysis and compared with similar operations without the TMA. The engineering data indicated that the operations with the TMA show a one to two minute per aircraft delay reduction during rush periods. The human factor data indicated a perceived reduction in en route controller workload as well as an increase in job satisfaction. The TMA also allowed the TRACON to increase the average airport acceptance rate by 5%.

3.5 Operational Evaluation of Passive Final Approach Spacing Tool

A human factors assessment [Lee, 1996] was carried out during operational testing of PFAST at Dallas/Fort Worth TRACON facility. The assessment showed that controller workload was not significantly increased or decreased by PFAST even though runway assignments, sequences and spacing were discussed with far greater frequency (by about 300 percent) under PFAST conditions than under baseline conditions.

Operational evaluation [Davis, 1997] of FAST in live traffic conditions at the Dallas/Forth Wort TRACON facility showed that FAST was able to increase the airport throughput by about 13 percent without any negative impact on safety. Controllers accepted and utilized over 83 percent of sequence

advisories and 96 percent of runway allocation advisories. PFAST appeared to provide a safety benefit by decreasing the intrail separation below IFR standards that occurred during VFR conditions.

4.1 Introduction

This chapter briefly describes the methodology used for conducting this research. As mentioned earlier the goal of this research is to develop a framework to evaluate the benefits and costs of implementation of new technologies like CPDLC, TMA, PFAST and URET and hence to provide a framework to answer key questions like what is the benefit as compared to the current scenario of only voice communication channel when data link is used as a supplement to the voice communication channel; what would be the true benefits if data link and decision support tools are used together in a non-integrated scenario and would the additional benefits due to the integration of decision support tools with data link justify the additional cost required for the integration?

A model is proposed that will accurately represent accurate causal relationships between all factors that would influence the benefits of data link and decision support tools in a integrated and non-integrated scenario.

4.2 System Dynamics

A Systems Dynamics methodology is adopted in building the model. The methodology relies on the use of causal relationships coupled with feedbacks as a means to model complex economic and technological systems. System Dynamics makes possible the representation of decision policies and information flows. A systems dynamics methodology provides for a more efficient economic analysis.

The System Dynamics model should have the following characteristics:

- Be able to describe any statement of cause effect relationship that one wishes to include
- Be simple in mathematical nature
- Be extendable to large number of variables without exceeding the practical limits of computers
- Be able to handle continuous interactions in the sense that any artificial discontinuity introduced by solution time intervals will not affect the results
- Should be able to generate discontinuous changes in decisions when these are needed [Forrester, 1961]

The three basic steps in the System Dynamics modeling process are:

- Verbal Description
- Causal Diagram
- Mathematical Model

The first step is to describe the problem verbally. The verbal description is then expressed as a flow diagram, also called a causal diagram. The next and final step is to convert this causal diagram into a mathematical form.

4.3 Description of STELLA 7.02

The software STELLA is used as the tool for building the model primarily because of the ease with which complex system dynamics models can be built in STELLA and also STELLA can model complex relations between different elements in an accurate manner. STELLA is an acronym for “Systems Thinking, Experimental Learning Laboratory with Animation”. STELLA executes dynamic simula-

tion model. It is a problem oriented software rather than computer oriented. The software has built in diagramming, model building and simulation capabilities.

STELLA has a three layer operating environment, the top layer being the interface layer, the middle layer being the map/model layer and the lower layer being the equation layer. The model is exclusively built in the map/model layer. The interface layer is primarily used for displaying the results as well as make changes in certain input variables. The equation layer displays the equations that are defined between different variables.

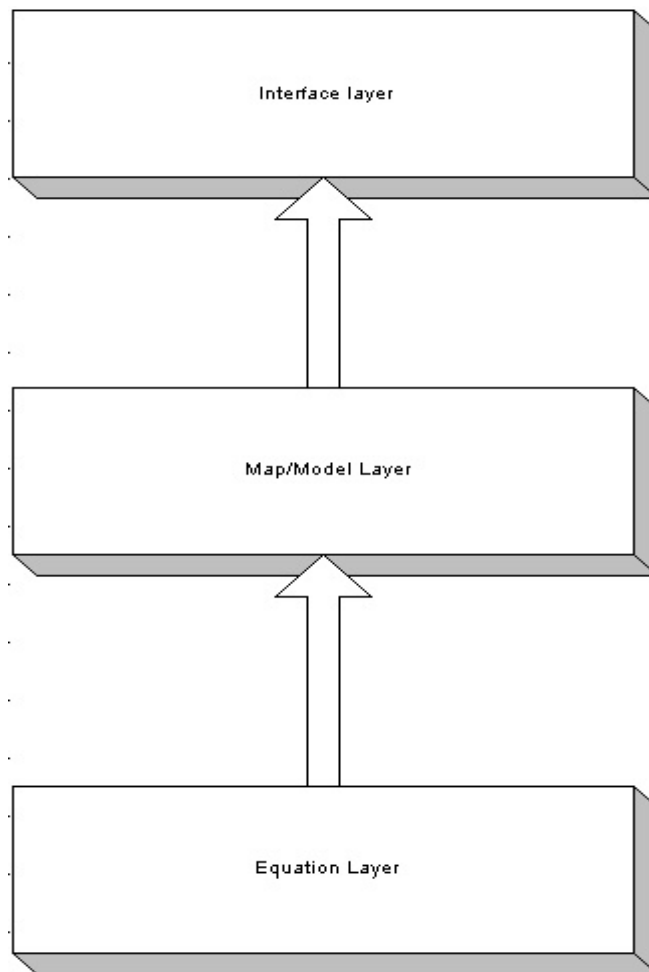


Figure 4.1 Three Layer Operating Environment in STELLA

4.3.1 Interface Layer

The interface layer is actually the Graphical User Interface (GUI) layer. The interface layer has mainly two purposes. Firstly it can be used for displaying any results in graphical or table form after the model has been run and secondly it can also be used to make changes into any input variable that has been linked to the interface layer by some input device without actually having to enter into the model/map layer.

There are three building blocks on the Interface layer: the Process Frame, the Bundled Flow, and the Bundled Connector. The Process Frame allows you to represent high-level processes. It facilitates a "top-down" approach to model construction. It also provides capabilities for navigating to the associated Sector Frame and its stock/flow structure on the Map/Model level. The Bundled Flow allows you to represent, at a high level, the material flows between processes in your model. Like the Process Frame, the Bundled Flow facilitates a "top-down" approach to model construction. It also provides navigational capabilities for finding sector to sector flows on the Map/Model level when "Link High-Level Map to Model" is checked in the Interface Preferences. The Bundled Connector allows you to represent, in summary form on the Interface level, any sector-to-sector connectors which exist in your model. Like the other mapping building blocks, the Bundled Connector facilitates a "top-down" approach to model construction, and provides navigational capabilities.

Apart from these basic building blocks there are also number of input devices that allow a user to input the value of a variable from the interface layer. These devices are sliders, knobs, list input device, graphical input device. The Slider Input Device allows model users to adjust constant values, and to override equation logic (and graphical function relationships) with numerical inputs. The Knob is useful principally for providing initial values for Stocks. Knobs also can be used to adjust values for constants. Unlike the Slider, the Knob cannot be adjusted during the course of a simulation. It is set prior to the outset of a simulation and remains fixed throughout the simulation. Variables which contain equations or graphical functions can not be assigned to a Knob. The List Input Device (LID) is a simple spreadsheet-like input device. Users of your models can use the LID to set the values for converters

and flows in the model. In addition, users can use the LID to set the initial values for stocks in the model. Multiple model variables can be assigned to a single LID. A single LID can contain multiple pages. The Graphical Input Device enables model users to: (1) see, at a glance, the shape of a graphical function, (2) edit a graphical function from the Interface level; (3) restore a graphical function to its author defined relationships; and (4) animate graphical functions during a simulation.

:

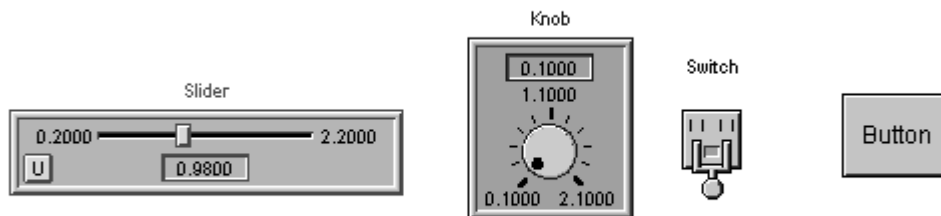


Figure 4.2 Interface Layer Devices

There is also a device called switch which is used to turn things on or off in a model. When a switch is assigned to a converter, the converter will take on the value of 1 when the switch is on, and 0 when the switch is off.

Finally there is also a device called button. When "pushed," buttons perform one of several operations such as navigating to a new location, executing a menu command like run or pause, or providing pop-up information.

4.3.2 Map/Model Layer

The Map/Model Layer is the level at which the main model building is done. The basic blocks in the map/model layer are Stocks, Flows, Converters, and Connectors.

Stocks or levels are accumulations or state variables and are represented by rectangles. Stocks are accumulations. They collect whatever flows into them, net of whatever flows out of them. The default

stock type is the Reservoir. Think of a Reservoir as a pool of water, or as an undifferentiated pile of "stuff." A Reservoir passively accumulates its inflows, minus its outflows. A stock can also be a Conveyor, Queue or Ovens. Conveyor stock can be likened to a conveyor belt where material gets on it and rides it for sometime and then gets off where the transit time can be constant or variable. Queue stock is like a line of items awaiting entry into some process or activity. It follows a First In First Out (FIFO) principle where whichever item enters first will exit first. Oven stock is like a processor of discrete batches of stuff. The Oven opens its doors; fills (either to capacity or until it is time to close the door); bakes its contents for a time (as defined by its outflow logic); then unloads them in an instant.

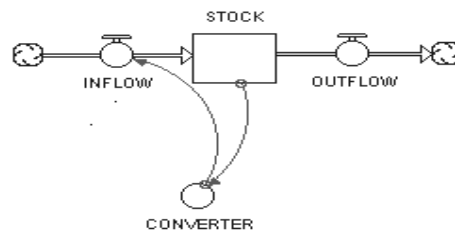


Figure 4.3 Basic Building Blocks at the Map/Model Layer

Flows are rates of change and they regulate flow in and out of stocks. Flows are meant to fill and drain accumulations. The unfilled arrow head on the flow pipe indicates the direction of positive flow.

The converter serves a utilitarian role in the software. It holds values for constants, defines external inputs to the model, calculates algebraic relationships, and serves as the repository for graphical functions. In general, it converts inputs into outputs. Hence, the name "converter." Converters can represent auxiliary variables, constant parameters or supplementary variables.

Connectors are used to connect model elements. The software provides for two distinct types of connector: the action connector and the information connector. Action connectors are signified by a solid, directed wire. Information connectors are signified by a dashed wire. Connectors link stocks to converters and converters to other converters. Connectors do not take on any numerical value, they represent inputs.

4.3.3 Equation Layer

The equation layer is just a representation of all model elements and relations that have been built in the map/model layer in equation form. At this level values of various variables and equations can be altered.

4.4 Methodology

The thesis aims to provide a framework to answer key questions like what would be true benefits as compared to the current scenario of only voice communication channel when data link is used as a supplement to voice communication channel; what would be the benefits as compared to the current scenario of only voice communication channel when data link is used in conjunction with decision support tools in a non integrated scenario and would the additional benefits due to the integration of decision support tools with data link justify the additional cost required for the integration. A system dynamics methodology is adopted for this research endeavour.

A modeling framework is proposed that represents accurate causal relationships between all factors that influence the benefits and costs of data link and decision support tools in an integrated and non-integrated scenario. A systems dynamics methodology is adopted in building the model using causal relationships coupled with feedbacks as a means to model complex technological systems. A two level model system is proposed so that the lower model can capture various metrics at a more microscopic (daily) level for a typical day and feed it into the upper level model which uses these metrics and run's over the life cycle period to output benefits and costs over the entire life cycle. Both models consider integrated and non-integrated scenario to assess the deployment schedule of Air Traffic Control (ATC) and airplane infrastructure. Figure 4.4 shows the two level model system.

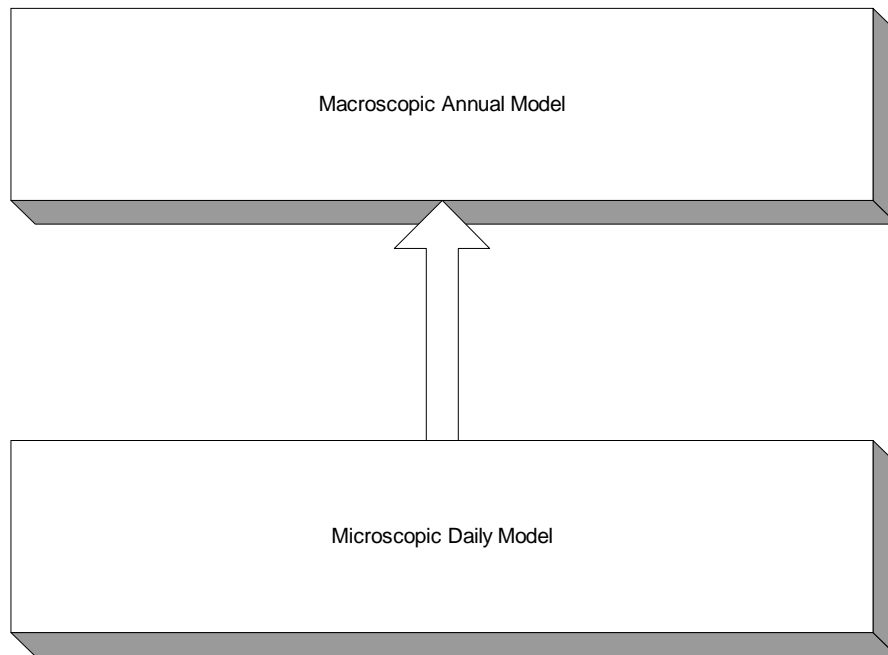


Figure 4.4 Two level model system

The methodology is to define a scenario and to evaluate the four alternatives for each scenario. The time of implementation of each CPDLC Build or any of the decision support tools can be described as a scenario by itself. In addition to that, since the model is an open ended model where a number of parameters can be changed, each parameter change can be described as a scenario as well.

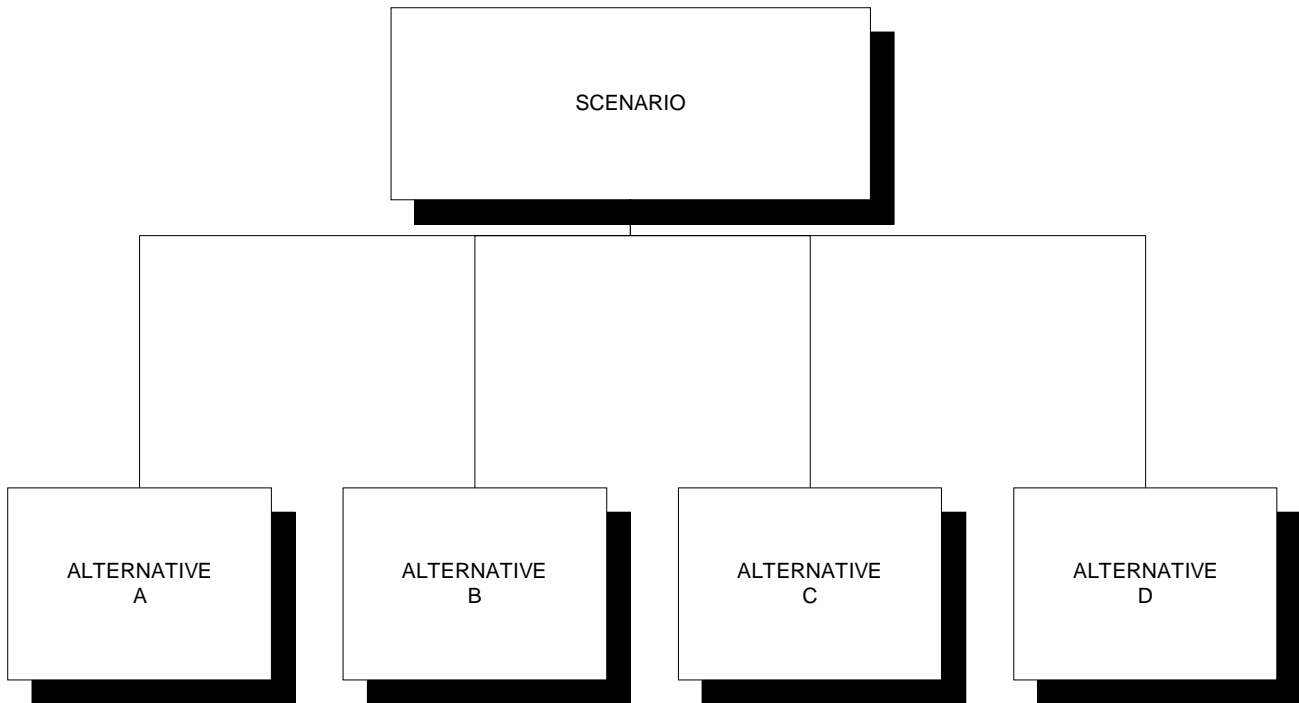


Figure 4.5 Alternative

The four alternatives which are evaluated for each scenario are:

4.4.1 Alternative A

This is the base or current scenario in NAS. All other alternatives are compared against this base alternative. In this alternative, voice channel is the only method of communication between a controller and a pilot.

4.4.2 Alternative B

Implementation of Controller Pilot Data Link Communication (CPDLC) System to supplement the voice communication channel as a mean of communication between controllers and pilots.

4.4.3 Alternative C

Implementation of Controller Pilot Data Link Communication (CPDLC) System and decision support tools like User Request Evaluation Tool (URET), Traffic Management Advisor (TMA) and Passive Final Approach Spacing Tool (PFAST) in a non integrated setup. A non integrated setup is one where the decision support tools function independently of data link and there is no tie up between data link and the tools.

4.4.4 Alternative D

Implementation of Controller Pilot Data Link Communication (CPDLC) System and decision support tools like User Request Evaluation Tool (URET), Traffic Management Advisor (TMA) and Passive Final Approach Spacing Tool (PFAST) in an integrated setup. In an integrated setup, each one of the decision support tools are tied with data link.

The integration of URET with CPDLC is the only integration evaluated in the model since no real foreseeable benefit could be identified due to the integration of PFAST or TMA with CPDLC. The typical benefit that is identified due to the integration of URET with CPDLC is the time saving since the controller can directly upload a conflict advisory from the URET display without having to retype and upload the advisory.

Description of Microscopic Model

5.1 Modeling framework

A two level model system is proposed so that the lower model can capture various metrics at a more microscopic (daily) level for a typical day and feed it into the upper level model which uses these metrics and run's over the life cycle period to output benefits and costs over the entire life cycle. Both models consider integrated and non-integrated scenario to assess the deployment schedule of Air Traffic Control (ATC) and airplane infrastructure. A low level microscopic model simulates air traffic in enroute sector and terminal airspace for a day and quantifies airspace occupation times, controller workload, pilot workload and communication channel utilization as the major outputs. Airspace dwell time benefit surfaces for alternative B, C and D as compared to base alternative A are obtained by regressing airspace occupation time data as a function of equipage level of aircraft and aircraft density. The microscopic model is composed of nine modules, each module for each of the four alternatives in both enroute airspace and terminal area and also an aircraft demand generator module.

The high level or macroscopic model is a life cycle model fed by the results from the microscopic simulation model and runs over a life cycle period quantifying benefits and costs. The high level model is composed of four modules namely operational benefits module, safety benefit module, training cost

module and technology cost module. The airspace occupation time benefit surfaces obtained from the microscopic model are embedded into the operational benefits module in the life cycle cost model. Benefits are quantified and separated in terms of applicability to the user (airline), the service provider (FAA), or both. To achieve this, all variables and factors known to significantly affect both the benefits and costs are modeled using mathematical relationships between these variables. One of the main applications for the life cycle cost model is the ability to use the model to study any deployment schedule of CPDLC and other decision support tools to ascertain the economic viability of the schedule.

The model is a very open model with a number of parameters that can be changed and re-run. The main reason for having a open model is that some of these technologies are not yet fully operational and only a prototype is being used right now in certain area's and hence some of its parameters cannot be accurately quantified at the present moment and hence a range is provided for each of these parameters so that a parameter can be changed to a more accurate value in the future, if and when it is known. The advantage of having an open model is that it gives great degree of flexibility to the user of this model, whether it is the airline or the FAA, to change any parameter or variable so as to study the effect of such a change over the entire life cycle of the model.

The objective of the two level model system is to ascertain the viability of the following four alternatives:

- Alternative A – Baseline or 'do nothing' scenario
- Alternative B – Implementation of CPDLC to supplement the voice channel in the enroute and terminal scenario
- Alternative C – Implementation of CPDLC with decision support tools like URET, TMA and PFAST in a non integrated scenario
- Alternative D - Implementation of CPDLC with decision support tools like URET, TMA and PFAST in an integrated scenario

Non-integrated scenario represents the situation where CPDLC and decision support tools are used independently of each other. Integrated scenario represents the situation where functioning of CPDLC is intertwined with the functioning of decision support tools like using data link to upload conflict advisories directly from the trial planning facility in URET.

5.1 Modeling framework

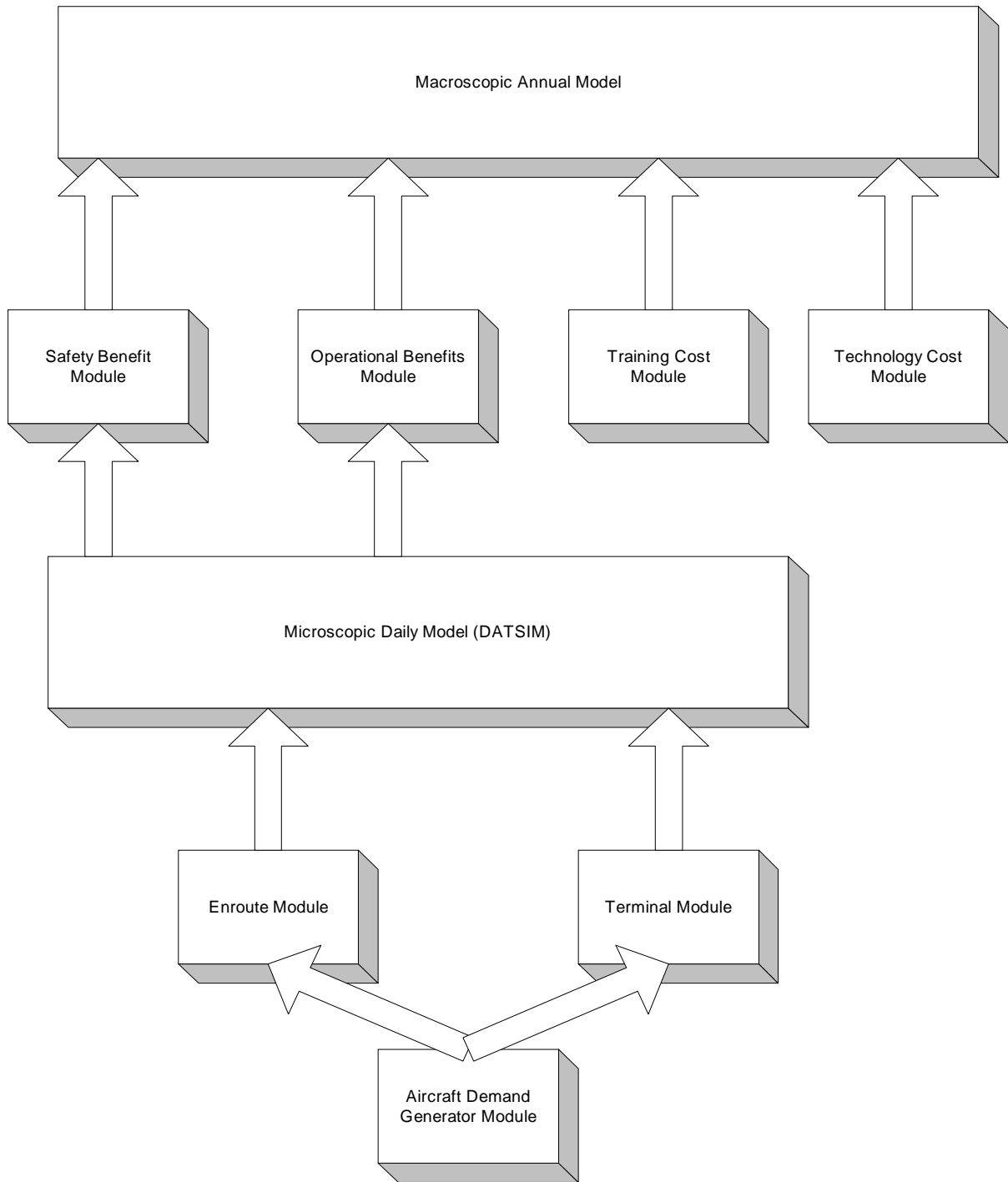


Figure 5.1 Two Level Model System

5.2 Microscopic Daily Model (DATSIM)

The microscopic daily model is also called DATSIM which is an acronym for Data Link and Air Traffic Technologies SIMulation and it simulates air traffic in the enroute sector and terminal airspace for a single day and captures the measures of effectiveness at a microscopic level and feeds its output to the macroscopic annual model which then runs over the entire life cycle of the system. DATSIM is composed of nine modules, each module for each of the four alternatives in both enroute airspace and terminal area and also an aircraft demand generator module. Aircraft are generated by a demand function in the aircraft demand generator module and then simulated through an enroute sector and terminal airspace.

The microscopic daily model simulates air traffic for varying traffic densities and equipage level of aircraft in an enroute sector and terminal airspace. The model runs over the entire day with a time step of 6 seconds. A time step of 6 seconds was chosen so as to model certain controller activity tasks with smaller activity times more accurately.

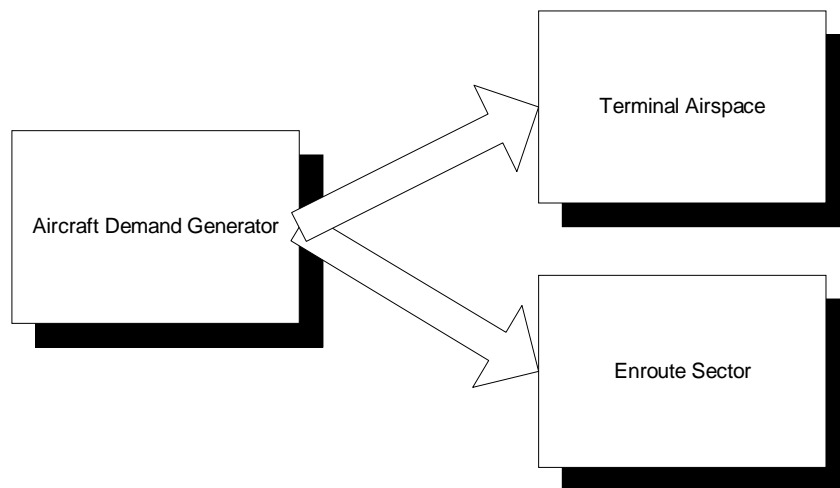


Figure 5.2 Outline of Microscopic Daily Model

Aircraft are generated by a demand function in the aircraft demand generator module and then simu-

lated through an enroute sector and terminal airspace. The microscopic daily model has four modules for the four alternatives that are being evaluated. Each terminal airspace module is arrayed into high density, medium density and low density airports where high density corresponds to a hub airport, medium density corresponds to a medium size airport and low density corresponds to a small airport.

The major outputs from the microscopic daily model are Controller Workload, Pilot Workload, Communication Channel Utilization and Airspace Occupation times.

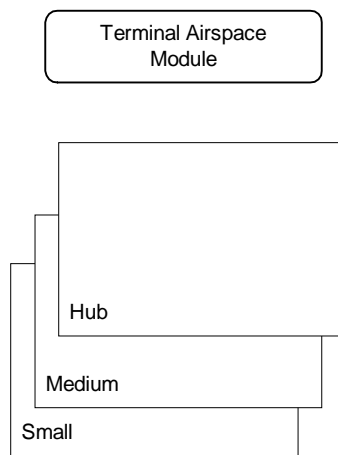


Figure 5.3 Classification of Terminal Airspace Module into types of airport

The remainder of this chapter describes all the concepts and the variables in the microscopic daily model.

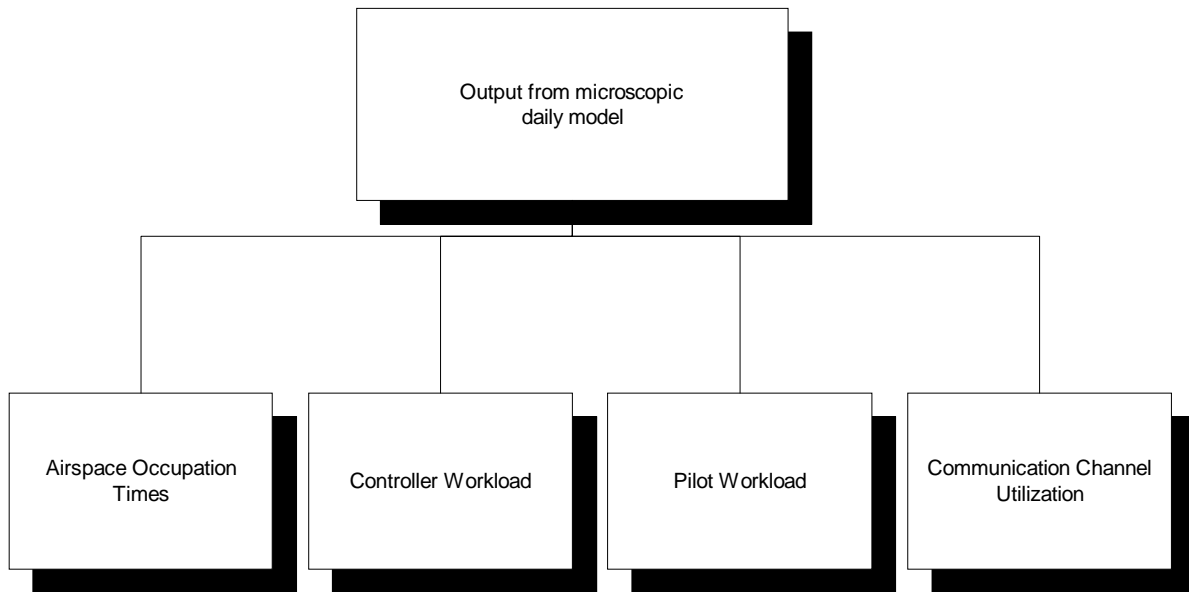


Figure 5.4 Output from Microscopic Daily Model

5.2.1 Simulation Parameters of microscopic daily model

The model is run simulating an entire day's of air traffic with a time step of 6 seconds resulting in 14400 time steps over the entire day. For higher traffic volumes the model is allowed to run for more than a day until all the air traffic has exited from the enroute sector and terminal airspace. A time step of 6 seconds is chosen so as to model certain controller activity tasks with smaller activity times more accurately. The model runs from 1 time step to 14400 time steps if all the air traffic has been processed through the simulation otherwise its allowed to run until all air traffic has been processed and have exited the simulation. The simulation is started at 1 and not 0 to avoid division by zero of some variables. The run mode for the model can be "Normal," or "Cycle-time." Cycle-time mode is selected since cycle time metrics like airspace occupation times in enroute and terminal airspace for each aircraft can only be generated and collected in this mode. There are three methods of integration available in STELLA namely Euler's, Runge-Kutta second-order, and Runge-Kutta fourth-order. When operating in the Cycle-time mode, the integration method is automatically set to Euler's. Also since there are Queue and

Conveyor variables and Runge Kutta does not deal well with such discrete objects, Euler's method is chosen.

From	0 time step
To	14400 time step
Time step	6 seconds
Run mode	Cycle time
Integration method	Euler's

TABLE 5.1 Simulation Parameters of microscopic daily model

5.2.2 Aircraft Demand Generator module

The aircraft demand generator module injects aircraft into the enroute sector and terminal airspace depending on the inter arrival time which depends on the time of day and the traffic growth factor. Inter arrival time is the expected time interval between two consecutive aircraft in an enroute sector or terminal airspace. The inter arrival time varies according to the time of day hence the day is divided into four six hour segments (12 am to 6 am, 6a.m to 12 pm, 12 pm to 6 pm and 6 pm to 12 am) to capture the true peak or off peak value of inter arrival time in each segment and not an average value over the entire day. Inter arrival times for each segment of the day for the base year were obtained from the Airspace Occupancy Model (AOM) developed at Virginia Tech. The year 2002 was considered as the base year for all analysis with a traffic growth factor accounting for the increase in traffic in future years as compared to the base year.

Traffic Growth Factor (TGF)

Traffic Growth Factor is the percentage of flights of the base year that is expected to increase over the entire National Airspace System (NAS). Base year in this model is considered to be 2002.

Traffic Scale Factor (TSF)

It is a factor which accounts for increase in air traffic due to the traffic growth rate. It modifies the inter arrival time (IAT) of aircraft depending upon the traffic growth factor.

$$TSF = 1 + TG \tag{5.1}$$

Inter Arrival Time (IAT)

It is expected time interval between two consecutive aircraft in an enroute sector or terminal airspace. The inter arrival time varies according to the time of day hence the day is divided into four segments to capture the true value of inter arrival time in each segment and not an average value over the entire day. The four segments are 0 to 6 a.m, 6a.m to 12 p.m, 12 p.m to 6 p.m and 6 p.m to 12 a.m. Inter arrival times for each segment of the day for the base year were obtained from the Airport Operational Model (AOM) developed at Virginia Tech. Atlanta and Jacksonville ATRCC’s were simulated in the AOM model and entry times of each aircraft for each sector were obtained and then sorted into four segments of the day to obtain the mean inter arrival times for each segment. In order to compute the Inter arrival time for any future traffic growth, the base year values are divided by the Traffic Scale Factor (TSF).

$$IAT(t) = \frac{IAT_{base}(t)}{TSF} \tag{5.2}$$

The values of Inter arrival time for the base year are:

	Time Segment	Inter Arrival Times (base year) (minutes)
Time Segment	12 AM - 6 AM	60
	6 AM - 12 PM	10
	12 PM - 6 PM	12
	6 PM - 12 AM	18

TABLE 5.2 Inter Arrival times for base year

Time elapsed since last generation (TLG)

This is a variable which keeps track of the time that has elapsed since injection of the last aircraft in the enroute airspace. It is initialized to zero when a new aircraft enters the enroute sector and keeps a track of the time elapsed since the injection of the last aircraft.

Aircraft Injector (AI)

Aircraft Injector variable injects aircraft into the enroute sector depending on the time elapsed since last injection of an aircraft. Aircraft Injector compares the value of the Inter arrival time (IAT) for the given segment of day and the variable time elapsed since last generation (TLG) and when the value of time elapsed since last generation becomes equal to or greater than IAT, it injects an aircraft into the enroute sector.

$$IF(TLG(t) \geq IAT(t)) \quad THEN(1)ELSE(0) \quad (5.3)$$

5.2.3 Basic Structure of the Enroute Sector Module

The basic structure of the enroute module for all the four alternatives is the same. In the enroute module, aircraft operations in a single enroute sector are simulated. The enroute sector is represented by a Conveyor Stock with a variable transit time. There is also a Reservoir Stock before the Conveyor Stock which represents the Queue of aircraft waiting to enter the enroute sector when the sector has reached its physical capacity or when the controller has reached his own mental capacity to handle anymore aircraft in the sector. Realistically, there is never any physical Queue outside an enroute sector when a sector cannot accommodate anymore aircraft. When a sector cannot accommodate anymore aircraft, the aircraft which are scheduled to enter the sector in the near future are delayed either by slowing down their cruising speed or by vectoring. The Reservoir Stock representing the queue outside the enroute sector achieves the same result as slowing down an aircraft or vectoring by queueing all aircraft outside the sector until the sector is able to accommodate more aircraft. Figure 5.5 shows the basic building blocks of the enroute module.

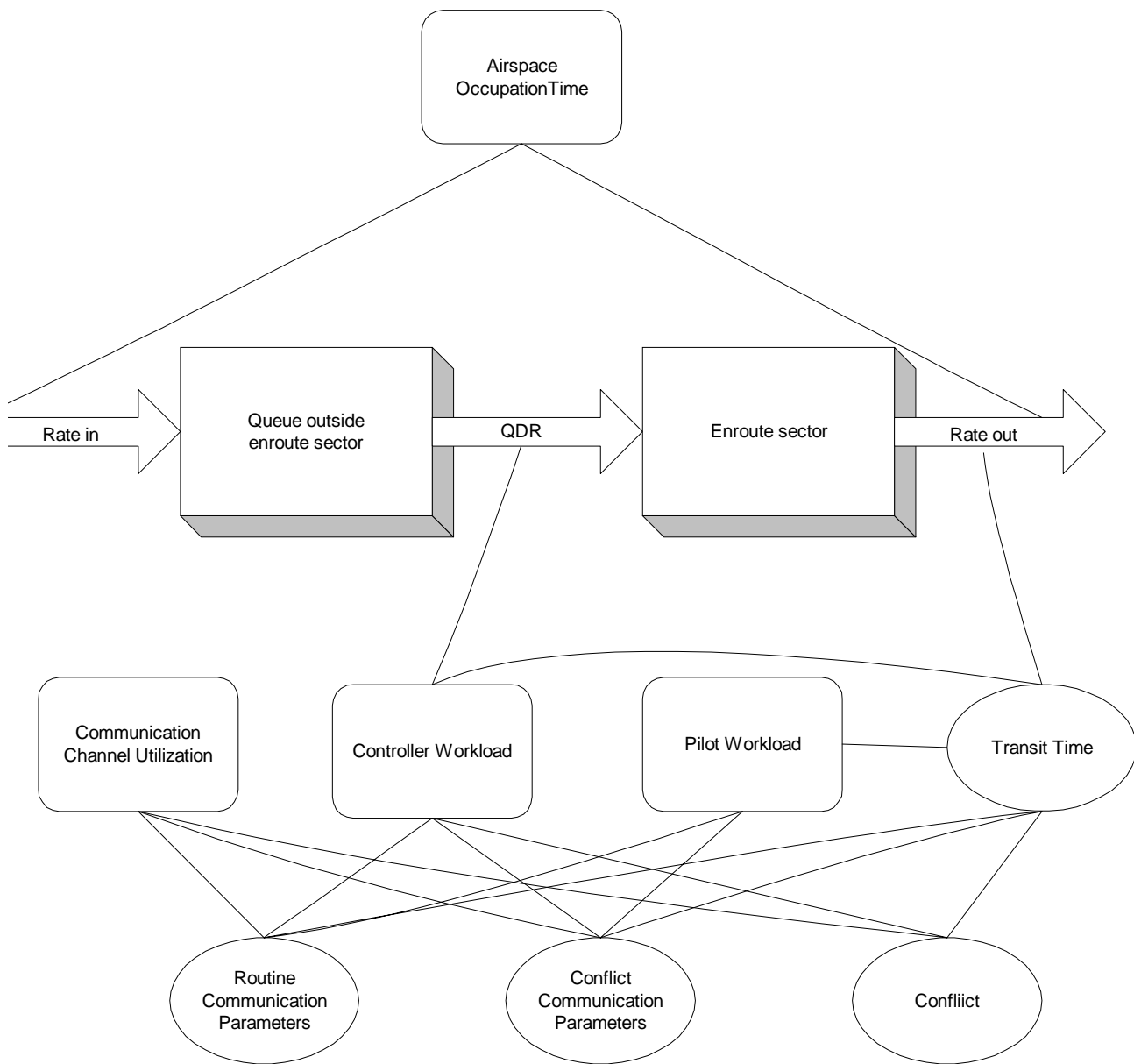


Figure 5.5 Basic structure of the enroute module

Rate in enroute sector (Rin_e)

It is the number of aircraft per time step (6 seconds) that enter's the Queue outside the enroute sector,

if such a queue exists. If there is no queue it is then the number of aircraft per time step that enter's the enroute sector. It is basically equal to the Aircraft Injector (AI) variable from the Aircraft Demand Generator module.

$$Rin_e(t) = AI(t) \tag{5.4}$$

Aircraft Queue outside enroute sector (Q_e)

It is the number of aircraft waiting in queue to enter the enroute sector due to mental resources capacity constraints of the controller in the enroute sector. There is a finite number of aircraft that a controller can actively control in an enroute sector at any point of time. This finite number of aircraft corresponds to mental saturation level of the controller at any point of time which when equalled or exceeded, no further aircraft are allowed to enter the enroute sector and are queued outside the sector.

$$Q_e(t) = Q_e(t - dt) + \int (Rin_e(t) - QDR(t))dt \tag{5.5}$$

The initial value of the Queue is zero and the queue is of infinite capacity. The variable is modelled as a Reservoir Stock.

Queue Dissipation Rate (QDR)

It is the number of aircraft exiting from the queue outside enroute sector per time step. It is a rate variable which exits from the aircraft queue outside enroute sector stock and feeds into the enroute sector

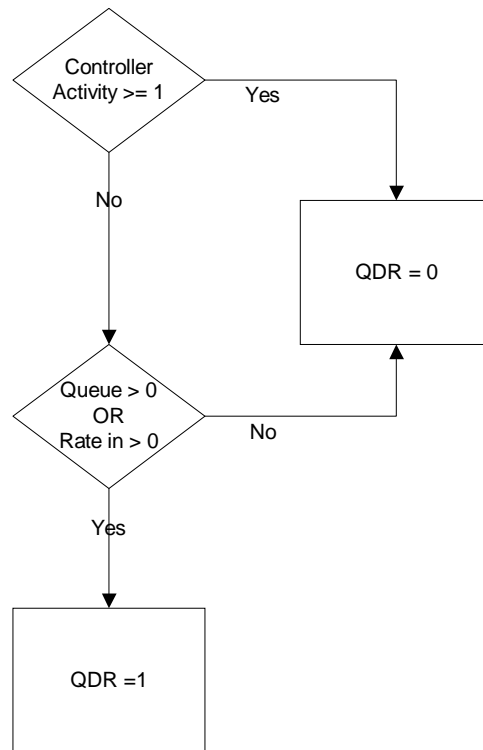


Figure 5.6 Flow chart outlining the QDR logic

stock. Since it feeds into the Aircraft in enroute sector ($ACFT_e$) Stock it has to be modeled to consider the capacity constraints of the enroute sector. Mental resources constraint of the controller is a more critical factor than the physical capacity of the sector hence at every time step the controller workload is determined represented by the variable controller activity, which is described later in this chapter, and aircraft are only injected into the enroute sector if the controller workload is within acceptable levels. The flow chart in figure 5.6 describes the logic of QDR variable.

The actual equation for QDR is:

$$IF(CAL_e(t) \geq 1) THEN(0) \quad ELSE(IF(Rin_e(t) = 0) OR(Q_e(t) = 0)) THEN(0)) ELSE(1) \quad (5.6)$$

The CAL_e variable denotes Controller Activity Level of an enroute controller which will be described later.

er in this chapter.

Rate out enroute sector ($Rout_e$)

It is the number of aircraft per time step that exits from the enroute sector. It is reciprocal of the time that an aircraft spends in an enroute sector which is equal to the transit time (TT_e) of the Conveyor Stock, Aircraft in enroute sector ($ACFT_e$).

$$Rout_e(t) = 1/(TT_e(t)) \quad (5.7)$$

Transit time (TT_e) is the time taken by an aircraft to traverse an enroute sector. The concept of transit time is explained later in the chapter.

Aircraft in enroute sector ($ACFT_e$)

It is the number of aircraft that are present in the enroute sector at any point in time. The maximum value is the capacity of the enroute sector (C_e).

$$ACFT_e(t) = ACFT_e(t - dt) + \int(QDR(t) - Rout_e(t))dt \quad (5.8)$$

The variable is modeled as a Conveyor Stock with finite capacity equal to C_e and inflow limit of 1 every time step. The transit time in the sector is variable.

5.2.4 Basic Structure of the Terminal Airspace Module

The terminal airspace module is classified according to traffic density into high density, medium density and low density airports where high density corresponds to a hub airport, medium density corresponds to a medium size airport and low density corresponds to a small airport. The basic structure of the terminal airspace depends on the class of airport. Terminal airspace of a hub airport is represented by a typical four corner post system while as a medium size airport and small size airports are represented by a two corner and one corner post system respectively. There are two arrival streams merging into each corner post.

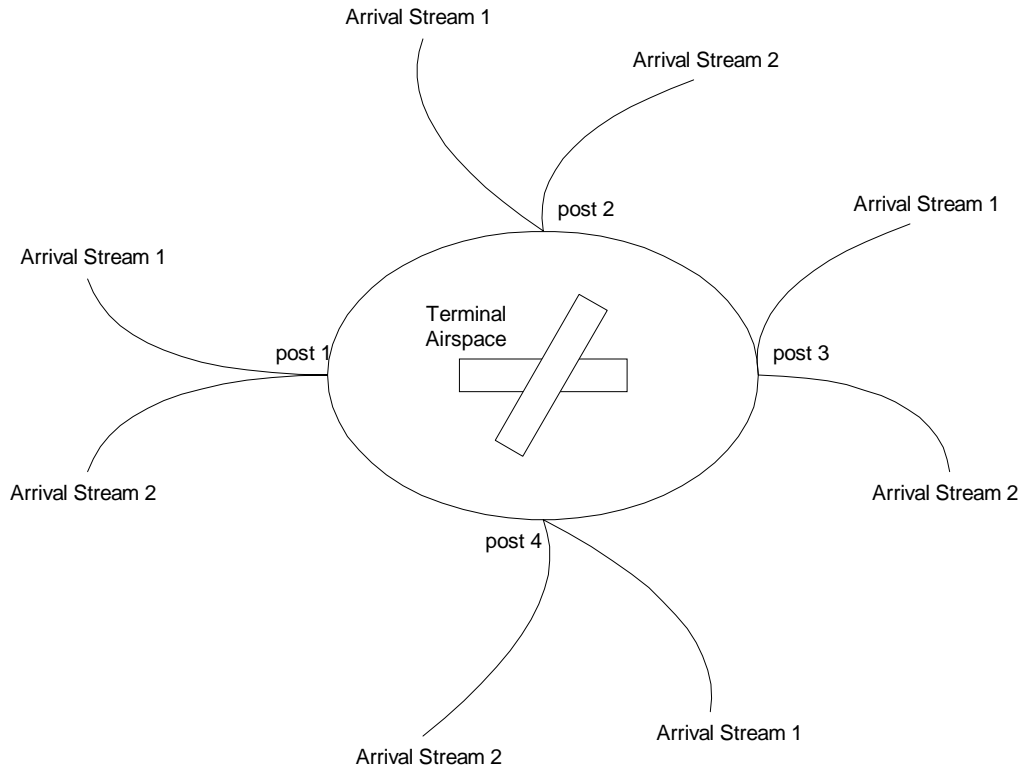


Figure 5.7 Four corner post system of a hub airport

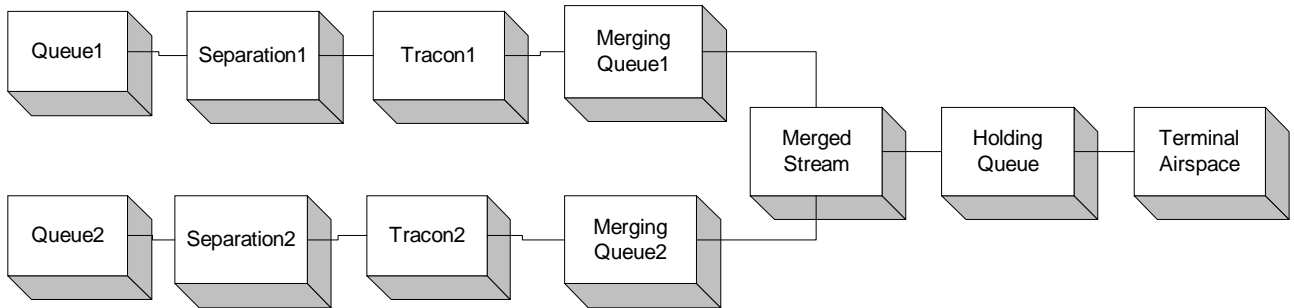


Figure 5.8 Basic Structure of single feeder post of Terminal Airspace

Figure 5.8 shows the basic structure of a typical corner post. Each post has two arrival streams which merge into a single stream which is then injected into the terminal airspace. It begins with a Queue outside the Separation variable. The Separation variable enforces the Intrail Separation depending on the aircraft mix and is represented by a Conveyor Stock. The Queue before the Separation is represented by a Reservoir Stock and it holds aircraft if the Separation variable is occupied so as to enforce the intrail separation. The Tracon variable represents the TRACON airspace and is typically represents 40 nautical miles of airspace before the terminal airspace. It is depicted by a Conveyor Stock. The two arrival streams merge into single stream represented by the Merged Stream variable. The Merged Stream variable is depicted by a Conveyor Stock and it enforces the intrail separation between merging aircraft. The Queues before the Merged Stream hold aircraft so as to enforce the intrail separation. After merging, the aircraft move into the Terminal Airspace. The Terminal Airspace variable is represented by a Conveyor Stock. There is a Holding Queue outside the post to hold aircraft if the capacity of the Terminal Airspace is saturated.

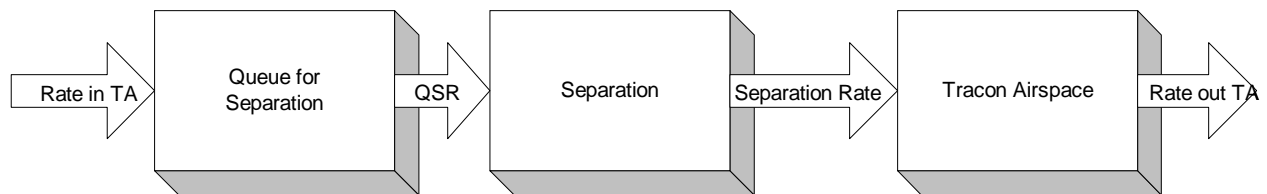


Figure 5.9 Basic structure of single arrival stream at single post

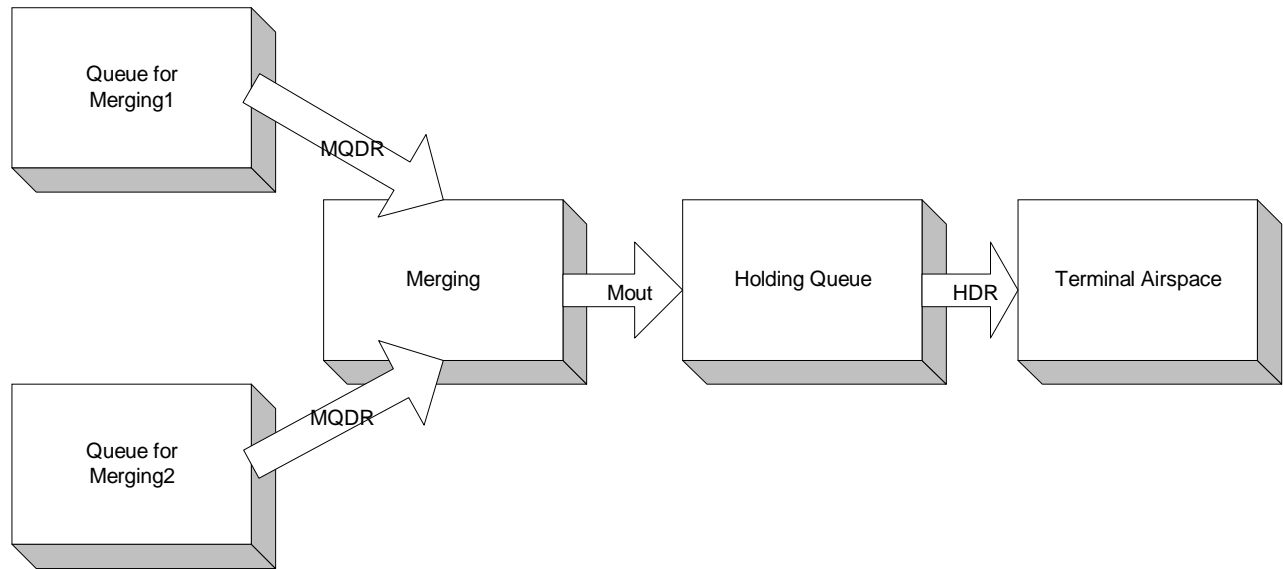


Figure 5.10 Basic structure of single feeder post

Rate in Tracon Airspace (Rin_t)

It is the number of aircraft per time step (6 seconds) that enter's the Queue outside the Tracon Airspace, if such a queue exists. If there is no such queue it is the number of aircraft per minute that enter's the Tracon Airspace. A proportion of all aircraft which exit the enroute sector enter the tracon airspace. To determine at every time step, whether an aircraft should be injected into Tracon Airspace, a check is first made whether any aircraft is generated at that time step. In case an aircraft is generated in the aircraft demand generator module, then to determine whether this aircraft will enter the Tracon Airspace, a random experiment is performed in which a random variable is drawn from a uniform distribution between 0 and 1. If the random variable drawn is less than the proportion of enroute aircraft that should be injected into the arrival stream, then the aircraft is injected into the arrival stream for that feeder post. Different random seeds are used for each arrival stream so as to not to generate aircraft on each arrival stream at the same time. The logic is explained in the figure 5.11.

$$Rin_t = IF(Rout_e = 1)AND(RANDOM(0, 1, seed) \leq P_{ta})THEN(1)ELSE(0) \tag{5.9}$$

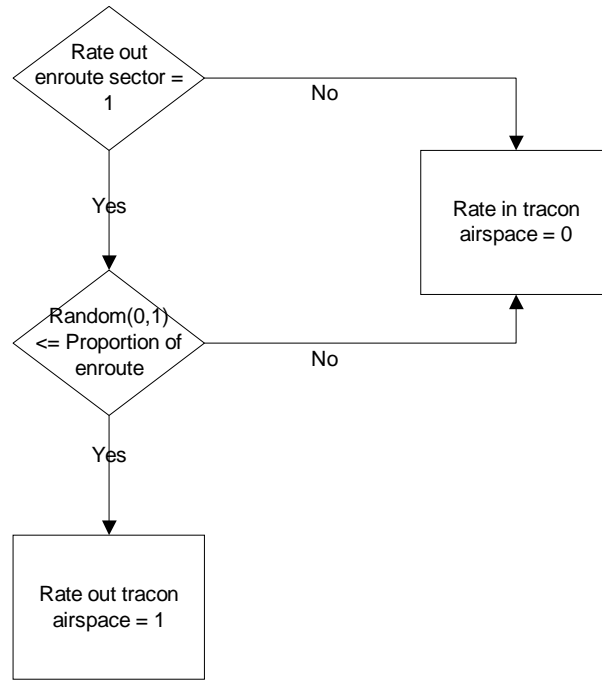


Figure 5.11 Flow chart explaining logic of injection of aircraft in tracon airspace

Proportion of enroute flights into tracon airspace (P_{ta})

It is the proportion of aircraft, generated by the demand module, that enter's each arrival stream of each feeder post in the Tracon Airspace. The table shows the proportion value's for each arrival stream of each post for each classification of airport.

	Feeder Post							
	1		2		3		4	
	Arrival Stream	Arrival Stream	Arrival Stream	Arrival Stream	Arrival Stream	Arrival Stream	Arrival Stream	
	1	2	1	2	1	2	1	2
Hub	0.8	0.7	0.8	0.7	0.6	0.5	0.6	0.5
Medium	0.7	0.6	0.4	0.3	0	0	0	0
Small	0.7	0.5	0	0	0	0	0	0

TABLE 5.3 Proportion of aircraft entering Tracon Airspace

Queue for separation (Q_s)

It is the number of aircraft waiting in queue to enter the tracon airspace either due to mental resources capacity constraints of the feeder controller or due to enforcement of intrail separation. Aircraft enter the arrival stream of the tracon airspace from different enroute sector's at different entry times. In order to maintain the minimum intrail separation between two aircraft when an aircraft enter's the arrival stream it is held in queue until the required intrail separation has been achieved.

$$Q_s(t) = Q_s(t - dt) + \int Rin_t(t) - QSR(t)dt \quad (5.10)$$

The initial value of the Queue is zero and the queue is of infinite capacity. The variable is modeled as a Reservoir Stock.

Queue Separation Rate (QSR)

It is no of aircraft exiting from the queue outside tracon airspace per time step. It is a rate variable which exits from the queue for separation stock and feeds into the separation stock. It is modeled to consider the mental resources capacity constraints of the feeder controller and to enforce the intrail separation.

At every time step the controller workload is determined represented by the variable controller activity level, which is described later in this chapter, and aircraft are only injected into the if two conditions are satisfied i.e the controller workload is within acceptable levels and intrail separation is maintained. Controller workload criteria is checked by determining whether the controller activity (CAL) is greater than one or not and intrail separation is maintained by checking if the Separation variable is equal to 1. If the Separation variable is equal to 1 it means that there is a preceding aircraft at a distance further down the arrival stream but the distance between the two aircraft is less than the minimum intrail separation and hence the aircraft is held in queue.

$$\begin{aligned}
 &IF(CAL_t(t) \geq 1)OR(S(t) = 1)THEN(0) \\
 &ELSE(IF(Rin_t((t) > 0)OR(Q_s((t) > 0)))THEN(1))ELSE(0)
 \end{aligned} \quad (5.11)$$

The flow chart below describes the logic of the Queue Separation Rate (QSR).

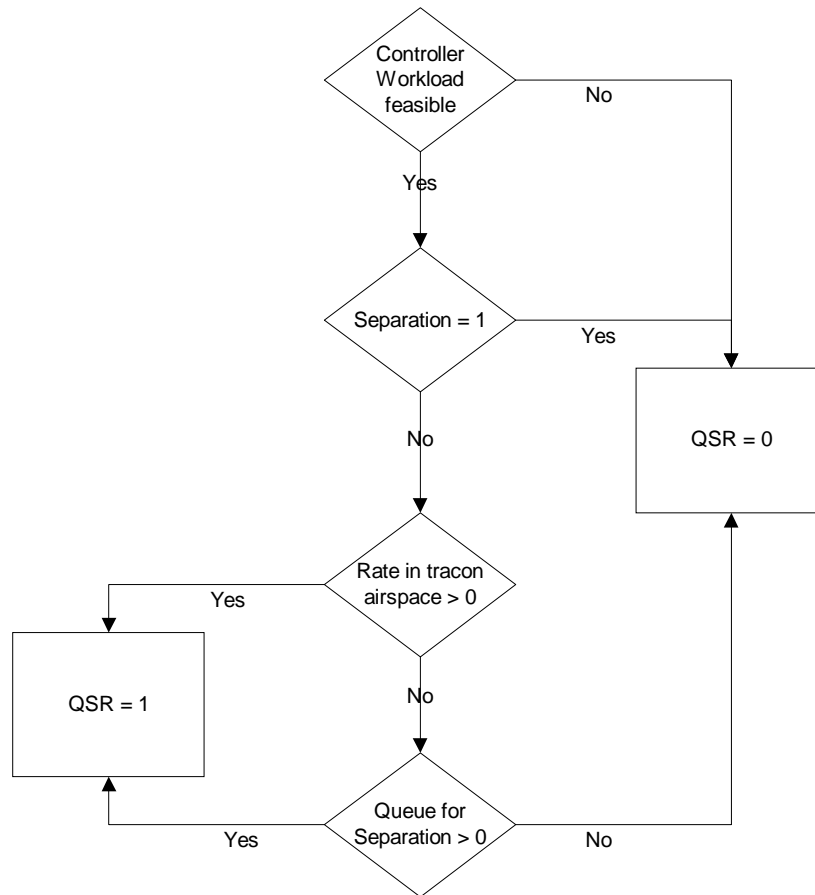


Figure 5.12 Flow chart describing the logic of QSR

Separation (S)

The Separation variable is modeled so as to enforce the intrail separation depending upon the aircraft mix. It is modeled as a Conveyor Stock with a transit time which corresponds to the required intrail separation. When an aircraft enters the Separation Stock, no other aircraft is allowed to enter it until the preceding aircraft has exited it. The capacity of the Conveyor Stock is one to enforce the intrail Separation with an inflow limit of one.

$$S(t) = S(t-dt) + \int(QSR(t) - SR(t))dt \tag{5.12}$$

Separation Rate (SR)

It is the number of aircraft exiting per time step from the Separation Stock and entering the tracon airspace. It is equal to the reciprocal of the Separation Time (ST).

$$SR(t) = 1/(ST(t)) \quad (5.13)$$

Separation Time (ST)

It is the transit time of aircraft in the Separation Stock. It corresponds to the time lag that is required to be present between two aircraft so as to maintain the intrail separation (ITS). The aircraft are classified into three categories depending on their gross weight and hence wake vortex. The categories are large, medium and small. The table 5.4 shows the descent speed (Sp) and proportion (Pr) of each category of aircraft. Descent speed in the table is the average True Airspeed (TAS) over the descent stage up to the point the aircraft reaches the outer metering fix. The descent speed data was obtained from the descent performance profile's of a typical aircraft for each category in the BADA model. For large aircraft, the data for a Boeing 747 was collected and for a medium aircraft a SAAB 20 data was collected and for a small aircraft a Cessna 560 data was collected.

The data for proportion of each category of aircraft is obtained from Air Traffic Activity Data System (ATADS). Atlanta Hartsfield International (ATL), Atlantic City International (ACY) and Roanoke Regional Airport is used as a representative of a hub airport, medium size and small size airport respectively. Data for all three airports is collected is from January 2000 to January 2002. The mean value of the data is used in the model.

	Large	Medium	Small
Descent Speed (knots)	396	339	272
Proportion- hub airports	0.7551	0.2264	0.0185
Proportion- medium airports	0.2368	0.23467	0.5285
Proportion- small airports	0.0922	0.5018	0.406

TABLE 5.4 Descent Speed [BADA] and Proportion for each category of aircraft [ATADS]

The proportion of each category of aircraft depends on the class of airport whether it is a hub, medium size or small size airport. Hub airports have a higher proportion of large airplanes and small airports have a very small proportion of large airplanes.

Separation Time (ST) is the average minimum intrail separation (AITS) in tracon airspace plus the excess separation due to inefficient sequencing of aircraft divided by the average descent speed.

$$ST(t) = \frac{(AITS + ES_i(t)) \times 60 \times 10}{\sum_{i=1}^3 Sp_i \times Pr_i} \quad (5.14)$$

Average minimum Intrail Separation (AITS)

It is the average minimum horizontal distance that should be maintained between two aircraft due to wake vortex consideration. The average intrail separation depends on the aircraft mix. The minimum intrail separation (ITS) in nautical miles between different aircraft categories is given in the table below.

	Leading		
	Small	Medium	Large
Small	3	4	5
Medium	3	3	4
Large	3	3	3

TABLE 5.5 Intrail Separation in nautical miles

$$AITS = \sum_{j=1}^3 \sum_{i=1}^3 (Pr_i \times Pr_j \times ITS_{ij}) \tag{5.15}$$

Wake vortices are formed any time an airfoil is producing lift. Lift is generated by the creation of a pressure differential over the wing surfaces. The lowest pressure occurs over the upper surface and the highest pressure under the wing. This pressure differential triggers the rollup of the airflow of the wing resulting in swirling air masses trailing downstream of the wingtips. Viewed from behind the generating aircraft, the left vortex rotates clockwise and the right vortex rotates counterclockwise. The intensity or strength of the vortex is primarily a function of aircraft weight and configuration (flap setting etc.). The strongest vortices are produced by heavy aircraft, flying slowly, in a clean configuration.

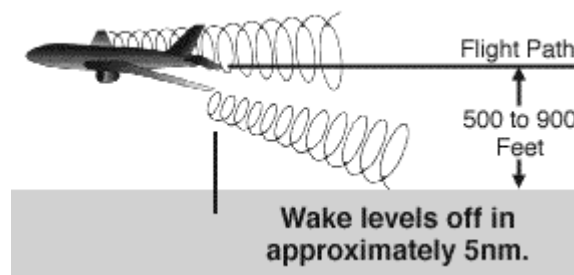


Figure 5.13 Wake vortex

Excess Separation (ES)

It is the additional horizontal separation that is maintained between two aircraft. This additional separation is due to two reasons, firstly usually a controller adds a buffer to the intrail separation so as to

not to violate the minimum separation criteria and secondly due to non optimal sequencing of aircraft. Excess Separation depends mainly on the aircraft mix and secondly on the traffic density since the aircraft mix is different for each category of airport, the excess separation is different.

Excess in-trail separation on final approach is a measure of the efficiency of runway utilization and aircraft sequencing. Excess in-trail separation in the tracon airspace is a measure of the optimality of sequencing of aircraft into a single merged stream from a number of arrival streams. While controllers currently perform the task of in-trail separation well, they provide a buffer of excess separation to account for uncertainties in weather, pilot response, and other factors. Their performance in separating aircraft is a function of the volume of traffic, their own skill, and the complexity of other decisions, such as sequencing and runway assignments, that they must perform at the same time.

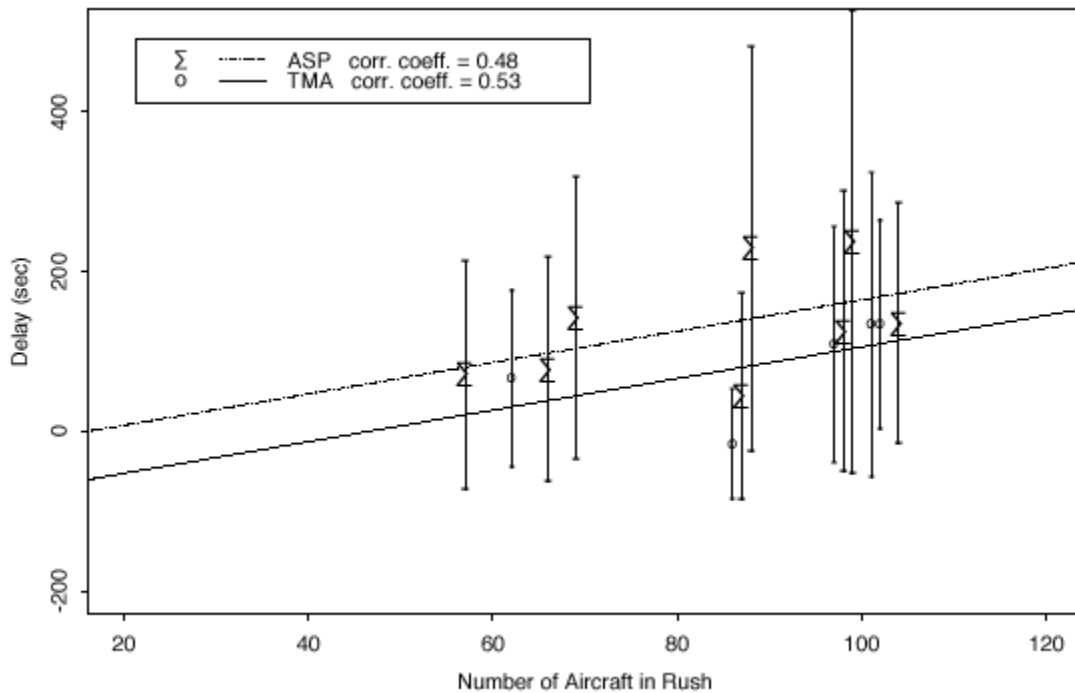


Figure 5.14 TMA and ASP statistical delay comparison at metering fix [Swenson, 1997]

In alternative C and D, which is a TMA scenario, the average delay reduction per aircraft to the metering fix was found to be 70 seconds at an operational evaluation of TMA conducted at DFW [Swenson, 1997]. The corresponding arrival rate was 108 aircraft per hour. This was primarily due to more optimal sequencing of aircraft and more accurate estimation of arrival times of aircraft leading to a reduction in the in-trail separation. The delay reduction depends upon the traffic density of aircraft approaching the metering fix. The Excess Separation reduction is product of the delay reduction depending upon the traffic density and average descent speed (S_p).

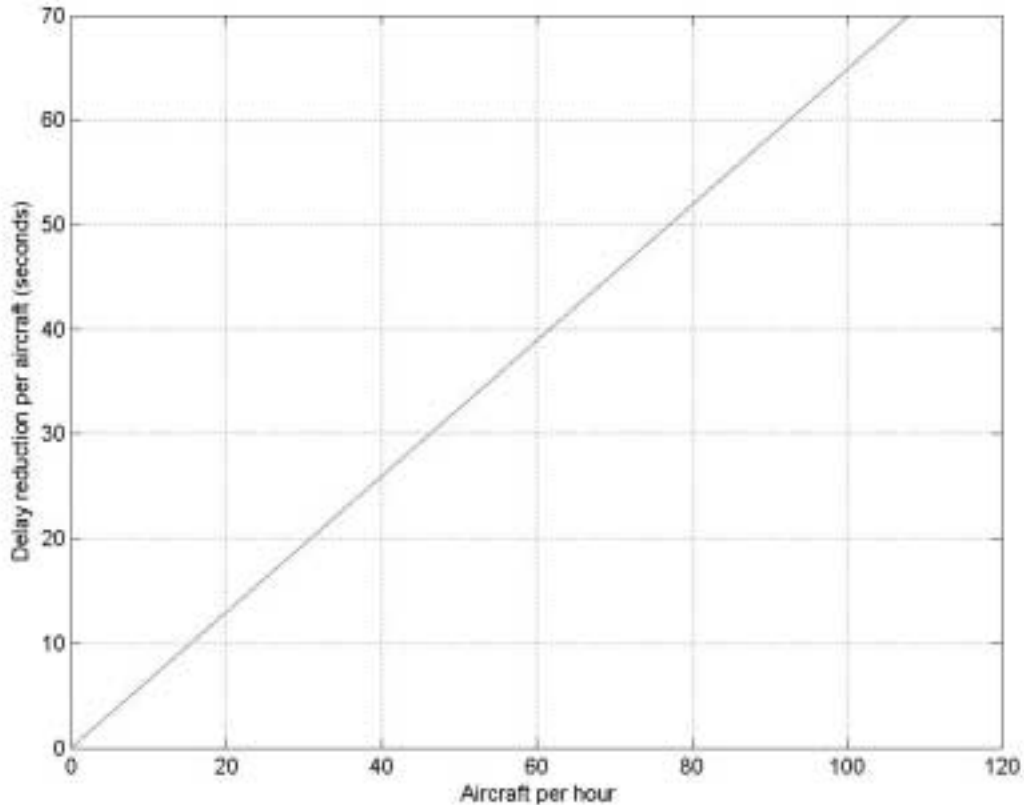


Figure 5.15 Delay reduction per aircraft in TMA scenario

Delay reduction depends upon the aircraft rate as shown by figure 5.15. A linear relationship is assumed between delay reduction and aircraft rate.

$$DR = 0.65 \times AR_t \tag{5.16}$$

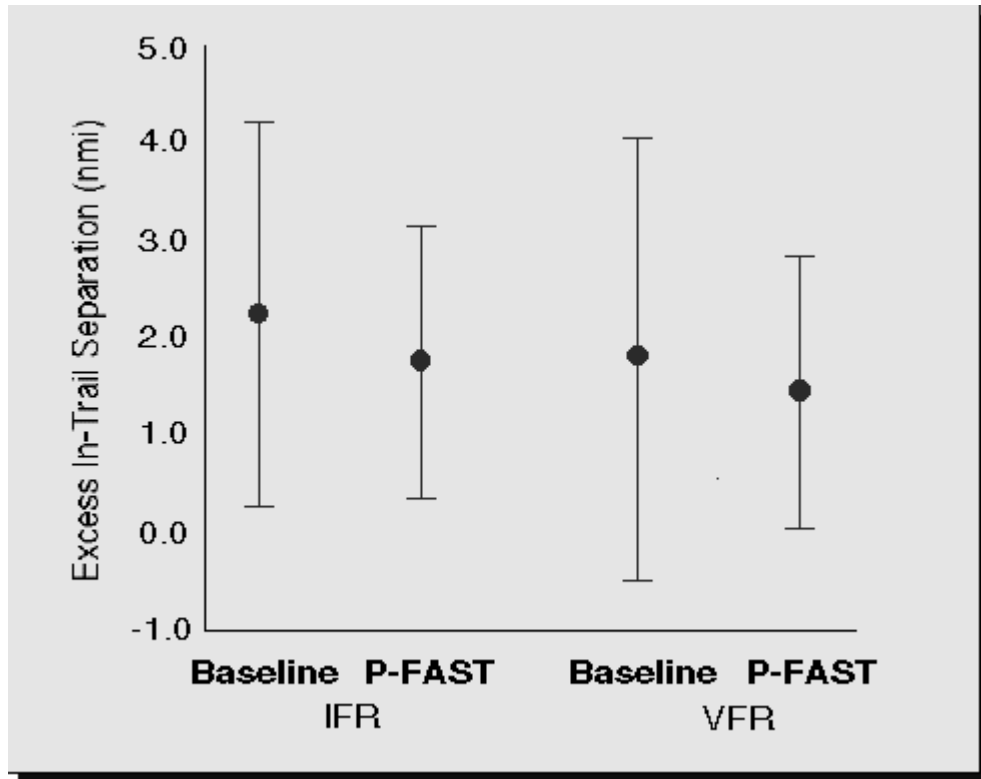


Figure 5.16 Excess in-trail separation [ctas.arc.nasa.gov]

Figure 5.16 shows the excess in-trail separation for baseline scenario and for pfast scenario. For baseline scenario, which is same as alternative A and B, it ranges from 0.2 to 4.2 nautical miles with a mean of 2.2 nautical miles. The excess in-trail separation depends upon the traffic density and aircraft mix. The excess in-trail separation in tracon airspace is assumed to vary quadratically with aircraft rate in tracon airspace (AR_t) and following equation is used compute the excess intrail separation for a given aircraft rate:

$$ES_t = \begin{cases} 0.000154 \times AR_t^2 \times AMF + 0.4 & \text{Non-TMA} \\ 0.000154 \times AR_t^2 \times AMF + 0.4 - (DR \times Sp / 60 \times 60) & \text{TMA} \end{cases} \quad (5.17)$$

where AR_t is the aircraft rate per hour in tracon airspace,

AMF is the aircraft mix factor,

DR is the delay reduction in seconds.

.

For pfast scenario, which is same as alternative C and D, the excess intrail separation ranges from 0.25 to 3.15 nautical miles with a mean of 1.7 nautical miles. The excess in-trail separation depends upon the traffic density and aircraft mix and adherence factor to pfast. The excess in-trail separation in terminal airspace is assumed to be vary quadratically with aircraft rate in terminal airspace (AR_{te}) and following equation is used compute the excess intrail separation for a given aircraft rate:

$$ES_{te} = \begin{cases} 0.000154 \times AR_{te}^2 \times AMF + 0.4 & \text{Non-PFAST} \\ 0.000093 \times AR_{te}^2 \times AMF \times (1 - ADF) / (1 - 0.9) + 0.4 & \text{PFAST} \end{cases} \quad (5.18)$$

where AR_{te} is the aircraft rate per hour in terminal airspace,

AMF is the aircraft mix factor,

ADF is the adherence factor. The equation corresponds to an adherence factor of 0.9.

Adherence factor (ADF)

It is the percentage of pfast runway assignments and aircraft sequences accepted and implemented by the controller. The greater is the adherence factor, the lower is the excess separation.

Figure 5.17 shows the excess in-trail separation for baseline (non-pfast) and pfast scenario with an aircraft mix factor of 1.

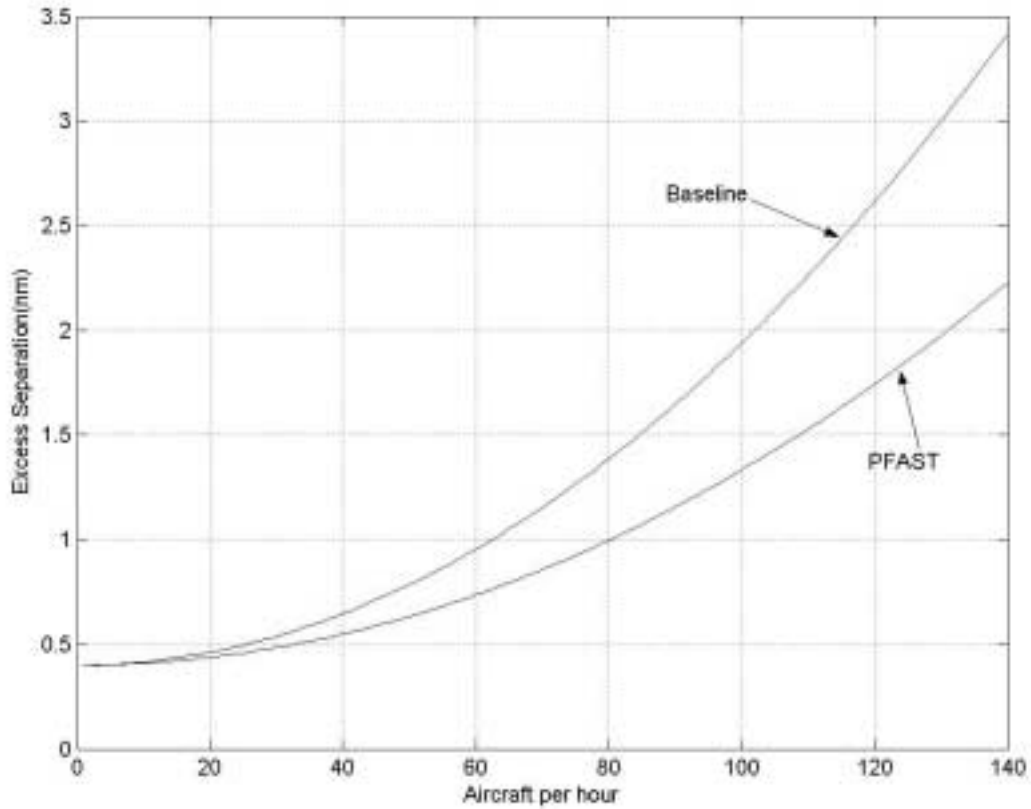


Figure 5.17 Excess in-trail separation as a function of aircraft rate

:

Aircraft Mix Factor (AMF)

Aircraft mix factor accounts for the change in excess separation due to different aircraft mixes. The more homogenous a mix is, the lower is the value of aircraft mix factor and hence a lower excess separation.

Aircraft in tracon airspace ($ACFT_t$)

It is the number of aircraft that are present in a single arrival stream in the tracon airspace at any point of time. Tracon airspace is defined as the airspace beginning from the point a aircraft descends from an enroute sector to join an arrival stream to the feeder post. The tracon airspace usually spans to a distance of about 40-50 nautical miles from the airport. It is considered the second ATC segment after the terminal airspace.

$$ACFT_t(t) = ACFT_t(t - dt) + \int (SR(t) - Rout_t(t))dt \quad (5.19)$$

The variable is modeled as a Conveyor Stock with an inflow limit of 1. The transit time for Conveyor Stock is described later in the chapter.

Rate out tracon airspace ($Rout_t$)

It is the number of aircraft per time step that exits from the tracon airspace and enter's into the terminal airspace. Tracon airspace is defined as the airspace beginning from the point a aircraft descends from an enroute sector to join an arrival stream to the feeder post. It is the reciprocal of the Transit Time in tracon airspace (TT_t).

$$Rout_t(t) = 1/(TT_t(t)) \quad (5.20)$$

Transit Time in tracon airspace is the time taken by an aircraft to traverse the tracon airspace. It is explained later in this chapter.

Queue for Merging (Q_m)

It is number of aircraft waiting from each arrival stream to merge into merged arrival stream leading to the feeder post. A feeder post represents the junction of two arrival streams. When two aircraft from different arrival streams are trying to merge onto a single stream at the time, one of two aircraft depending on the arrival priority will wait in queue until the first aircraft has successfully merged and intrail separation has between two aircraft has been achieved. It is modeled as a Queue Stock.

$$Q_m(t) = Q_m(t-dt) + \int (Rout_t(t) - QMR(t))dt \quad (5.21)$$

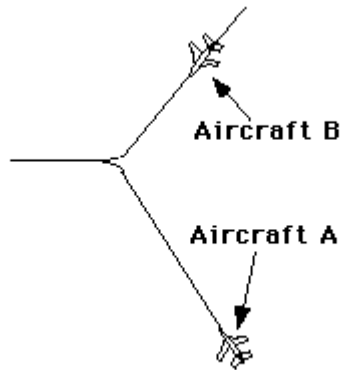


Figure 5.18 Merging from two arrival streams into a feeder post

Merging Queue Dissipation Rate (MQDR)

It is number of aircraft per arrival stream exiting from the Queue for Merging and merging into the merged arrival stream per time step. The logic of the Queue Merging Rate is that if there are aircraft waiting to merge and if the capacity of the Merged Stream (MS) is not exceeded than it is equal to 1 otherwise zero. The capacity of the Merged Stream is 1 to enforce the intrail separation between merging aircraft.

$$MQDR(t) = \begin{matrix} IF(Q_m(t) > 0)AND(MS(t) < 1) \\ THEN(1) \quad ELSE(0) \end{matrix} \quad (5.22)$$

The flow chart in figure 5.19 explains the logic.

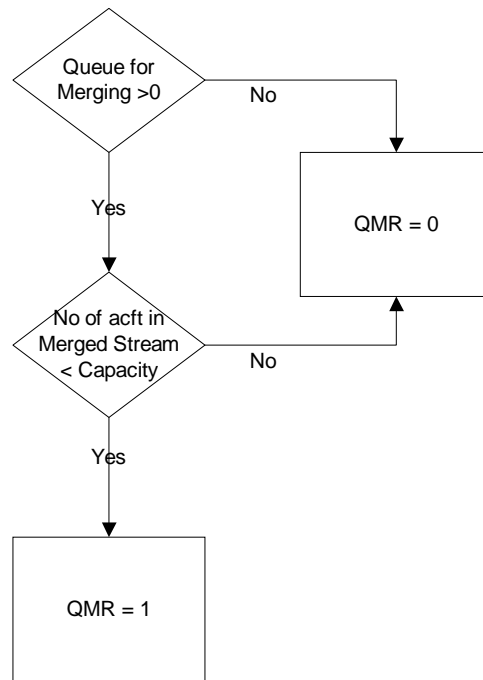


Figure 5.19 Flow chart explaining the logic of Queue Merging Rate

Merged Stream (MS)

Aircraft from two arrival streams merge into a single arrival stream just before a feeder post. This single arrival stream is known as merged stream. Arrival stream 1 has higher priority than arrival stream 2 so if there are queues existing on both arrival stream, aircraft from arrival stream 1 is allowed to merge first and only after entire queue from arrival stream 1 has merged into the Merged Stream then only aircraft from arrival stream 2 is allowed to merge. The Merged Stream ends at the feeder post and is modeled with a transit time which corresponds to the required intrail separation. When an aircraft enters the Merged Stream, no other aircraft is allowed to enter it until the preceding aircraft has exited it. It is modeled as a Conveyor Stock with a transit time equal to the Separation Time (ST). The capacity of the Conveyor Stock is one to enforce the intrail Separation with an inflow limit of one.

$$MS(t) = MS(t - dt) + \int (MQDR(t) - Mout(t))dt \quad (5.23)$$

Merging out Rate (Mout)

It is the number of aircraft exiting per time step from the Merged Stream. It is equal to the reciprocal of the Merging Time (MT).

$$Mout(t) = 1/(MT(t)) \quad (5.24)$$

Merging Time (MT)

It is time taken by an aircraft to merge from its arrival stream into the merged stream leading to the metering fix. It takes into account the intrail separation needed between merging aircraft and the excess separation in tracon airspace that takes place due to inefficient sequencing of aircraft.

$$T_v(t) = \frac{AITS}{3 \sum_{i=1} (Pr_i \times Sp_i)} \quad \text{Voice - Scenario} \quad (5.25)$$

$$T_d(t) = ST_v(t) + RT_d - RT_v + lag_{(d,te)} - lag_{(v,te)} + TRU - THU \quad \text{Datalink - Scenario} \quad (5.26)$$

where RT_d and RT_v are the routine time per communication message via voice and datalink channel,

$lag_{(d,te)}$ and $lag_{(v,te)}$ are the lag times via voice and datalink channel in terminal airspace,

TRU and THU are the pilot reaction times to a datalink and voice communication respectively.

Holding Queue (Q_h)

It is number of aircraft waiting in queue at the feeder post to land at the airport due to the capacity constraints of the terminal airspace. It is modeled as a Queue Stock

$$Q_h(t) = Q_h(t - dt) + \int (Mout(t) - HDR(t))dt \quad (5.27)$$

Holding dissipation rate (HDR)

It is number of aircraft exiting per time step from the queue at the feeder post. If a queue exists at the feeder post and if the capacity of the terminal airspace is not exceeded then HDR is equal to 1 for every time step until the queue is dissipated otherwise if the capacity of the terminal airspace is reached or exceeded then it is equal to zero.

$$HDR(t) = IF(Q_h(t) > 0)AND(ACFT_{te}(t) < C_t)THEN(1)ELSE(0) \quad (5.28)$$

Aircraft in terminal airspace (ACFT_{te})

It is the number of aircraft that are present in the terminal airspace. The maximum value is the capacity of the terminal airspace (C_t). The airspace around the airport upto a distance of 5 nautical miles or upto a feeder post is defined as terminal airspace.

$$ACFT_{te}(t) = ACFT_{te}(t - dt) + \left(AAR - \sum_{i=1}^j HDR_i(t) \right) \quad (5.29)$$

j is the number of feeder post where terminal capacity is reached.

Since there can be upto four feeder posts, the terminal airspace will prioritize the acceptance of aircraft from each feeder post. Highest priority is given to feeder post 1 followed by post 2, 3 and 4. The terminal airspace accepts a aircraft from each feeder post at every time step provided a queue exists at the feeder post until the capacity of the terminal airspace is reached.

The variable is modeled as a Conveyor Stock with finite capacity equal to C_t . The transit time in the Conveyor is the Airport Acceptance Rate (AAR).

Capacity of terminal airspace (C_t)

It is the maximum number of aircraft that can be present in the terminal airspace at any instantaneous point of time.

	Category of Airport		
	Hub	Medium	Small
Capacity of Terminal Airspace	8	4	2

TABLE 5.6 Capacity of terminal airspace

It depends on the category of airport since a hub airport has higher capacity due to larger infrastructure like number of runways.

Rate out terminal airspace ($Rout_{te}$)

It is the number of aircraft exiting per time step from the terminal airspace. It is equal to the reciprocal of the Transit Time in terminal airspace (TT_{te}).

$$Rout_{te}(t) = 1/(TT_{te}(t)) \tag{5.30}$$

Transit time in terminal airspace (TT_{te})

It corresponds to the time taken by an aircraft to traverse from the outer metering fix to the runway exit point.

$$TT_{te} = \frac{(AITS + ES_{te})}{3 \sum_{i=1} (Sp_i \times Pr_i)} \tag{5.31}$$

5.2.5 Routine Communication Parameters

All non-conflict transactions between a controller and a pilot are termed as routine communications. All communications which are not meant to resolve conflicts like waypoint clearances, handoffs etc. are termed as non conflict transactions.

No of routine communications per aircraft in enroute sector (NRC_e)

It is the average number of routine communications transacted between a controller and a pilot when

an aircraft traverses through the entire enroute sector. All non-conflict communications are termed as routine. For Alternative A and B, which are non-uret scenario's, the number of uplink messages varies between 5 and 7. A uniform distribution with a minimum of 5 and a maximum of 7 is used in the model. Since one of the applications of uret is to relax routing restrictions, hence for Alternative's C and D, which are uret scenarios, number of routine communications (NRC_e) is equal to the number of routine communication in Alternative's A and B minus no of routing restrictions relaxed since relaxation of each restriction would eliminate the need for the communication to divert the aircraft.

No of routine communications per aircraft per sector in tracon airspace (NRC_e)

It is the average number of routine communications transacted between a controller and a pilot when the aircraft traverses through a single sector in the tracon airspace. All non-conflict communications are termed as routine. The number of uplink messages varies between 3 and 7. A uniform distribution with a minimum of 3 and a maximum of 7 is used in the model.

	En route	Terminal
Uplink Messages	5-7 per sector	3-7 per sector
Downlink Messages	4-6 per sector	3-6 per sector

TABLE 5.7 Number of routine communications [Cote, 1999]

Average time per routine communication via voice (RT_v)

It is the average time that a controller spends in issuing an advisory for a routine task via the voice communication channel. All non-conflict communications like handoffs and waypoint clearances are termed as routine communication. It typically composes of two components, speaking time and pause interval time. Speaking time is time spent by the controller in speaking out the message. At an average a person can speak 2 words a second and so for an 12 word routine communication, the time spent for conveying the message is 6 seconds. Pause interval time is time spent in pausing between words which is typically about 0.5 seconds. Assuming a frequency of 4 such intervals in a message, the time spent

in pausing per routine communication is 2 seconds giving an average time per routine communication via voice equal to 8 seconds or 1.33 time steps.

Average time per routine communication via datalink (RT_d)

It is the average time that a controller spends in issuing an advisory for a routine task via the datalink communication channel. All non-conflict communications like handoffs and waypoint clearances are termed as routine communication. It typically consists of the time in composing a datalink message from different message elements if such a composition is required. This was taken as 4 seconds [FAA, 1995].

CPDLC Build I Switch (CSI)

CPDLC is to be implemented in three Builds namely Build I, Build IA and Build II. CPDLC Build I Switch is intended to kick in all the message set components for Build I when it is turned on. A Switch is provided for the purpose at the interface level.

CPDLC Build IA Switch (CSIA)

CPDLC Build IA Switch is intended to activate all the additional message set components for Build IA when it is turned on. CPDLC Build I Switch should be turned on before CPDLC Build IA Switch can be activated. A Switch is provided for the purpose at the interface level.

CPDLC Build II Switch (CSII)

CPDLC Build II Switch is intended to activate all the additional message set components for Build II when it is turned on. CPDLC Build I Switch and CPDLC Build IA Switch should be turned on before CPDLC Build II Switch can be activated. A Switch is provided for the purpose at the interface level.

Message set for Build I (MSI)

The entire message set of CPDLC will be implemented in three Builds with a certain number of message sets implemented every Build leading to full implementation in Build II. MSI is no of message sets that are going to implemented for Build I. Message set for Build I is for Domestic U.S. service only, using a small message set of 4.

Additional Message set for Build IA (AMSIA)

It is the additional number of message sets that will be implemented in Build IA as compared to Build I. Message set for Build IA is for Domestic U.S. service only, using a additional five message sets.

Additional Message set for Build II (AMSII)

It is the additional number of message sets that will be implemented in Build II as compared to Build IA. Message set for Build II is for Domestic U.S. service only, using a additional three message sets.

Message set ratio for Build I

It is proportion of message sets implemented in Build I to the total number of message sets in CPDLC.

$$MSRI = (MSI)/(MSI + AMSIA + AMSII) \quad (5.32)$$

Additional Message set ratio for Build IA

It is additional proportion of message sets implemented in Build IA as compared to the total number of message sets in CPDLC.

$$AMSRIA = (AMSIA)/(MSI + AMSIA + AMSII) \quad (5.33)$$

Additional Message set ratio for Build II

It is additional proportion of message sets implemented in Build II as compared to the total number of message sets in CPDLC.

$$AMSRII = (AMSII)/(MSI + AMSIA + AMSII) \quad (5.34)$$

Percentage of messages allocated to datalink (P_d)

It is the percentage of messages that are transacted in each Build via datalink out of the message sets implemented in that Build. From the ‘man in the loop’ simulation conducted at Atlantic City, the average value is equal to 0.58 [FAA, 1996].

Proportion of comm by datalink for Build I (PcdI)

It is the proportion of messages that are transacted in Build I via datalink. It is the product of the message set ratio for Build I and percentage messages allocated to datalink.

$$PcdI = MSRI \times P_d \quad (5.35)$$

Additional Proportion of comm by datalink for Build IA (APcdIA)

It is the additional proportion of messages that are transacted in Build IA via datalink. It is the product of the additional message set ratio for Build IA and percentage messages allocated to datalink.

$$APcdIA = AMSRIA \times P_d \quad (5.36)$$

Additional Proportion of comm by datalink for Build II (APcdII)

It is the additional proportion of messages that are transacted in Build II via datalink. It is the product of the additional message set ratio for Build II and percentage messages allocated to datalink.

$$APcdII = AMSRII \times P_d \quad (5.37)$$

Data link proportion of messages (DP)

It is total proportion of messages that are transacted using the datalink channel across all Builds. It is the summation of the product of the Build proportions with the respective Build Switches. The Build proportions are multiplied with the respective switches so as to activate or deactivate the respective proportions according to the Builds.

$$DP = (CSI \times PcdI) + (CSIA \times APcdIA) + (CSII \times APcdII) \quad (5.38)$$

Percentage extra comm per comm (PEC)

It is the percentage of routine communications which will be additionally transacted between controller's and pilot's due to errors in speaking, listening thereby requiring the communication to be repeated.

It is assumed to be 10 percent or 0.1.

Extra voice communications in enroute sector (EVC_e)

It is defined as the additional voice communications per aircraft which are transacted between controller's and pilot's in the enroute sector due to errors in speaking, listening thereby requiring the communication to be repeated. It is basically the no of routine communications per aircraft in enroute sector multiplied by the percentage of extra communications per communication. In datalink scenarios, it is further multiplied by the proportion of voice communications which is same as multiplying it by (1 - Proportion of datalink communications).

$$EVC_e = \begin{cases} NRC_e \times PEC & \text{Alternative A} \\ NRC_e \times PEC \times (1 - DP) & \text{Alternative B} \\ (NRC_e - NRRR) \times PEC \times (1 - DP) & \text{Alternative (C, D)} \end{cases} \quad (5.39)$$

Extra voice communications in tracon airspace (EVC_t)

It is additional voice communications per aircraft which are transacted between controller's and pilot's in the enroute sector due to errors in speaking, listening thereby requiring the communication to be repeated. It is basically the no of routine communications in tracon airspace per aircraft multiplied by the percentage of extra communications per communication. In datalink scenarios, it is further multiplied by the proportion of voice communications which is same as multiplying it by (1 - Proportion of datalink communications).

$$EVC_t = \begin{cases} NRC_t \times NST \times PEC & \text{Alternative A} \\ NRC_t \times NST \times PEC \times (1 - DP) & \text{Alternative (B, C, D)} \end{cases} \quad (5.40)$$

5.2.6 Conflict Communication Parameters

All communication transactions between a controller and pilot which are meant to resolve conflicts are termed as conflict communication. A conflict communication can be a speed, altitude or vectoring ad-

visory.

Conflict Time (CT)

Conflict time is the average time that a controller spends in perceiving and detecting the conflict, finding a resolution to the conflict and then executing the resolution via the communication channel. Hence there are three components of conflict time namely Conflict Perception Time (CPT), Resolution Finding Time (RFT) and Resolution Execution Time (RET).

$$CT = CPT + RFT + RET \quad (5.41)$$

Conflict Perception Time (CPT)

Conflict Perception Time is the time taken by a controller to perceive and detect a conflict. In a non uret scenario like for Alternative's A and B, it is basically the time taken by a controller to perform manual calculations so as to determine whether a conflict will take place between two aircraft. Alternative C and D are uret enabled and since uret is a conflict probe tool and displays conflicts upto 20 minutes into the future hence there is no need for a controller to perform manual calculations. In a uret scenario like for Alternative's C and D, it is basically time taken by a controller to detect the conflict on the display screen.

$$CPT_n = 0.4 \quad Non - Uret \quad (5.42)$$

$$CPT_u = 0.1 \quad Uret \quad (5.43)$$

Resolution Finding Time (RFT)

Resolution Finding Time is the time taken by a controller to determine the advisory that is required to resolve the conflict. In a non uret scenario, a controller has to make a mental judgement of which speed

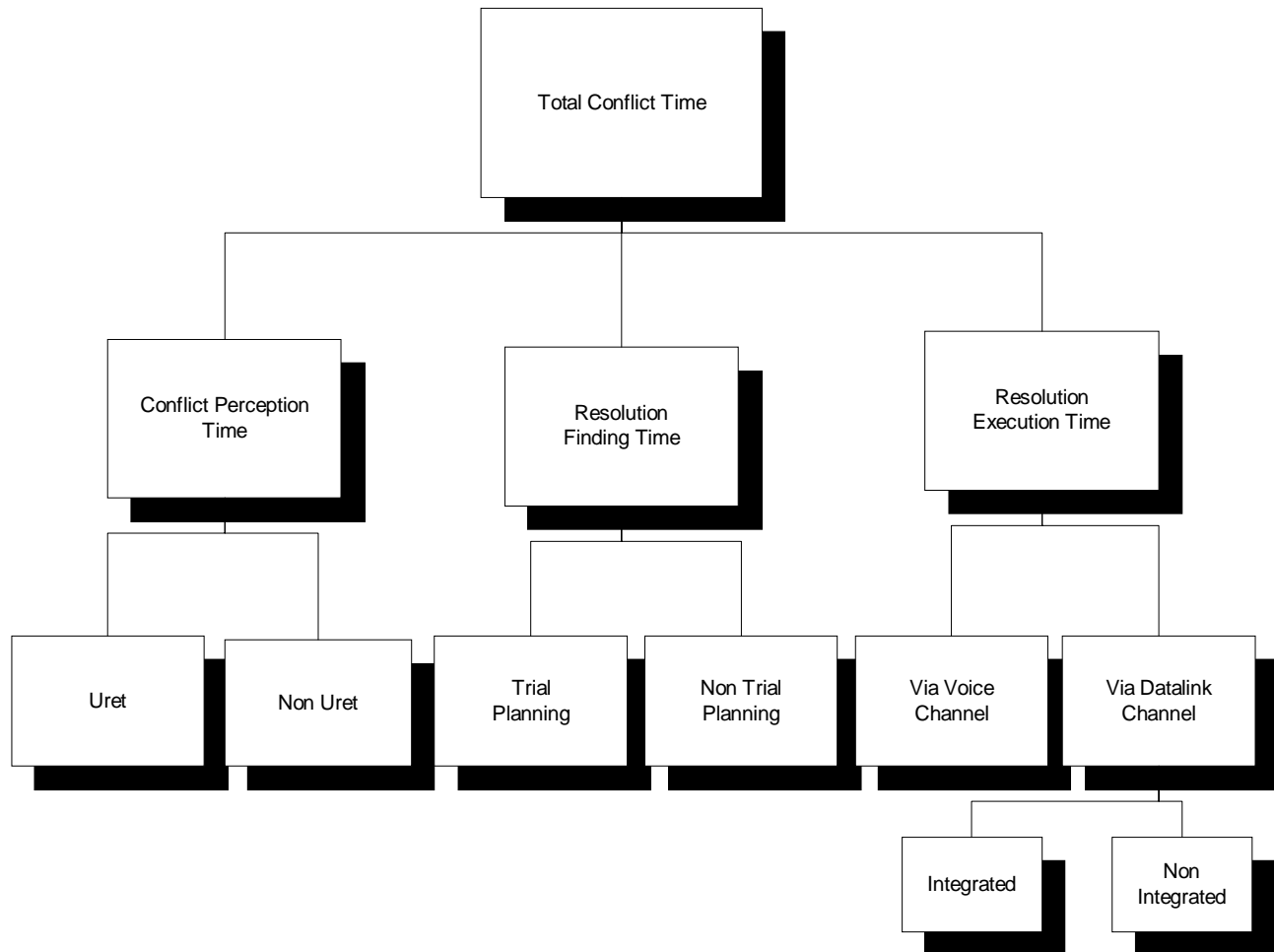


Figure 5.20 Conflict Time Breakdown

or altitude or vectoring advisory would resolve the conflict and resolution finding time is time taken to make that mental judgement and from data it is equal to 0.4 minutes. In a uret scenario, the controller has the option of using the trial planning tool to determine the advisory that will effectively resolve the conflict. In a trial planning scenario, a number of trial plans (NT) are generated by the controller before one is selected to be executed. Hence the RFT would be the product of no of trial plans (NT) and the

time taken to generate a single trial plan (TTP).

$$RFT = \frac{0.4 \quad NonTrialPlanning}{NT \times TTP \quad TrialPlanning} \quad (5.44)$$

Time taken per Trial Plan (TTP)

Trial planning allows the controller to check a desired flight plan amendment for potential conflicts before a clearance is issued. The controller can then construct the amendment from that trial plan with the click of a button. The time taken by a controller to generate a flight plan is 0.2 minutes.

No of Trial Plans per conflict (NT)

A controller generates a number of trial plans so as to determine the desired flight plan amendment which would not produce any additional conflicts. It is the number of trial plans generated per conflict. It is equal to the number of trial plans generated per aircraft (NTA) divided by the adjusted number of conflicts per aircraft (ACAS).

$$NT(t) = \frac{NTA}{ACAS(t)} \quad (5.45)$$

No of Trial Plans generated per aircraft (NTA)

It is the number of trial plans generated per aircraft. It is equal to 0.2104 [Burski, 2000].

$$NTA = 0.2104 \quad (5.46)$$

Resolution Execution Time (RET)

Resolution Execution Time is the time taken by a controller to convey the change in flight amendment to the pilot so as to resolve the conflict. The flight amendment can be conveyed either via the voice channel or datalink channel. The Resolution Execution Time via the voice channel typically composes of two components, speaking time and pause interval time. Speaking time is time spent by the control-

ler in speaking out the message. At an average a person can speak 2 words a second and so for an 12 word routine communication, the time spent for conveying the message is 6 seconds. Pause interval time is time spent in pausing between words which is typically about 0.5 seconds. Assuming a frequency of 4 such intervals in a message, the time spent in pausing per routine communication is 2 seconds giving a an average time per routine communication via voice equal to 8 seconds or 1.33 time steps which is same as average time per routine communication via voice channel (RT_v).

Resolution Execution Time via the datalink channel depends on whether datalink is integrated with uret. In an non integrated scenario, it is time taken to retype or compose it from message elements the flight amendment and upload it to the designated aircraft. From data, this time is 4 seconds which is same as average time per routine communication via datalink channel (RT_d). In an integrated scenario, it is the time taken to upload the flight amendment to designated aircraft by the press of a key. From data, this time is 1 second.

The resolution execution times via datalink does not consist of end to end transfer delay for uploading a datalink message since it doesn't utilize the time resources of the controller. End-to-end transfer delay is defined as the period elapsed from the time at which the originating user or controller initiates the triggering event until the time the transmitted information is available for display to the intended recipient or pilot. The resolution execution time via voice includes pause interval due to hesitation between words.

Hence Conflict Time depends on firstly for the conflict perception stage whether the alternative is uret enabled or not, secondly for the resolution finding stage whether the alternative is uret enabled or not and if it is uret enabled whether trial planning is used or not and thirdly for resolution execution stage which communication channel is used, datalink or voice. Hence a number of scenarios can be derived as shown in table 5.8.

Conflict Perception Time (seconds)	Resolution Finding Time (seconds)	Resolution Execution Time (seconds)	Conflict Time (seconds)
24 (Non urret)	24 (Non Trial Planning)	8 (Voice)	56
24 (Non urret)	24 (Non Trial Planning)	4 (Datalink)	52
6 (Uret)	24 (Non Trial Planning)	8 (Voice)	38
6 (Uret)	24 (Non Trial Planning)	4 (Datalink)	34
6 (Uret)	20 (Trial Planning)	8 (Voice)	34
6 (Uret)	20 (Trial Planning)	4 (Datalink)	30
6 (Uret)	20 (Trial Planning)	1 (Datalink Integrated)	27

TABLE 5.8 Sample Conflict Times

5.2.7 Conflicts in enroute sector

A conflict is defined as a circumstance where two or more aircraft, if allowed to proceed along their designated paths, are in the danger of violating each other’s minimum separation criteria at some point of time in the near future. The time that an aircraft spends in an enroute sector depends upon the number of conflict situations it would be in during entire time it traverses the sector.

Based on earlier research done by a former Virginia Tech student, data was obtained for different minimum separation (MS) which showed the relationship between no of conflicts per day per ARTCC and aircraft rate per day on an ARTCC level. The data was obtained by running simulations in Total Airspace and Airport Model (TAAM) software with different traffic densities.

Since the scope of this research is to simulate a single enroute sector and to obtain the number of conflicts per aircraft per sector, the number of conflicts per day per ARTCC was divided by the aircraft rate per day per ARTCC to obtain the number of conflicts per aircraft which when further divided by the number of sectors (NS) traversed in an ARTCC gave the number of conflicts per day per sector

(CPAS). The aircraft rate per day per ARTCC was divided by the number of sectors in an ARTCC (NSA) to obtain the aircraft rate per day per sector (ARPD). CPAS and ARPD data was fitted to a second order polynomial with zero intercept to obtain quadratic regression equations for each minimum separation (MS). The quadratic equations are:

$$CPAS(t) = \begin{cases} 2 \times 10^{-7} \times ARPD(t)^2 + 2 \times 10^{-4} \times ARPD(t) & MS = 2 \\ 3 \times 10^{-7} \times ARPD(t)^2 + 2 \times 10^{-4} \times ARPD(t) & MS = 3 \\ 4 \times 10^{-7} \times ARPD(t)^2 + 3 \times 10^{-4} \times ARPD(t) & MS = 5 \\ 6 \times 10^{-7} \times ARPD(t)^2 + 5 \times 10^{-4} \times ARPD(t) & MS = 7.5 \\ 9 \times 10^{-7} \times ARPD(t)^2 + 8 \times 10^{-4} \times ARPD(t) & MS = 10 \end{cases} \quad (5.47)$$

All the quadratic equations had a coefficient of correlation greater than 95 percent. The regressed quadratic equations are shown in figure 5.21.

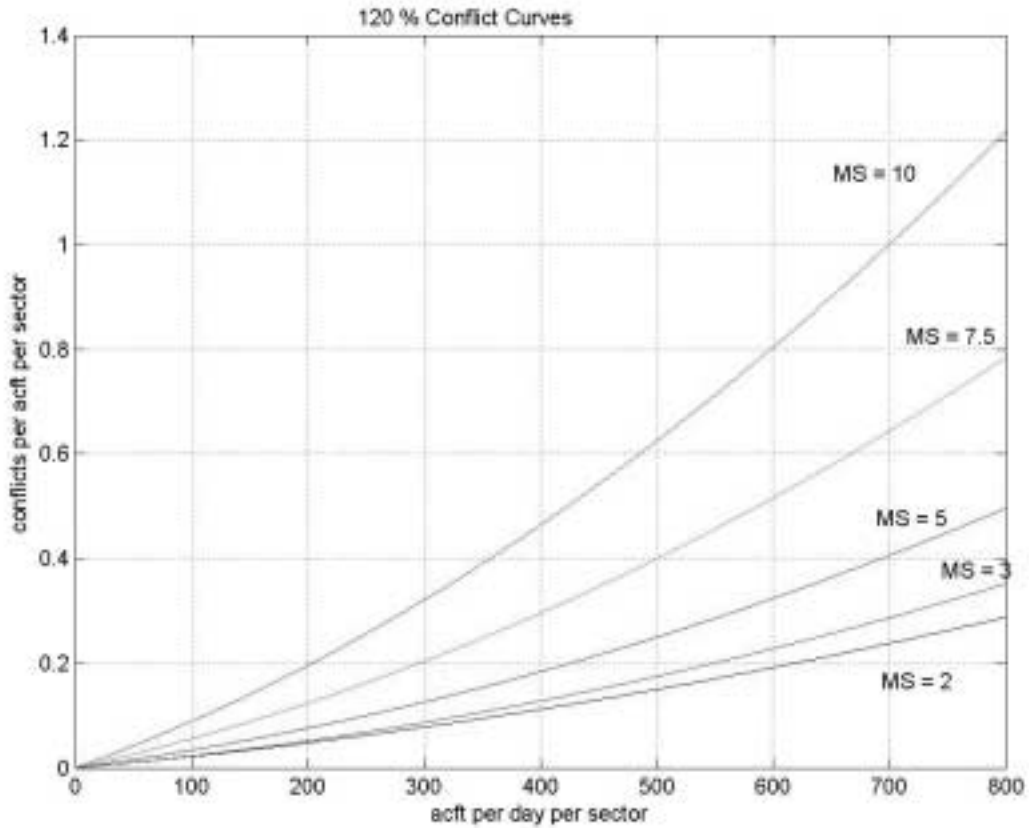


Figure 5.21 Regressed conflict equations

Minimum Separation (MS)

It is the minimum horizontal separation in nautical miles that must be maintained between two aircraft.

Total aircraft in enroute sector (TA_e)

It is the total aircraft that have entered the enroute sector since the simulation started.

$$TA_e(t) = TA_e(t - dt) + \int QDR(t)dt \tag{5.48}$$

No of sectors in an ARTCC (NSA)

It is the average no of enroute sectors that are typically contained in an ARTCC. From data, the average value is 40.

No of sectors traversed (NS)

It is the number of enroute sectors that an aircraft will pass through while crossing an entire ARTCC. From data, the average value is 3.

Aircraft Rate per day per sector (ARPD)

It is number of aircraft that traverse an entire sector per day. The Total aircraft in enroute sector are normalized to a daily time frame by dividing it by the simulation time (TIME) and multiplying it by the total number of time steps (10*24*60) in a day.

$$ARPD(t) = TA_e(t) \times 10 \times 60 \times 24 / (TIME) \quad (5.49)$$

Expected number of conflicts per aircraft per sector (ECAS)

It is number of conflicts per aircraft per sector. It is obtained by interpolating from the CPAS values for a given minimum separation (MS).

$$ECAS(t) = ((CPAS_{x2}(t) - CPAS_{x1}(t)) \times (MIT - x1) / (x2 - x1)) + CPAS_{x1}(t) \quad (5.50)$$

where x1 and x2 are the lower and upper bound respectively of the range of values in which MS is located.

Adjusted number of conflicts per aircraft per sector (ACAS)

For non uret scenario's, like Alternative A and Alternative B, ECAS is the accurate value of conflicts taking place per aircraft since the conflict curves were derived in a non uret airspace but for uret scenario's, like Alternative C and Alternative D, ECAS has to be modified to factor in the effects of implementation of uret on conflicts.

The three main effects due to the implementation of uret are reduction in conflicts due to uret conflict detection (RCD), proportionate increase in conflicts due to relaxation of routing restrictions (ICRRR) and reduction in conflicts due to trial planning (RTP).

$$ACAS(t) = ECAS(t) \times RCD(t) \times (1 + ICRRR) \times RTP \quad (5.51)$$

Reduction in conflicts due uret conflict detection (RCD)

In a non uret scenario, a controller detects conflicts by performing manual calculations and mental judgements. In case of a judgement error a controller would resolve a conflict that actually doesn't exist leading to over-estimation of conflicts. In a uret scenario, no manual calculations are required to be done since uret detects conflicts upto 20 minutes into the near future leading to a correct estimation of conflicts.

Due to uncertainty in the mental judgement of the controller, a controller may perceive conflicts which may not actually exist but maybe close to a conflict. As the traffic density increases, this uncertainty maybe heightened due to lack of situational awareness. Uret conflict detection capability causes an increase in the situational awareness and hence a reduction of conflicts perceived by the controller.

RCD factors for decrease in conflicts due to gain in situational awareness in an uret scenario. It is not an constant and depends on the traffic density. From simulation's run in TAAM, conflict data was obtained corresponding to 100 percent of minimum separation which is the actual number of conflicts and 100-120 percent of minimum separation which is number of conflicts perceived by the controller. Conflicts corresponding to 100 percent of minimum separation were found to be 29 percent less as compared to conflicts corresponding to 100-120 percent of minimum separation. Hence the minimum value that RCD can take is 0.71. RCD is assumed to vary linearly with traffic density or aircraft rate per day (ARPD) as shown in the equation below.

$$RCD(t) = \begin{cases} 1 - (0.0014 \times ARPD(t)) & \text{if}(ARPD(t) \leq 200) \\ 0.71 & \text{if}(ARPD(t) > 200) \end{cases} \quad (5.52)$$

RCD varies inversely with aircraft rate per day per sector because as the traffic density increases, the difference in the perceived conflicts and actual conflicts increases due to lack of situational awareness

and hence RCD accounts for the increase in difference.

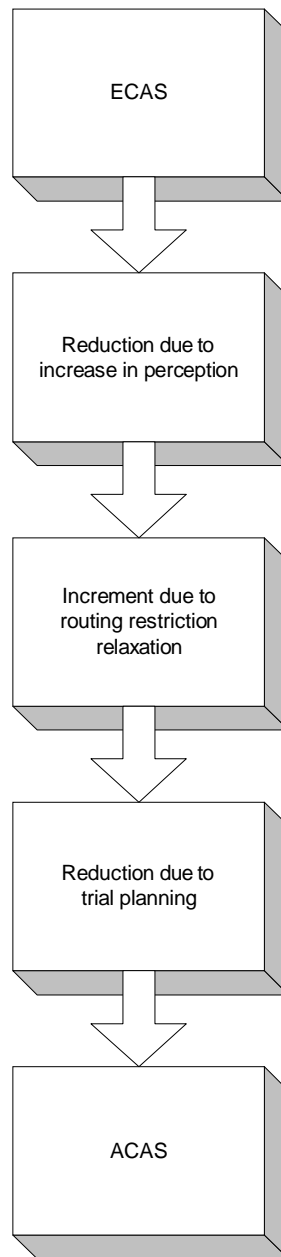


Figure 5.22 3-fold modification of conflicts due to uret implementation

Proportionate increase in conflicts due to relaxation of routing restrictions (ICRRR)

Routing restrictions can be defined as rigid routes that make aircraft fly less optimal and less direct routes so as to separate aircraft from airspace. Relaxation of these restrictions would lead to aircraft flying more direct routes thereby increasing conflicts. ICRRR factors for the increase in conflicts and depends on the percentage of routing restrictions relaxed (PRRR). It is assumed to be equal to the percentage of routing relaxations relaxed.

$$ICRRR = PRRR \quad (5.53)$$

Percentage of routing restriction relaxed (PRRR)

It is the percentage of the total number of routing restrictions that are relaxed per sector. Currently 20 percent of routing restrictions are relaxed at ZFW.

Reduction in conflicts due to trial planning (RTP)

Trial planning allows a controller to check whether a particular flight amendment will create any additional conflicts thereby reducing the conflicts per aircraft further downstream. It depends on the proportion of conflicts resolved by trial planning (PTP).

$$RTP = 1 - (0.3 \times PTP) \quad (5.54)$$

Proportion of conflicts resolved by trial planning (PTP)

It is the percentage of all conflicts that are resolved using the trial planning tool in URET. The proportion is higher for alternative D as compared to alternative C because of the short execution time in alternative D via datalink, there is a tendency for controller's to resort to trial planning more frequently.

$$PTP = \begin{cases} 0.6 & \text{Alternative C} \\ 0.8 & \text{Alternative D} \end{cases} \quad (5.55)$$

5.2.8 Conflicts in tracon airspace

In the tracon airspace, conflicts occur at two possible points, first is when the aircraft is entering the an

arrival stream from the enroute sector known as separation conflict and second is when the aircraft from two arrival streams are merging into one arrival stream just before the feeder post known as merging conflict.

Separation Conflict (SC)

When an aircraft is entering an arrival stream, a potential conflict situation could arise if adequate intrail separation is not maintained between the aircraft and the preceding one. To determine whether a potential conflict will take place or not when a aircraft enters an arrival stream, a check is done to determine if an aircraft is present downstream in the Separation Conveyor Stock. If an aircraft is present in the Separation Conveyor Stock that means it is a conflict situation since adequate intrail separation is not maintained and controller has to resolve the conflict.

$$SC(t) = IF(Rin_t(t) > 0)AND(S(t) > 0)THEN(1)ELSE(0) \quad (5.56)$$

Merging conflict (MC)

A merging conflict occurs when two aircraft from two different arrival streams is trying to merge into a single stream just before the feeder post and the expected times of merger of both aircraft is such that the difference in the two times is less than the time (Separation Time) what is required for minimum intrail separation. To determine whether a merging conflict will take place or not when a aircraft is about to merge into the single stream, a check is done to determine if an aircraft is present downstream in the Merging Conveyor Stock. If a aircraft is present in the Merging Conveyor Stock that means it is a conflict situation since adequate intrail separation is not maintained and controller has to resolve the conflict.

$$MC(t) = IF(Rout_t(t) > 0)AND(MS(t) > 0)THEN(1)ELSE(0) \quad (5.57)$$

5.2.9 Concept of Transit Time (TT)

Transit time is defined as the time taken by an aircraft to traverse a certain amount of airspace account-

ing for routine tasks and conflicts. Typically transit time is composed of three main components namely Free Flow Time, Additional Time for Routine tasks and Additional Time for conflicts.

Transit time is like a performance function of an enroute sector or tracon airspace. The performance function depends on the average conditions as regards to conflicts and routine diversions existing in the enroute sector or tracon airspace. At any moment of time, all aircraft in the sector will have the same transit time depending on conditions in the sector or tracon airspace.

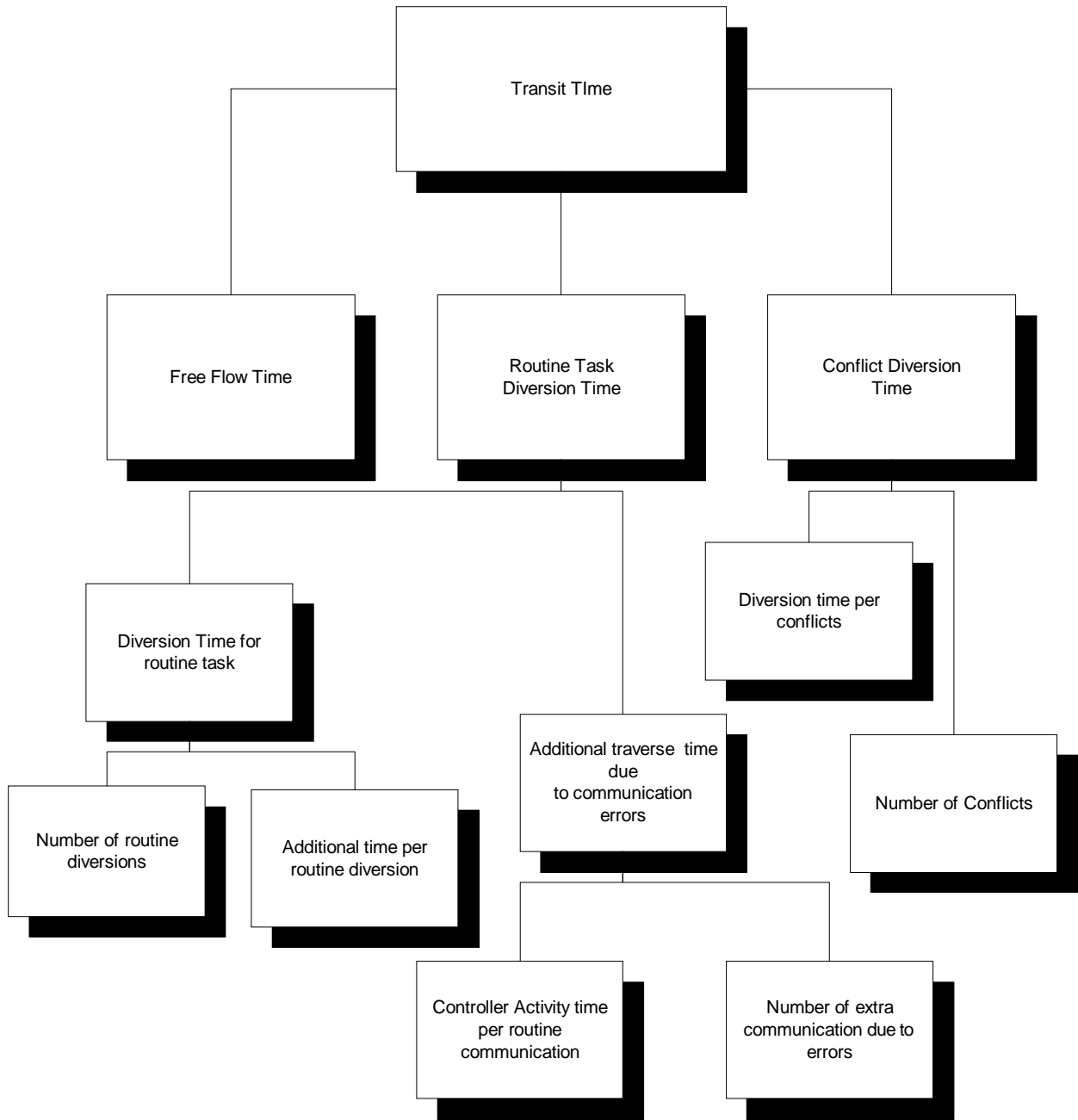


Figure 5.23 Components of Transit Time

Hence the equation for Transit Time is:

$$TT(t) = FFT + RTDT(t) + CDT(t) \quad (5.58)$$

Where FFT is the Free Flow Time, RTDT is the Routine Task Diversion Time and CDT is the Conflict Diversion Time. Even though FFT is the same for all four alternatives, the Transit Time will be different due to differing RTDT and CDT for the four alternatives.

5.2.10 Free Flow Time (FFT)

Free Flow Time in an enroute sector is defined as the time taken by an aircraft to travel from the beginning of an enroute sector to the end of the sector along a straight, undiverted path under zero conflict conditions. It can be determined by dividing the straight path distance between an entry and exit point of an enroute sector by the cruising velocity of the aircraft. Figure 5.7 shows an enroute sector with a single route. This route between entry point 1 and exit point 2 is the direct distance without any diversions. It represents the minimum time required for an aircraft to traverse an enroute sector.

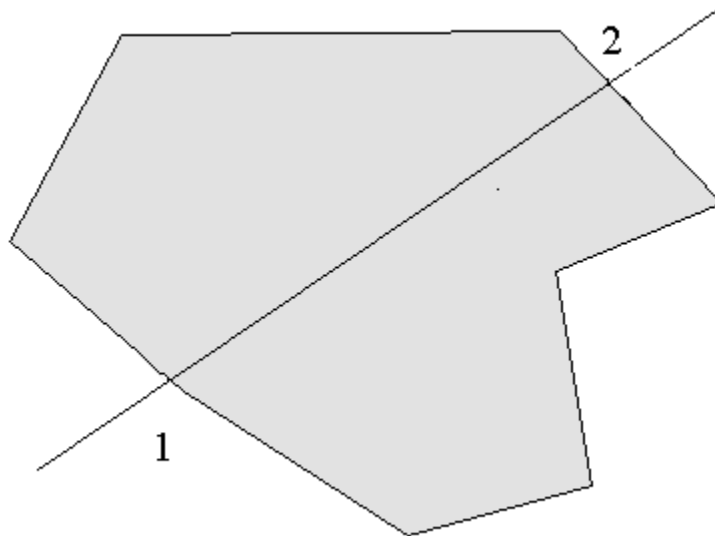


Figure 5.24 Free Flow Route

Free flow transit time data was obtained by simulating Atlanta and Jacksonville ARTCC's in the AOM model. Entry time (ENT) and exit time (EXT) of each aircraft for each enroute sector in the two ARTCC's was obtained and the FFT was computed by subtracting the entry time from the exit time. Figure 5.25 shows the histogram of the FFT data.

$$FFT_e = EXT - ENT \tag{5.59}$$

The arithmetic mean of the data is 9.2279 minutes and standard deviation is 6.3203 minutes.

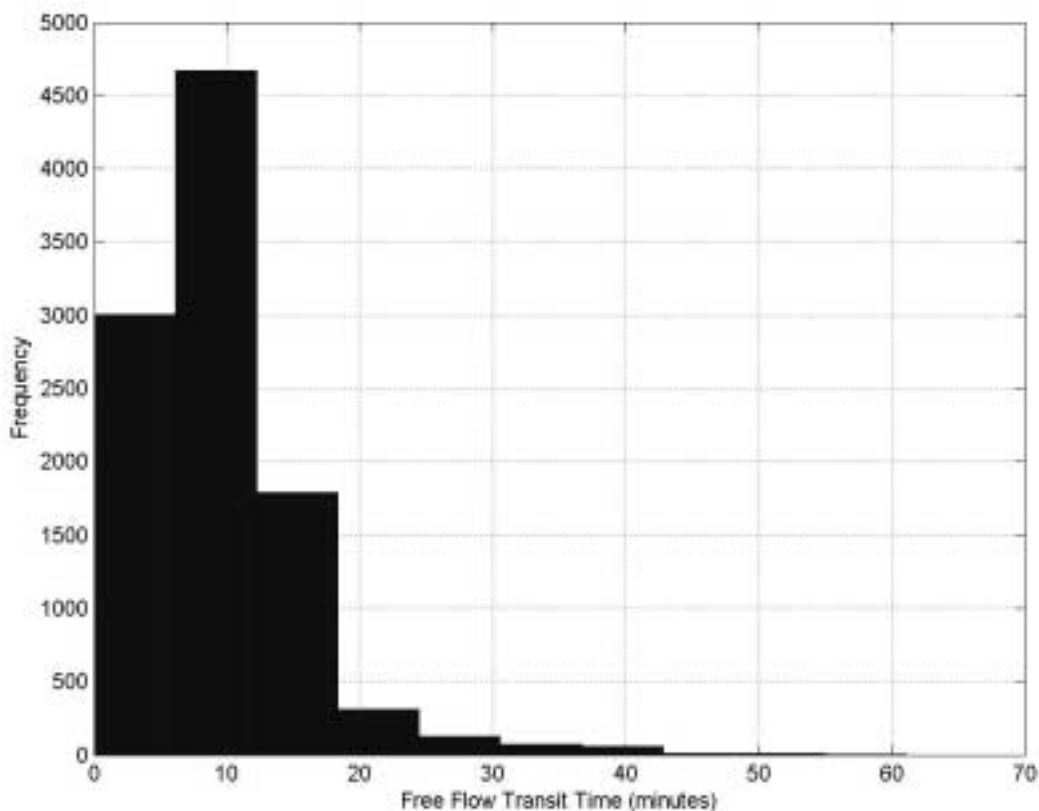


Figure 5.25 Histogram of Free flow transit time data

A cumulative probability density function is derived from the FFT data. The cumulative probability density function was inputted into the microscopic model as a table function as shown in table 5.9. FFT corresponding to 50 percentile cumulative probability was used in model. This corresponds to a time of 5.707 minutes.

Free Flow Time (minutes)	Cumulative Probability
0	0
1.025	0.1
2.05	0.2
3.079	0.3
4.393	0.4
5.707	0.5
7.022	0.6
8.336	0.7
10.42	0.8
13.84	0.9
58.04	1

TABLE 5.9 Cumulative Probability of Free Flow Time

Free Flow transit time for tracon airspace is defined as the time taken by an aircraft to fly an undiverted, straight path from the point it joins the arrival stream to the metering fix without any routine diversions and zero conflict conditions. It is computed by dividing the Tracon area distance (TAD) by the average speed of aircraft in the tracon airspace.

$$FFT_t = \frac{TAD}{3 \sum_{i=1} (Sp_i \times Pr_i)} \quad (5.60)$$

Tracon Area Distance (TAD)

It represents 40 nautical miles of airspace beyond the terminal airspace area.

5.2.11 Routine Task Diversion Time (RTDT)

Since the route structure is very rigid, it is seldom possible for aircrafts to fly direct routes hence the time taken for an aircraft to traverse an enroute sector is greater than the Free Flow Time. Secondly due to communication errors and repeats via the voice channel delays the execution of routine communications thereby increasing the dwell time of the aircraft in the sector. This additional time taken by an aircraft to traverse an enroute sector due to the route structure and communication errors is defined as Routine Task Diversion Time. It depends on the diversion time per routine communication and number of extra communications due to communication errors.

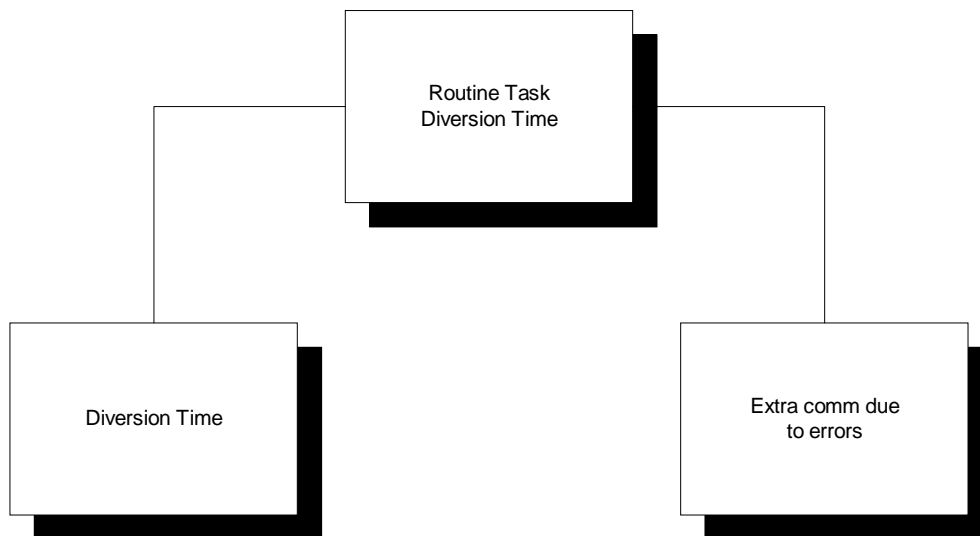


Figure 5.26 Routine Task Diversion Time Classification

For example, as shown in figure 5.27, if an aircraft has to fly from point 1 to point 3 via point 2 instead of directly being able to go from point 1 to point 2 would entail additional dwell time for the aircraft.

No of routine diversions (NRD)

It is the number of diversions that an aircraft has to take from its flight path in an enroute sector due to rigidity in the route structure. Figure 5.27 shows a single diversion in the flight path. The average number of diversions per enroute sector for a non uret scenario is 1.75 [Burski, 2000]. For a uret scenario, number of routine diversions per enroute sector is equal to the number of diversions in a non uret scenario minus the number of routing restrictions relaxed.

$$NRD_n = 1.75 \quad Non - uret \quad (5.61)$$

$$NRD_u = NRD_n - NRRR \quad Uret \quad (5.62)$$

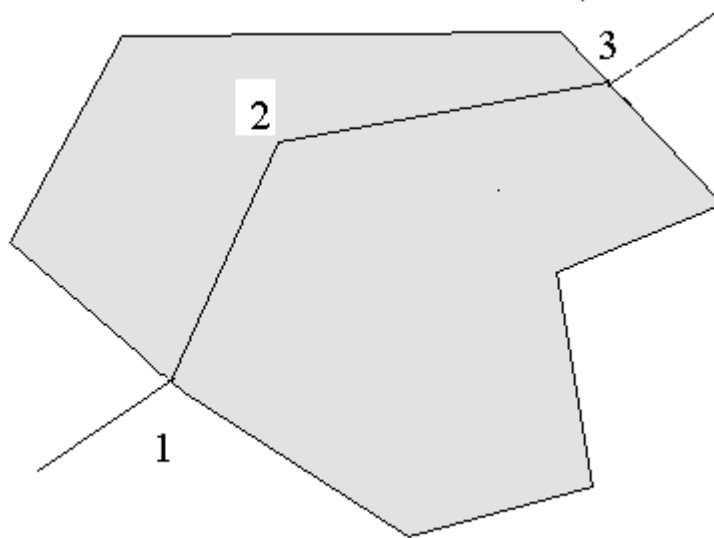


Figure 5.27 Diverted Route

For alternative A since all transactions between controller and pilot are carried out via the voice channel, the Routine Task Diversion Time is the summation of the product of number of routine diversions and diversion time per routine communication via voice and product of the extra voice communications

and average time per routine communication via voice.

$$RTDT_A = \begin{cases} NRD_n \times DTR_v + EVC_e \times RT_v & \text{Enroute - sector} \\ NRD_n \times NST \times DTR_v + EVC_t \times RT_v & \text{Tracon - Airspace} \end{cases} \quad (5.63)$$

For alternative B, C or D the Routine Task Diversion Task will depend on whether the aircraft is a datalink equipped or not a random experiment is performed at every time step in which a random variable is drawn from a uniform distribution between 0 and 1. If the random variable is less than or equal to the equipage level which means all aircraft are datalink equipped at that time step and the Routine Task Diversion Time is weighted average of routine diversion times of datalink and voice transactions depending upon proportion of datalink messages.

$$RTDT_B = \begin{cases} NRD_n \times (DTR_v + DP \times (DTR_d - DTR_v)) + (EVC_e \times RT_v) & \text{Enroute} \\ NRD_n \times NST \times (DTR_v + DP \times (DTR_d - DTR_v)) + (EVC_t \times RT_v) & \text{Tracon} \end{cases} \quad (5.64)$$

$$RTDT_x = \begin{cases} NRD_u \times (DTR_v + DP \times (DTR_d - DTR_v)) + (EVC_e \times RT_v) & \text{Enroute} \\ NRD_n \times NST \times (DTR_v + DP \times (DTR_d - DTR_v)) + (EVC_t \times RT_v) & \text{Tracon} \end{cases} \quad (5.65)$$

where x is alternative C or D.

If the random variable drawn is greater than the Equipage level then all aircraft at that time step is considered not to be equipped with datalink and hence the Datalink proportion of messages (DP) is equated to zero in equation 5.64 and 5.65.

Equipage rate for airplanes (E_a)

It is the percentage of the fleet of airplanes that are going to be equipped every year with infrastructure required on board airplanes to allow datalink message exchanges between pilots and controllers. A slider device is assigned to it at the interface layer to change its value either before or even during the simulation.

Equipage level for airplanes (El_a)

It is percentage of total number of aircraft equipped with infrastructure required on board airplanes to allow datalink message exchanges between pilots and controllers for a given year.

Message lag time (Lag)

It is defined as the period elapsed from the time at which the originating user or controller initiates the triggering event until the time the transmitted information is available for display to the intended recipient or pilot. The period elapsed is called end-to-end transfer delay. Table 5.10 shows the end to end transfer delay for datalink channel. The mean end-to-end transfer delay is used for the model for uploading a datalink message (Lag_d). For a voice message the end-to-end transfer delay (Lag_v) is a uniform distribution with lower limit of 1 second and upper limit of 2 seconds since a voice communication is almost instantaneous.

	Mean End-to-End Transfer Delay	95 percentile End-to-End Transfer Delay	99.996 percentile End-to-End Transfer Delay
Terminal	5 sec	8 sec	12.5 sec
En route	10 sec	15 sec	22 sec

TABLE 5.10 Message lag time parameters via datalink

Diversion time per routine communication (DTR)

It is the additional time spent by an aircraft per diversion in the route structure. For example in figure 5.27 if the aircraft flies from point 1 to 3 via point 2 instead of directly flying, then the additional time for the diversion is defined as diversion time per routine communication. For alternative A, the diversion time per routine communication is 2 minutes or 20 time steps. The diversion times for datalink equipped aircraft in alternative B, C and D are diversion time for A and difference in the average time per routine communication in voice and datalink and message lag time in datalink and difference in pilot reaction times between a datalink and voice message.

$$DTR_v = 2 \quad \text{voice} \quad (5.66)$$

$$DTR_d = DTR_v + RT_d - RT_v + Lag_d - Lag_v + TRU - TTU \quad \text{datalink} \quad (5.67)$$

Time for Typing Message (TTU)

It is time taken by a pilot or co-pilot to type the message and upload it into the FMS. The typing time for a message is about 24 seconds for a 12 word message at a rate of half a word a second.

5.2.12 Conflict Diversion Time (CDT)

A conflict is defined as a situation where two or more aircraft are in danger of violating each other's minimum separation. Whenever a potential conflict is detected, a controller issues advisories to the pilot to take a certain action which resolves the conflict. Usually the advisories given by the controller are in the form of either a altitude change or speed reduction or vectoring. All these advisories result in an aircraft spending more time in the airspace.

Conflict Diversion Time is defined as the additional time spent by an aircraft in the sector due to conflicts. It depends on the number of conflicts that an aircraft encounters and the diversion time per conflict.

For alternative A, since all transactions between controller and pilot are carried out via the voice channel, the Conflict Diversion Time is the product of number of conflicts per aircraft and diversion time per conflict via voice.

$$CDT_A(t) = ECAS_A(t) \times DTC_{(v,n)} \quad (5.68)$$

For alternative B, the Conflict Diversion Time will depend on whether the aircraft is a datalink equipped or not a random experiment is performed at every time step in which a random variable is drawn from a uniform distribution between 0 and 1. If the random variable is less than or equal to the Equipage level which means all aircraft are datalink equipped at that time step and the Conflict Diversion Time is weighted average of conflict diversion times via datalink and voice depending upon per-

centage of conflicts allocated to datalink.

$$CDT_B(t) = ECAS_B(t) \times (DTC_{(v, n)} + P_c \times (DTC_{(d, n)} - DTC_{(v, n)})) \quad (5.69)$$

For alternative C or D, the Conflict Diversion Time will depend on whether the aircraft is a datalink equipped and proportion of conflicts resolved by trial planning. A random experiment is performed at every time step in which a random variable is drawn from a uniform distribution between 0 and 1. If the random variable is less than or equal to the Equipage level which means all aircraft are datalink equipped at that time step and the Conflict Diversion Time is weighted average of conflict diversion times via datalink and voice and conflict diversion times for trial planning and non trial planning scenarios.

$$CDT_C(t) = \frac{ACAS_C(t) \times (P_c \times (DTC_{(d, nt)} + PTP_C \times (DTC_{(d, non)} - DTC_{(d, nt)})) + (1 - P_c) \times (DTC_{(v, nt)} + PTP_C \times (DTC_{(v, non)} - DTC_{(v, nt)}))}{(1 - P_c) \times (DTC_{(v, nt)} + PTP_C \times (DTC_{(v, non)} - DTC_{(v, nt)}))} \quad (5.70)$$

$$CDT_D(t) = \frac{ACAS_D(t) \times (P_c \times (DTC_{(d, nt)} + PTP_D \times (DTC_{(d, int)} - DTC_{(d, nt)})) + (1 - P_c) \times (DTC_{(v, nt)} + PTP_D \times (DTC_{(v, int)} - DTC_{(v, nt)}))}{(1 - P_c) \times (DTC_{(v, nt)} + PTP_D \times (DTC_{(v, int)} - DTC_{(v, nt)}))} \quad (5.71)$$

If the random variable is greater than the equipage level, then Percentage of conflicts allocated to datalink is equated to zero.

Percentage of conflicts (P_c)

It is proportion of conflicts that are resolved by via the datalink channel. Since the message sets in CPDLC Build I doesn't have capability to exchange messages for conflict resolution, hence atleast CPDLC Build IA has to be activated for controllers to resolve conflicts via the datalink channel. It is equal to the percentage of messages allocated to datalink (P_d) when atleast CPDLC Build IA is active.

$$P_c = IF(CSIA = 0)THEN(0)ELSE(P_d) \quad (5.72)$$

Diversion time per conflict (DTC)

It is additional time spent by an aircraft due to a conflict situation. The additional time that a aircrafts spends in a enroute sector because of a conflict is primarily due to two reasons, either because of vectoring which makes an aircraft fly a longer path or due to a reduced speed advisory slowing down the aircraft. For alternative A, the diversion time per conflict is 1 minute or 60 seconds or 10 time steps. The diversion time in alternative B will depend on whether the aircraft is datalink equipped or not and will be equal to the diversion time for A and difference in the average time per conflict communication in voice and datalink. For alternatives C and D, it will depend on the whether trial planning is used or not for resolving conflicts.

For alternative A:

$$DTC_{(v, n)} = 60 \quad (5.73)$$

For voice transaction in alternative B,C or D:

$$DTC_{(v, b)} = DTC_{(v, n)} + CT_{(v, b)} - CT_{(v, n)} \quad (5.74)$$

For datalink transaction in alternative B,C or D:

$$DTC_{(d, b)} = DTC_{(v, n)} + CT_{(d, b)} - CT_{(v, n)} + Lag_d - Lag_v \quad (5.75)$$

For datalink transactions the difference in lag times between datalink and voice is added since datalink message has a larger lag time then a voice message and hence a datalink communication would reach the pilot at a later time thereby delaying the diversion maneuver.

where a represents whether the conflict transaction is via datalink (d) or voice (v).

b denotes whether it is uret scenario or not (n). If it is a uret scenario, then whether trial planning is used or not (nt) for resolving the conflict. If trial planning is used whether its a integrated (int) or non

integrated (non) scenario.

For alternatives C and D, the diversion time will depend upon whether the aircraft is datalink equipped or not and whether trial planning is used or not.

No of routing restrictions relaxed (NRRR)

Routing restrictions can be defined as rigid routes that make aircraft fly less optimal and less direct routes so as to separate aircraft from airspace. For example in figure shown before, an aircraft has to fly to point 2 before proceeding onto point 3. This is known as a routing restriction. These restrictions can only be relaxed when uret is available since uret provides better and more accurate information to the D-side controller, which may enable the controller to dynamically relax restrictions in accordance with existing and planned traffic flows.

5.2.13 Controller Workload

Controller Workload is one of four main outputs from the microscopic daily model. Controller workload is measured by two metrics namely Controller Activity Level (CAL) and Controller Utilization (CU).

Enroute Controller Activity Level (CAL_e)

Enroute Controller Activity Level measures the amount of time per time step (0.1 minute) the enroute controller is busy. It is a non dimensional parameter since its a ratio of amount of time required by the controller to resolve routine and conflict tasks to amount of time available. The amount of time available per aircraft is the transit time (TT_e) of the aircraft. The amount of time required is the time required to resolve all conflicts and carry out all routine tasks per aircraft. This ratio gives the controller activity level per aircraft and when multiplied with the number of aircraft present in the enroute sector ($ACFT_e$) gives the total Controller Activity Level (CAL_e). When the CAL_e becomes equal to or greater than one no further aircraft are admitted into the enroute sector until it becomes less than one again after departure of an aircraft from the sector.

For Alternative A, which is a only voice channel scenario, the equation is:

$$CAL_e(t) = ACFT_e \times ((NRC_e + EVC_e) \times RT_v + (ECAS(t) \times CT_{(v,n)}/1.5)) / (TT_e(t)) \quad (5.76)$$

ECAS is divided by 1.5 since for any conflict, atleast a single communication is required for resolving it an maximum of 2 communications may be required giving an average of 1.5 communications.

For Alternative B, C and D since some aircraft are equipped with necessary infrastructure for datalink message exchange hence to determine whether an aircraft is equipped with datalink or not at every time step a random experiment is performed in which a random variable is drawn from a uniform distribution between 0 and 1. If the random variable is less than or equal to the Equipage level which means all aircraft are considered to be equipped with datalink infrastructure for that time step and the following equation is used:

For Alternative B:

$$CAL_e(t) = \frac{ACFT_e \times ((NRC_e \times (RT_v + DP \times (RT_d - RT_v))) + (EVC_e \times RT_v) + ())}{(ECAS(t))/1.5 \times (CT_{(v,n)} + P_c \times (CT_{(d,n)} - CT_{(v,n)}))} / (TT_e(t)) \quad (5.77)$$

For Alternative C and D:

$$CAL_e(t) = \frac{ACFT_e \times ((NRC_e - NRRR) \times (RT_v + DP \times (RT_d - RT_v))) + (EVC_e \times RT_v) + ()}{(ACAS(t))/1.5 \times (P_c \times (CT_{(d,n)} + PTP \times (CT_{(d,t)} - CT_{(d,n)}) + (1 - P_c) \times ())} / (TT_e(t)) \quad (5.78)$$

$$CT_{(v,n)} + PTP \times (CT_{(v,t)} - CT_{(v,n)}))$$

If the random variable drawn is greater than the Equipage level which means all aircraft in the enroute sector are considered not to be equipped with datalink infrastructure for that time step and equation 5.74 and 5.75 is used after equating Datalink Proportion of Messages (DP) and Percentage of conflicts resolved by datalink (P_c) to zero since no datalink messages can take place. Over the entire day, which

consists of 14400 time steps, the percentage of draws of random variable ($x = \text{random}(0,1)$) less than or equal to the equipage level comes to be approximately equal to the equipage level.

$$\text{Percentage}(x \leq El_a) = \frac{\sum_{i=1}^{14400} (x_i \leq El_a)}{14400} \approx El_a \quad (5.79)$$

Feeder Controller Activity Level (CAL_t)

The feeder controller's are controller's who control aircraft from the point they join the arrival stream to the feeder post. Each arrival stream is divided into a number of sectors and there is a feeder controller for each sector hence there are number of feeder controllers per arrival stream. Feeder Controller Activity Level measures the amount of time per time step (0.1 minute) an average feeder controller is busy. It is a non dimensional parameter since its a ratio of amount of time required to amount of time available. The amount of time available per aircraft is the transit time for tracon airspace (TT_t) of the aircraft. The amount of time required is the time required to resolve all conflicts and carry out all routine tasks per aircraft. This ratio gives the controller activity level per aircraft and when multiplied with the number of aircraft present in the tracon airspace (ACFT_t) and divided by the total number of feeder controllers per arrival stream gives the average Feeder Controller Activity Level (CAL_t). When the CAL_t becomes equal to or greater than one no further aircraft are admitted into the tracon airspace until it becomes less than one again after departure of an aircraft from the tracon airspace.

For Alternative A, which is a only voice channel scenario, the equation is:

$$CAL_t(t) = ACFT_t \times ((NRC_t + EVC_t) \times RT_v) / (TT_t(t) \times NF) \quad (5.80)$$

For Alternative B, C and D since some aircraft are equipped with necessary infrastructure for datalink message exchange hence to determine whether an aircraft is equipped with datalink or not at every time step a random experiment is performed in which a random variable is drawn from a uniform distribution between 0 and 1. If the random variable is less than or equal to the Equipage level which means

all aircraft are considered to be equipped with datalink infrastructure for that time step and the following equation is used:

For Alternative B, C and D:

$$CAL_t(t) = ACFT_t \times (NRC_t \times (RT_v + DP \times (RT_d - RT_v)) + (EVC_t \times RT_v)) / (TT_t(t) \times NF) \quad (5.81)$$

If the random variable is greater than the Equipage level then no aircraft is considered to be equipped with datalink infrastructure for that time step and Datalink Proportion of Messages (DP) is equated to zero.

No of feeder controllers (NF)

Each arrival stream is divided into a number of sectors and there is a feeder controller for each sector hence there are number of feeder controllers per arrival stream.

Enroute Controller Utilization (CU)

Controller Utilization is a measure of how busy a controller remains throughout the day in routine and conflict tasks. It is a ratio of the total time spent by a controller in routine and conflicts to the total time available which is a single day's period equal to 14400 time steps. It is the summation of Total Routine Time by voice (TRTV) and datalink (TRTD) and Total Conflict Time by voice (TCTV) and datalink (TCTD) divided by the total time in a day which is 14400 time steps.

$$CU = \frac{TRTD + TRTV + TCTD + TCTV}{14400} \quad (5.82)$$

Total Number of Routine Communications (TNRC)

It is total number of communications transacted between the controller and pilot in an enroute sector in carrying out routine tasks throughout the entire day.

For the enroute sector Queue Dissipation Rate (QDR) keeps track of the aircraft entering the enroute sector at every time, hence TNRC is the integral of the product of QDR and total routine communica-

tion per aircraft in enroute sector.

$$TNRC_e = \int_1^{14400} QDR(t) \times (NRC_e + EVC_e) dt \quad (5.83)$$

For the tracon airspace Rate in tracon airspace (Rin_t) keeps track of the aircraft entering the tracon airspace at every time step, hence TNRC is the integral of the product of Rin_t and total routine communication per aircraft in tracon airspace.

$$TNRC_t = \int_1^{14400} Rin_t(t) \times (NRC_t + EVC_t) dt \quad (5.84)$$

Total Number of Routine Communications by datalink (TNRCD)

It is total number of communications transacted between the controller and pilot in carrying out routine tasks via the datalink communication channel throughout the entire day. At every time step a random experiment is performed where a random variable is drawn from a uniform distribution between 0 and 1. If the random variable drawn at the time step at which an aircraft is entering the enroute sector, is less than or equal to the Equipage level then the aircraft is considered to be a datalink equipped aircraft.

$$TNRCD_e = \int_1^{14400} (QDR(t) \times NRC_e \times DP) dt \quad \text{Enroute} \quad (5.85)$$

$$TNRCD_t = \int_1^{14400} (Rin_t(t) \times NRC_t \times DP) dt \quad \text{Tracon} \quad (5.86)$$

If the random variable drawn is greater the Equipage level, then the aircraft is not datalink equipped and hence Datalink Proportion of messages (DP) is equated to zero.

Total Number of Routine Communications by Voice (TNRCV)

It is total number of communications transacted between the controller and pilot in carrying out routine tasks via the voice communication channel throughout the entire day. It is computed by subtracting the total number of routine datalink messages from the total number of routine messages.

$$TNRCV_e = TNRC_e - TNRCD_e \quad \text{Enroute} \quad (5.87)$$

$$TNRCV_t = TNRC_t - TNRCD_t \quad \text{Tracon} \quad (5.88)$$

Total Routine Time by voice (TRTV)

It is total time spent by a controller carrying out routine tasks via the voice communication channel throughout the entire day. It is the product of the total routine communication via voice channel and average time spent per routine communication via voice communication channel (RTV).

$$TRTV_e = TNRCV_e \times RTV \quad \text{Enroute} \quad (5.89)$$

$$TRTV_t = TNRCV_t \times RTV \quad \text{Tracon} \quad (5.90)$$

Total Routine Time by datalink (TRTD)

It is total time spent by a controller in carrying out routine tasks via the voice communication channel throughout the entire day. It is the product of the total routine communication via voice channel and average time spent per routine communication via the datalink communication channel (RTD).

$$TRTD_e = TNRCD_e \times RTD \quad \text{Enroute} \quad (5.91)$$

$$TRTD_t = TNRCD_t \times RTD \quad \text{Tracon} \quad (5.92)$$

Total Conflict Time by datalink (TCTD)

It is total time spent by a controller in an enroute sector resolving conflicts via the datalink communication channel throughout the entire day.

For Alternative A, which is a voice channel scenario, it is zero since there is no datalink channel.

For Alternative B, C and D since some aircraft are equipped with necessary infrastructure for datalink message exchange hence to determine whether an aircraft is equipped with datalink or not at every time step a random experiment is performed in which a random variable is drawn from a uniform distribution between 0 and 1. If the random variable is less than or equal to the Equipage level which means the aircraft entering the enroute sector or tracon airspace is equipped with datalink infrastructure for that time step and the following equation is used:

Alternative B:

$$TCTD_e = \int_1^{14400} (ECAS(t) \times CTD_n \times P_c) dt \quad \text{Enroute} \quad (5.93)$$

$$TCTD_t = \int_1^{14400} CTD_n \times P_c \times (MC(t) + SC(t)) dt \quad \text{Tracon} \quad (5.94)$$

For Alternative C and D:

$$TCTD_e = \int_1^{14400} (ACAS(t) \times P_c \times (CTD_n + PTP \times (CTD_y - CTD_n))) dt \quad \text{Enroute} \quad (5.95)$$

$$TCTD_t = \int_1^{14400} CTD_n \times P_c \times (MC(t) + SC(t)) dt \quad \text{Tracon} \quad (5.96)$$

If the random variable is greater than Equipage level, which means aircraft doesn't have the required datalink infrastructure for datalink message exchange and hence TRTD is zero.

Total Conflict Time by voice (TCTV)

It is total time spent by a controller in an enroute sector or tracon airspace resolving conflicts via the voice communication channel throughout the entire day.

For Alternative A:

$$TCTV_t = \int_1^{14400} (ECAS(t) \times CTV_n) dt \quad \text{Enroute} \quad (5.97)$$

$$TRTV_t = \int_1^{14400} CTV_n \times (MC(t) + SC(t)) dt \quad \text{Tracon} \quad (5.98)$$

For Alternative B, C and D since some aircraft are equipped with necessary infrastructure for datalink message exchange hence to determine whether an aircraft is equipped with datalink or not at every time step a random experiment is performed in which a random variable is drawn from a uniform distribution between 0 and 1. If the random variable is less than or equal to the Equipage level which means the aircraft entering the enroute sector or tracon airspace is equipped with datalink infrastructure for that time step and the following equation is used:

Alternative B:

$$TCTV_e = \int_1^{14400} (ECAS(t) \times CTV_n \times (1 - P_c)) dt \quad \begin{matrix} 0 < P_c \leq 1 & \text{Datalink} \\ P_c = 0 & \text{Non - Datalink} \end{matrix} \quad (5.99)$$

$$TCTV_t = \int_1^{14400} (MC(t) + SC(t)) \times CTV_n \times (1 - P_c) dt \quad \begin{matrix} 0 < P_c \leq 1 & \text{Datalink} \\ P_c = 0 & \text{Non - Datalink} \end{matrix} \quad (5.100)$$

For Alternative C and D:

$$TCTV = \int_1^{14400} (ACAS(t) \times (1 - P_c) \times (CTV_n + PTP \times (CTV_y - CTV_n))) dt \quad \begin{array}{l} 0 < P_c \leq 1 \\ P_c = 0 \quad ND \end{array} \quad (5.10D)$$

$$TCTV_t = \int_1^{14400} (MC(t) + SC(t)) \times CTV_n \times (1 - P_c) dt \quad \begin{array}{l} 0 < P_c \leq 1 \quad Datalink \\ P_c = 0 \quad Non - Datalink \end{array} \quad (5.102)$$

If the aircraft is not equipped with datalink infrastructure, the percentage of conflicts by datalink (P_c) is equated to zero.

5.2.14 Airspace Occupation Times

Airspace Occupation time is the time that an aircraft spends in a particular airspace. For enroute part, it is the time it spends in an entire enroute sector. For the terminal part, it is the time it spends in the airspace from where the arrival stream begins to the point where it lands at the airport. Airspace occupation time is defined by the variable sector time (ST) for enroute airspace and variable Terminal Time (TET) for tracon and terminal airspace.

Sector Time (ST)

Sector Time is the time taken by each individual aircraft to traverse an enroute sector. If there is a queue of aircraft waiting to enter the sector then it is time difference between the time it joins the queue and the time it exits the enroute sector.

The sector time is captured by using the cycle time function (CYCLETIME) in STELLA. By specifying the starting point and finish point of collection of time data, the time that an aircraft spends in a sector can be captured. The starting point is the rate in enroute sector variable (Rin_e) and finish point is the rate out enroute sector variable ($Rout_e$).

$$ST(t) = CYCLETIME(Rout_e(t)) \quad (5.103)$$

Mean Sector Time (MST)

Mean Sector Time captures the cumulative average of all sector times of all aircraft throughout the entire day. It is determined by the mean cycle time (CTMEAN) function in STELLA.

$$MST = CTMEAN(Rout_e(t)) \quad (5.104)$$

Terminal Time (TET)

Terminal Time is the time taken by each individual aircraft to traverse the airspace from the point it joins the arrival stream to the point it lands at the airport. If there is a queue of aircraft waiting to enter the arrival stream then it is time difference between the time it joins the queue and the time it lands at the airport.

The terminal time is captured by using the cycle time function (CYCLETIME) in STELLA. By specifying the starting point and finish point of collection of time data, the time that an aircraft spends in a sector can be captured. The starting point is the rate in tracon airspace variable (Rin_t) and finish point is Rate out Terminal Airspace ($Rout_{te}$).

$$TET(t) = CYCLETIME(Rout_{te}(t)) \quad (5.105)$$

Mean Terminal Time (MTET)

Mean Sector Time captures the cumulative average of all terminal times of all aircraft landing at the airport throughout the entire day. It is determined by the mean cycle time (CTMEAN) function in

STELLA.

$$MTET = CTMEAN(Rout_{te}(t)) \quad (5.106)$$

5.2.15 Communication Channel Utilization

Communication Channel Utilization is a measure of amount of time the voice and communication channel is busy during the entire day. It is non dimensional parameter since it is a ratio of the total time the communication channel is busy to the total time available in the day.

Voice Channel Utilization (VCU)

It is a ratio of the total time that the voice communication channel is busy during the entire day to the total amount of time available (14400 time steps) in the day. The total time the voice communication remains busy is a product of the total number of voice communications and the transfer time per message. The total number of voice communications is a summation of the routine voice communications and conflict communications via voice. The transfer time is the lag time via voice.

$$VCU_e = \frac{(TRNCV_e + TCNCV_e) \times lag_v}{14400} \quad (5.107)$$

$$VCU_t = \frac{(TRNCV_t + TCNCV_t) \times lag_v}{14400} \quad (5.108)$$

Datalink Channel Utilization (DCU)

It is a ratio of the total time that the datalink communication channel is busy during the entire day to the total amount of time available (14400 time steps) in the day. The total time the datalink communication remains busy is a product of the total number of datalink communications and the transfer time per message. The total number of datalink communications is a summation of the routine datalink communications and conflict communications via datalink. The transfer time is the lag time via datalink.

$$DCU_e = \frac{(TRNCD_e + TCNCD_e) \times lag_d}{14400} \quad (5.109)$$

$$DCU_t = \frac{(TRNCD_t + TCNCD_t) \times lag_d}{14400} \quad (5.110)$$

5.2.16 Pilot Workload

Pilot Workload is measured by the metric pilot utilization. It is a measure of how busy a pilot is during the transit of the aircraft through a given airspace.

Average Time for hearing and uploading message (THU)

It is the time spent by a pilot or co-pilot in hearing a voice message from the controller and typing it into the Flight Management System (FMS) of the aircraft. A pilot has to carry out two tasks, first he has to hear the message and then type the message into the FMS. The hearing time for the pilot is the same as the speaking time of the controller which is 8 seconds (RT_v). The typing time (TTU) for a message is about 24 seconds at a rate of half a word a minute giving a total time for hearing and uploading to be equal to 32 seconds.

$$THU = RT_v + TTU \quad (5.111)$$

Average Time for reading and uploading message (TRU)

It is the time spent by a pilot or co-pilot in reading a datalink message from the controller and uploading it into the Flight Management System (FMS) of the aircraft by the press of a button. A pilot has to carry out two tasks, he has to read the message and then upload it. The time for reading a message is 12 seconds at a rate of a word a second. The time for uploading is 2 seconds since it involves uploading the message into the FMS by the press of a key giving a total time for reading and uploading to be equal to 14 seconds.

Proportion of messages uploaded into the FMS (P_f)

It is percentage of all messages transacted between the controller and pilot that are uploaded into the Flight Management System (FMS) of the aircraft.

Pilot Utilization (PU)

Pilot Utilization is a measure of how busy a pilot remains hearing or reading messages and uploading them into the Flight Management System (FMS) of the aircraft during the transit in a given airspace. It is a ratio of the total time spent by a pilot in hearing or reading and uploading messages into the FMS to the total time available which is the transit time of the aircraft through the airspace. It depends upon the proportion of messages fed into the FMS. The total number of messages are divided by the total aircraft.

$$PU_e = \frac{P_f \times (THU \times (TRNCV_e + TCNCV_e) + TRU \times (TRNCD_e + TCNCD_e))}{(TA_e \times TT_e)} \quad (5.112)$$

$$PU_t = \frac{P_f \times (THU \times (TRNCV_t + TCNCV_t) + TRU \times (TRNCD_t + TCNCD_t))}{(TA_t \times TT_t)} \quad (5.113)$$

5.2.17 Interface level of microscopic daily model

In the STELLA environment, the interface level is the upper layer and is also called the graphical user interface layer. A number of things can be done at this level like the model can be run, the simulation parameters can be changed, input values of variables can be specified and results can be displayed in table or graphical format.

There are four windows or screens for the four major outputs namely Airspace Occupation Times, Controller Workload and Pilot Workload and Communication Channel Utilization. There is a navigation menu from where you can navigate to any of the windows.

When the model is opened, the navigation menu at the interface layer is the first screen from where any

of the windows can be accessed. The navigation menu is the common link between any of the windows. For example if you would want to go from the Controller Workload metrics window to the Airspace Occupation metrics window, first you would go to the Navigation Menu and from there to the Airspace Occupation metrics window. Figure 5.28 shows the outline of the interface layer.

Airspace Occupation metrics window displays the sector times (ST) and terminal airspace times (TET) in graphical format. The mean sector times (MST) and mean terminal times (MTET) are displayed in table format. Sliders are provided for variables like traffic growth (TG), Equipage level (EI_a) of airplanes and Message sets for each Build. Switches are provided for turning on or off any CPDLC Build at any time.

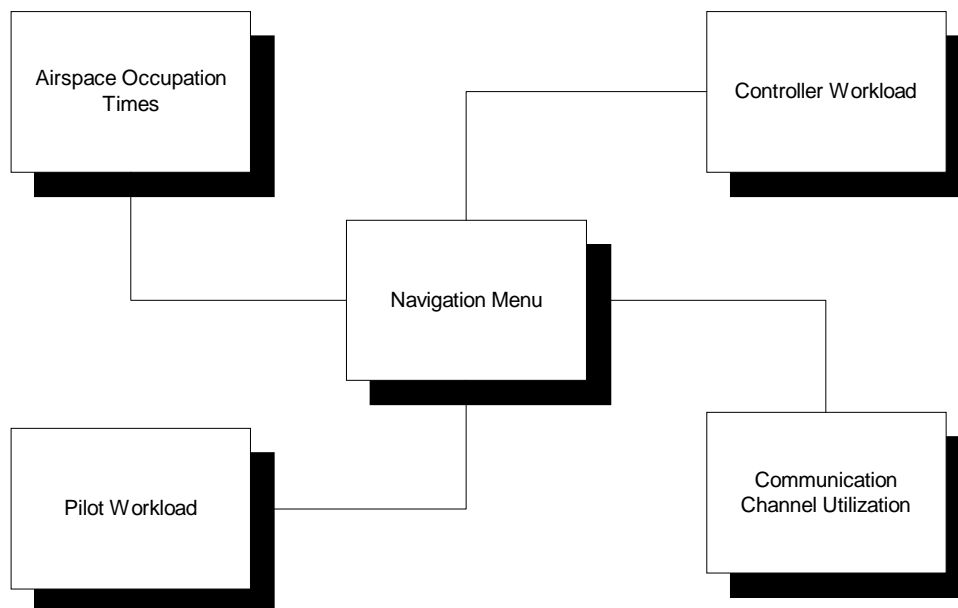


Figure 5.28 Outline of the interface layer of microscopic model

Controller Workload metrics window displays the controller utilization (CU) and controller activity level for each enroute and feeder controller. Sliders are provided for altering the values of variables like number of routine communications per aircraft per sector and number of routine communications per

5.2 Microscopic Daily Model (DATSIM)

aircraft per tracon airspace.

Pilot Workload metrics window displays the pilot utilization (PU) in the enroute and tracon airspace. Sliders are provided for altering the values of variables like average time for hearing and uploading message and average time for reading and uploading message.

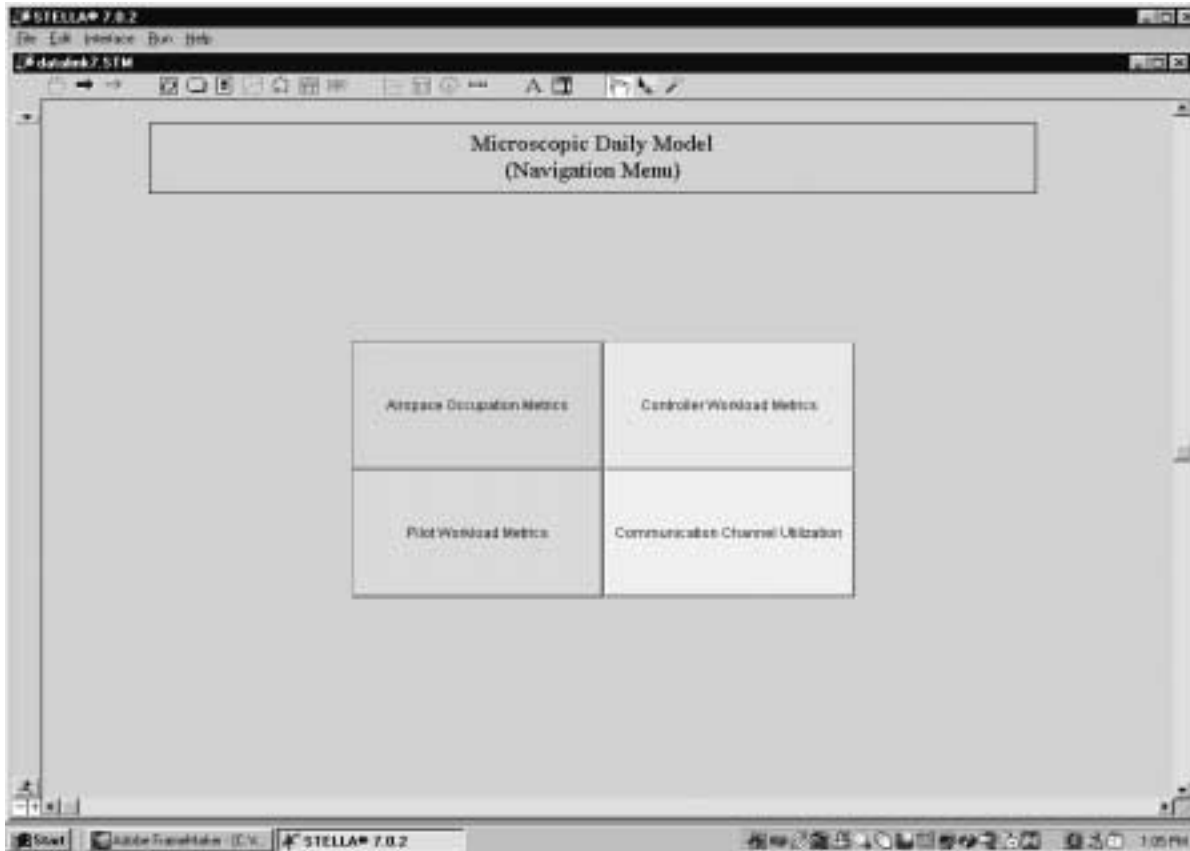


Figure 5.29 Snapshot of the navigation menu at the interface layer

Communication Channel Utilization metrics window displays the utilization of both datalink and voice channel in enroute sector and tracon airspace.

Microscopic Model Results

6.1 Overview

This chapter presents the results of the enroute module of the microscopic model. For each CPDLC Build, the equipage level was varied from 0 to 1 in steps of 0.25 and for each equipage level, the model was run for different air traffic flow conditions. Various output metrics were collected for each alternative. The microscopic daily model generated four main output metrics namely airspace occupation times, controller workload, pilot workload (not documented in this research effort) and communication channel utilization. Three dimensional regression surfaces showing differences in airspace occupation times for alternatives B, C and D as compared to alternative A are generated as a function of aircraft demand flow per day per sector and equipage level. Airspace occupancy time metrics are embedded into the macroscopic annual model, and a life cycle cost/benefit estimate is made.

All the regression surfaces have been estimated using the output of the microscopic model and are only valid in the range tested and should not be extrapolated to ranges outside the scope of the model. Only the output metrics of the enroute sector only has been documented in this research effort. The terminal area results follow the same methodology.

6.2 Enroute Sector Model

6.2.1 Airspace Occupation Metrics

The microscopic model is run with varying aircraft traffic densities and aircraft equipage levels. 3-D response surfaces are generated using non linear regression fits in MATLAB. These response curves quantify enroute time savings (per aircraft) per sector as a function of equipage level and traffic flows per sector per day. Different response surfaces are generated for each CPDLC Build with and without URET in a integrated and non integrated scenario. The 3-D surfaces for each scenario are divided into two regions, one region representing uncongested traffic flow conditions (i.e traffic flow conditions upto saturation flow) of an enroute sector for alternative A. The second region represents saturated air traffic flow conditions. Analysis using the model indicates a threshold at 630 aircraft per day separating the uncongested and congested regions. The controller workload activity level is the main criteria for deciding when aircraft density in the enroute sector becomes congested or not. From the output of the model, the controller workload for alternative A is saturated at approximately 630 aircraft flow per day per sector. The main reason for the segregation of output data into two different regions is needed because there are large differences in sector traversal times for alternatives B, C and D as compared to alternative A. The functional behavior of congested and uncongested cases is modeled separately in the annual macroscopic model.

Uncongested Flow

Uncongested flow represents all air traffic flow upto saturation flow which is 630 aircraft per day per sector. Figure 6.1 shows the mean sector traversal time per aircraft as a function of demand for alternative A (voice only) in the region of uncongested traffic flow. Enhanced traffic management system (ETMS) data was used in the analysis.

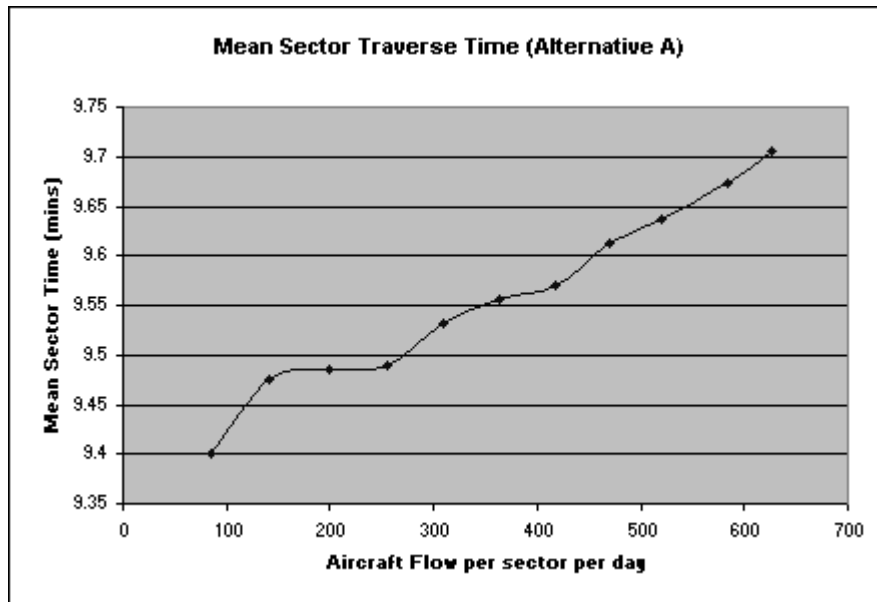


Figure 6.1 Mean sector traversal times per aircraft for Alternative A (Uncongested Case)

The difference in sector occupancy times (delta) between alternative B, C and D compared to alternative A depends on two factors 1) aircraft flow per day per sector (ADS) and 2) equipage level of aircraft. It also depends on the minimum separation but that was kept constant at 5 nautical miles. In order to develop a three dimensional regression surface between the two independent variables (Aircraft flow per day per sector and Equipage level) and dependent variable (difference in sector traverse times or delta per aircraft) first a good idea was obtained of the variance of the dependent variable with each independent variable separately.

Figure 6.2 shows the relationship between difference in sector traversal time per aircraft for CPDLC Build I as a function of aircraft flow and various equipage levels of aircraft.

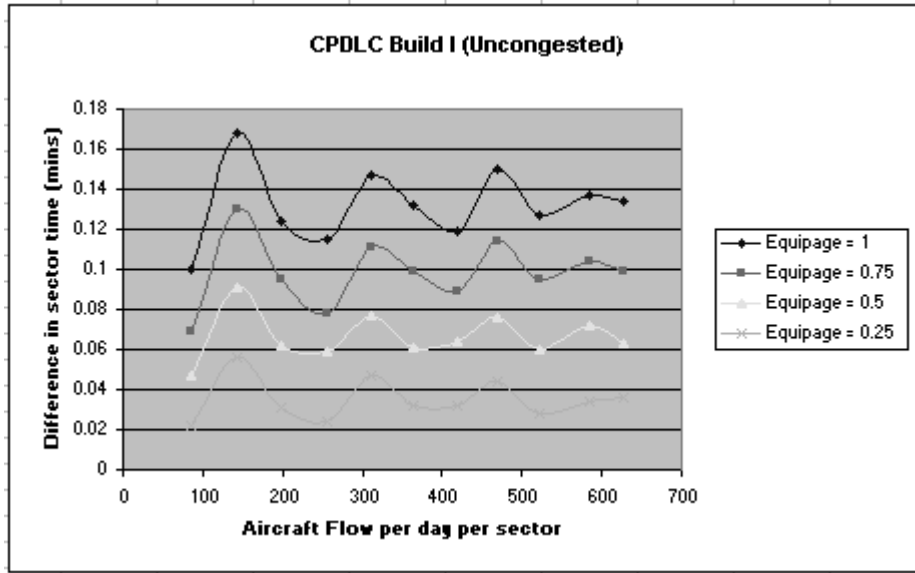


Figure 6.2 Sector Traversal Time difference per aircraft for CPDLC Build I v/s ADS (Uncongested Case)

The difference in sector traversal time (delta) per aircraft for CPDLC Build I versus aircraft density was obtained with the model and curve fitted with a curve fitting software CurveExpert. The non linear regression line was forced to cross the origin. A power curve fit model (see equation 6.1) was established to be a good fit between difference in sector traversal time (delta) for CPDLC Build I. The R-square varied from 0.65 to 0.92 for various equipage levels.

$$y = ax^b \tag{6.1}$$

where y is the difference in sector time per aircraft in minutes,

x is the aircraft flow per day per sector,

a and b are coefficients of the model.

Figure 6.3 shows an example of the regression line for CPDLC Build I as a function of demand for equipage level of 1. The R-square for the curve is 0.68.

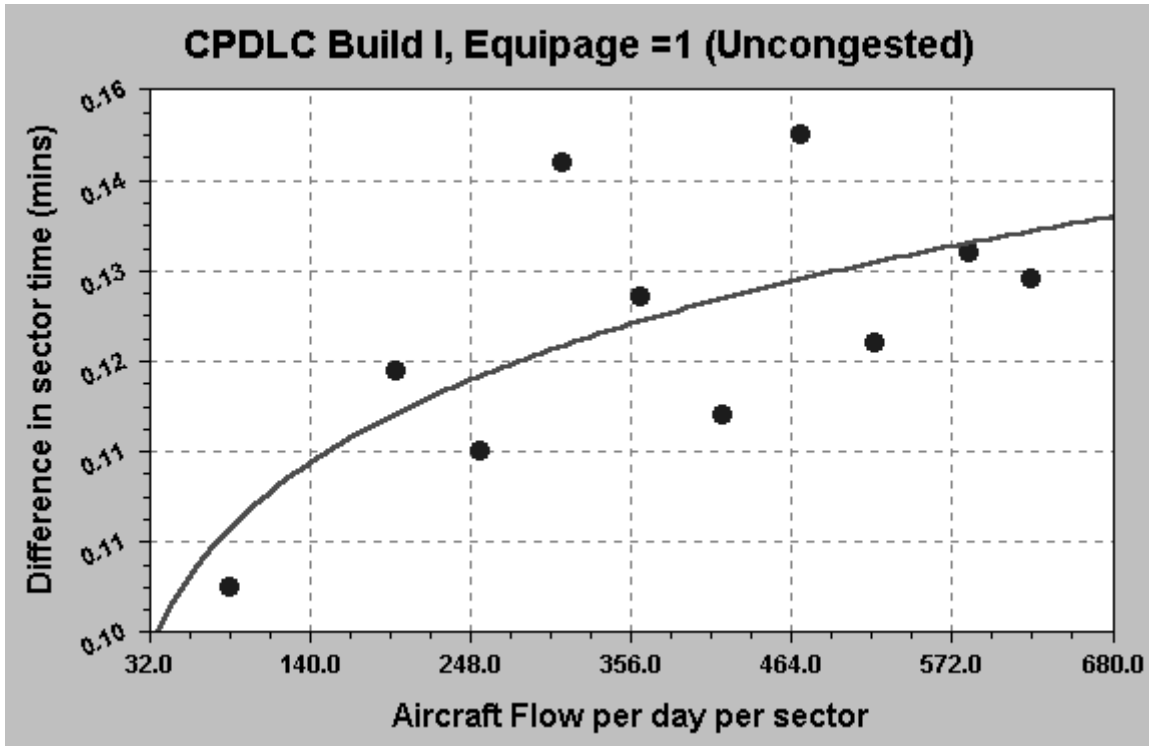


Figure 6.3 Power fit between delta and aircraft density for CPDLC Build I at 100 percent Equipage (Uncongested)

Figure 6.4 shows the relationship between difference in sector time per aircraft for CPDLC Build I and equipage level of aircraft for varying aircraft flow per day per sector (ADS). ACFT in Figure 6.4 is the aircraft flow per day per sector.

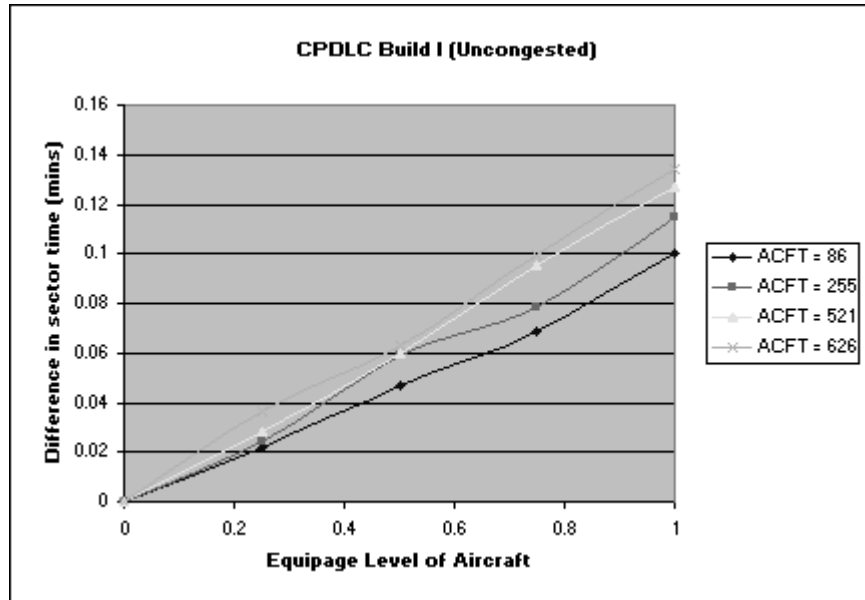


Figure 6.4 Sector Traversal Time difference per aircraft for CPDLC Build I v/s Equipage Level (Uncongested)

Figure 6.4 suggests a linear fit of the form as shown in the equation 6.2. The values of R-square varied from 0.91 to 0.99 for varying ADS and it has zero intercept and also intuitively it seems to be a very good fit.

$$y = ax \tag{6.2}$$

where y is the difference in sector traversal times in minutes,

x is the equipage level of aircraft,

a is the slope or coefficient of the model.

Figure 6.5 shows a sample linear fit relationship between delta for CPDLC Build I and equipage level for aircraft flow per day per sector of 86. The R-square for the fit is 0.99.

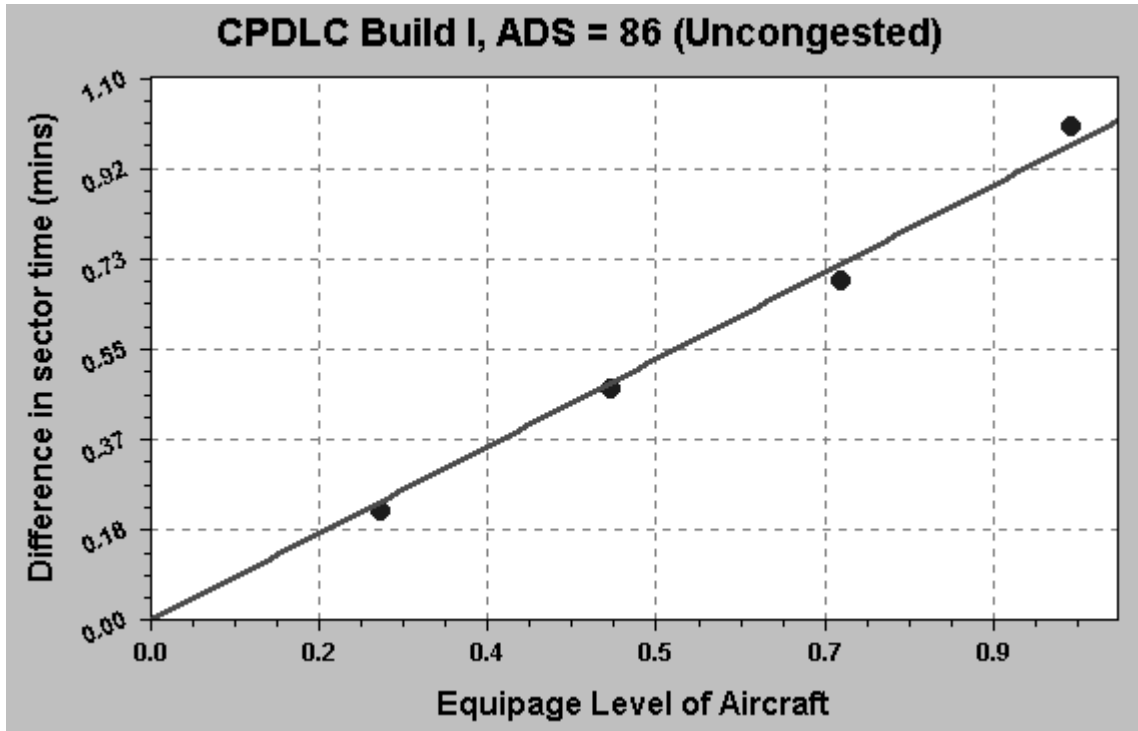


Figure 6.5 Linear fit between delta and Equipage level for CPDLC Build I at ADS = 86 (Uncongested) After determining the relationship of equipage level (EI_a) and ADS with sector time difference per aircraft for CPDLC Build I, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = ax_1x_2^b \quad (6.3)$$

where x_1 is the equipage level of aircraft,

x_2 is the aircraft flow per day per sector,

a and b are coefficients of the regression surface.

Two parameter non linear regression fitting is carried out in MATLAB using the entire output data set for CPDLC Build I and following values are obtained as shown in Table 6.1.

Figure 6.6 shows the regression benefit surface for CPDLC Build I (uncongested region). The regression surface has a R-square of 0.97.

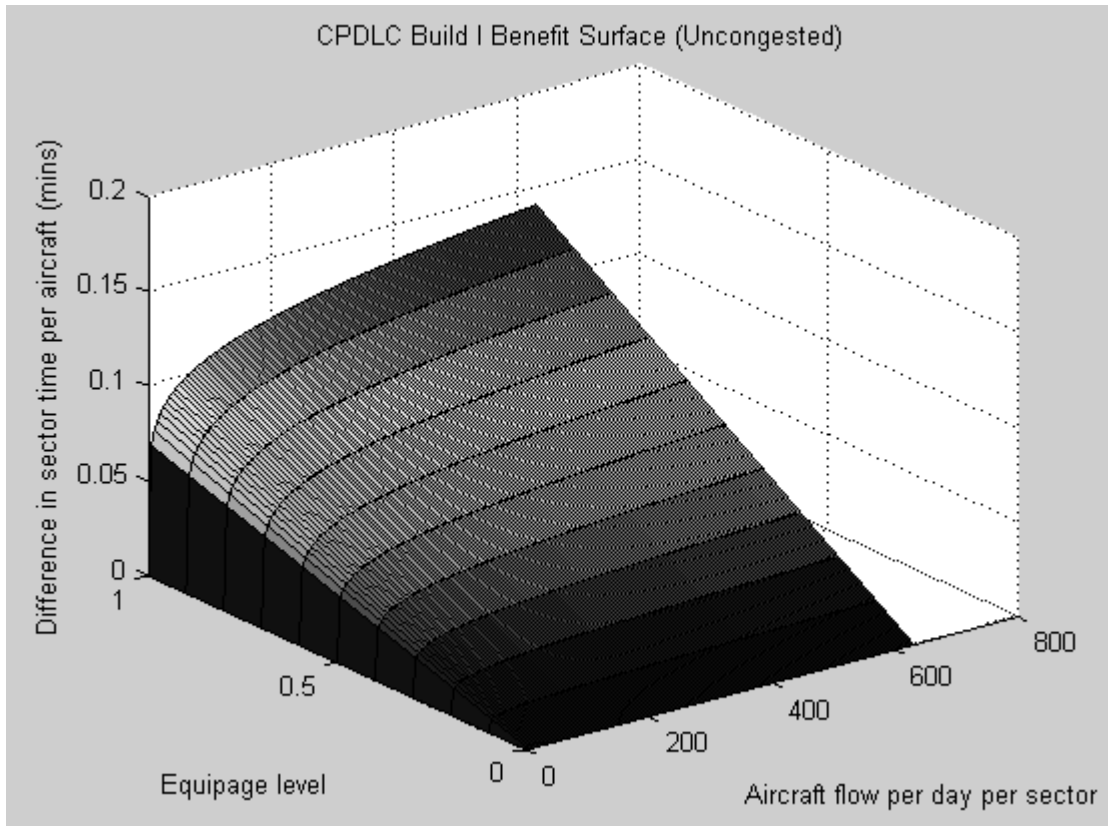


Figure 6.6 Regression Surface for CPDLC Build I (Uncongested)

Regression surfaces for the remaining scenarios were developed in the same fashion as for CPDLC Build I. Table 6.1 displays the R-square and coefficients of the regression surface for each scenario for uncongested case.

Figure 6.7 shows the relationship between difference in sector traversal time difference per aircraft for CPDLC Build I with non integrated URET and aircraft flow per day per sector for varying equipage level of aircraft.

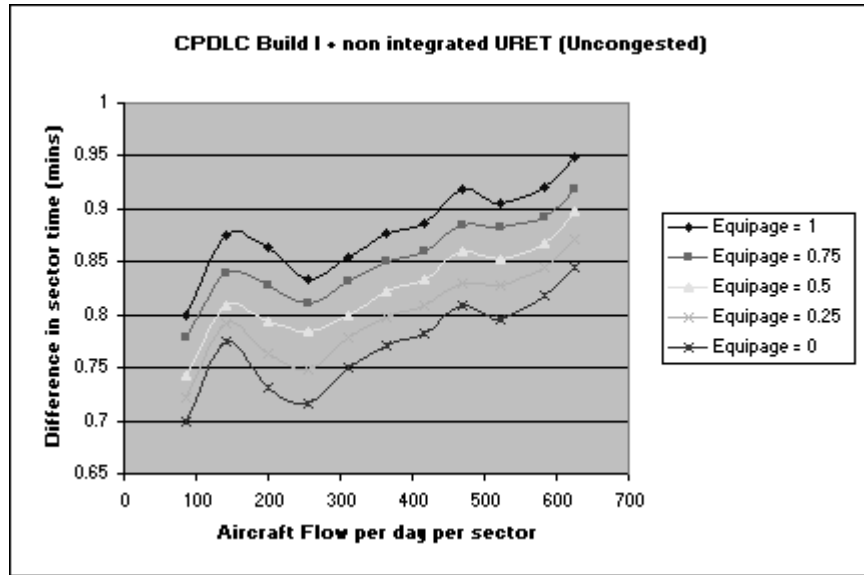


Figure 6.7 Sector Traversal Time difference per aircraft for CPDLC Build I and non integrated URET v/s ADS (Uncongested)

Figure 6.8 shows a sample power fit relationship between delta for CPDLC Build I with non integrated URET and aircraft flow per day per sector for equipage level of 0.25. The R-square for the fit is 0.94.

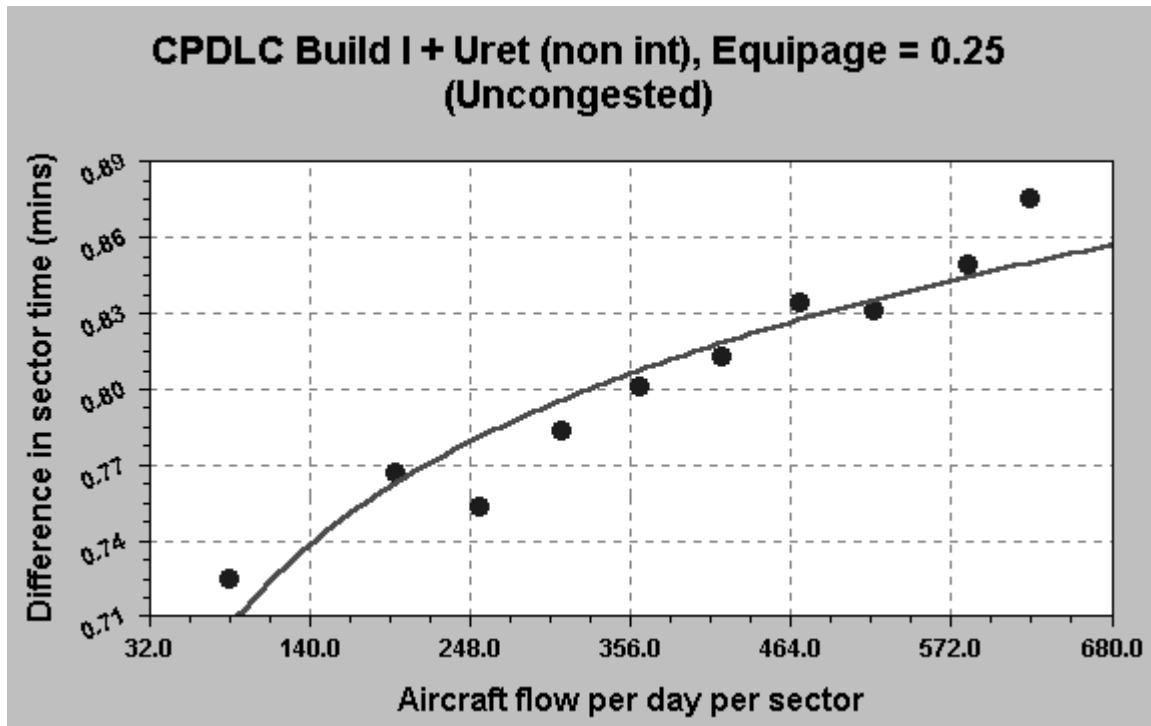


Figure 6.8 Power fit between delta and aircraft density for CPDLC Build I with non integrated URET at 25 percent Equipage (Uncongested)

Figure 6.9 shows the relationship between difference in sector traversal time per aircraft for CPDLC Build I with non integrated URET and equipage level of aircraft for varying aircraft flow per day per sector (ADS).

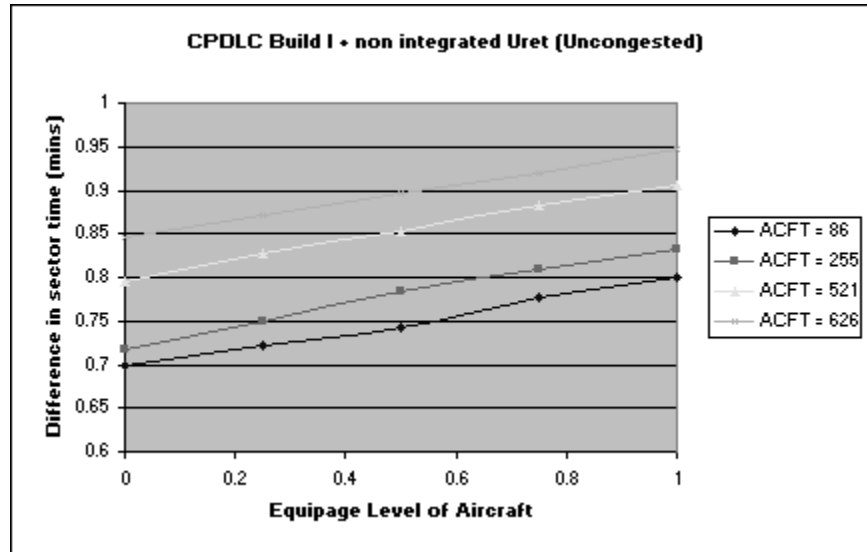


Figure 6.9 Sector time difference per aircraft for CPDLC Build I with non integrated URET v/s Equipage Level (Uncongested)

A zero intercept regressed line is not required unlike in the only CPDLC Build I case (non URET case), since even though no datalink transactions takes place when no aircraft are equipped with datalink infrastructure on board but some sector traversal time difference is there due to the conflict detection ability of URET. A linear fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build I with non integrated URET and equipage level since the R-square varies in the range 0.98 to 0.99 for different ADS.

$$y = ax + b \tag{6.4}$$

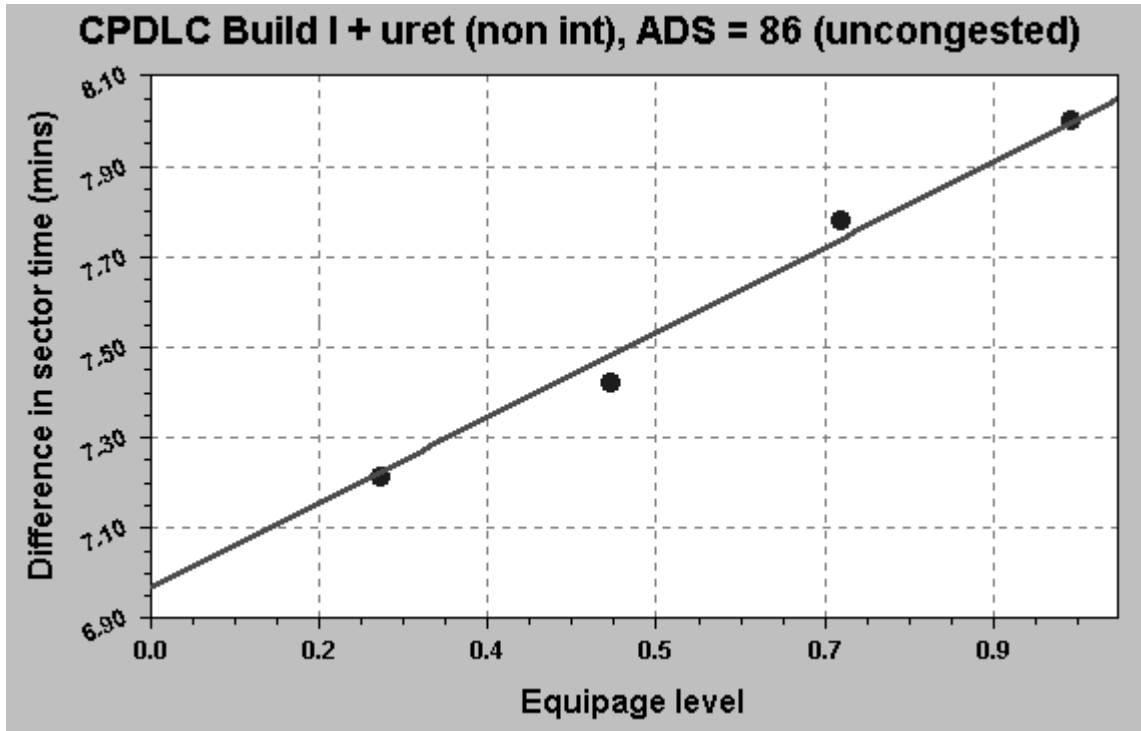


Figure 6.10 Linear fit between delta and equipage level for CPDLC Build I with non integrated URET at ADS = 86 (Uncongested)

Figure 6.10 shows a linear fit relationship between delta for CPDLC Build I with non integrated URET and equipage level for aircraft flow per day per sector for of 86. The R-square for the fit is 0.99.

After determining the relationship of equipage level (EI_a) and ADS with sector time difference per aircraft for CPDLC Build I with non integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = (ax_1 + b)x_2^c \quad (6.5)$$

Figure 6.11 shows the regression benefit surface for CPDLC Build I with non integrated URET (uncongested region). The regression surface has a R-square of 0.97.

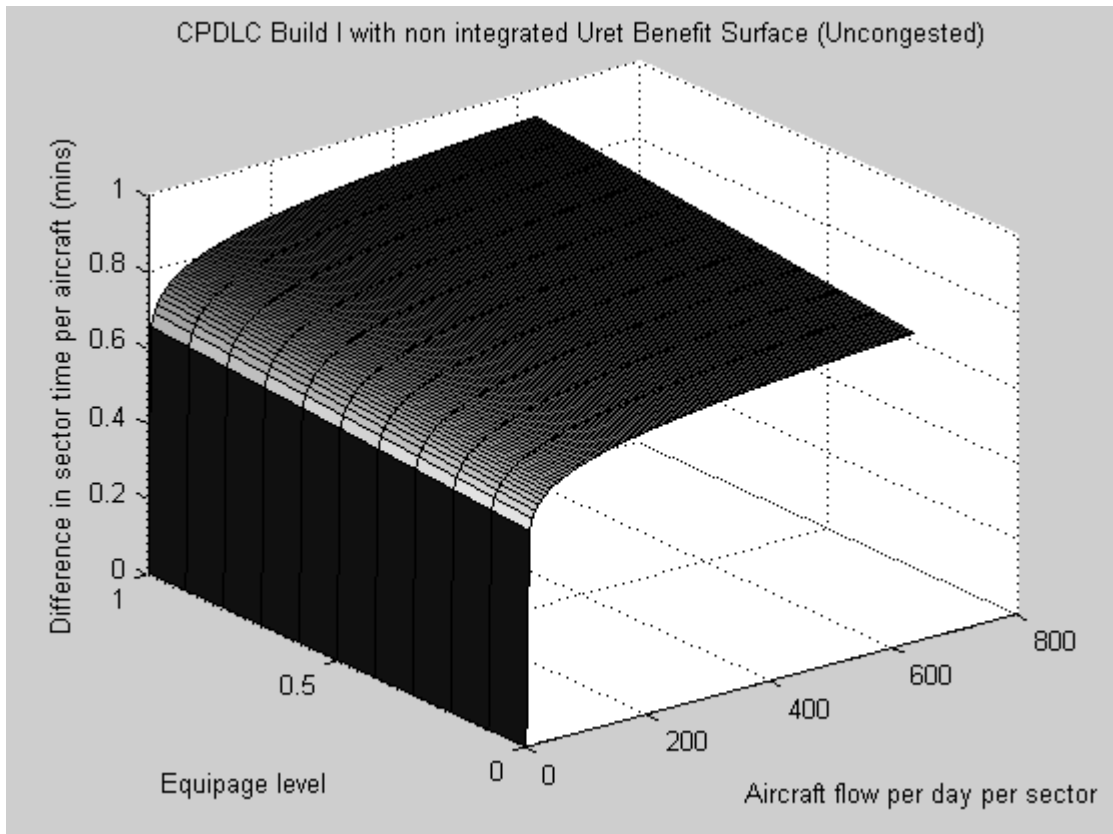


Figure 6.11 Regression Surface for CPDLC Build I with non integrated URET (Uncongested Case)

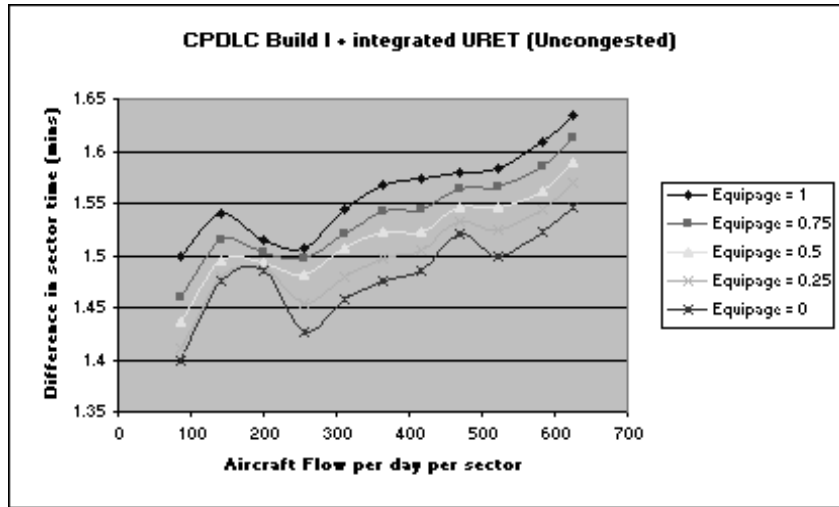


Figure 6.12 Sector time difference per aircraft for CPDLC Build I and integrated URET (Uncongested)

A power fit of the form shown in the equation 6.1 is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build I with integrated URET and ADS since the R-square varies in the range 0.90 to 0.95 for varying equipage levels and it has zero intercept and also intuitively it seems to be a very good fit.

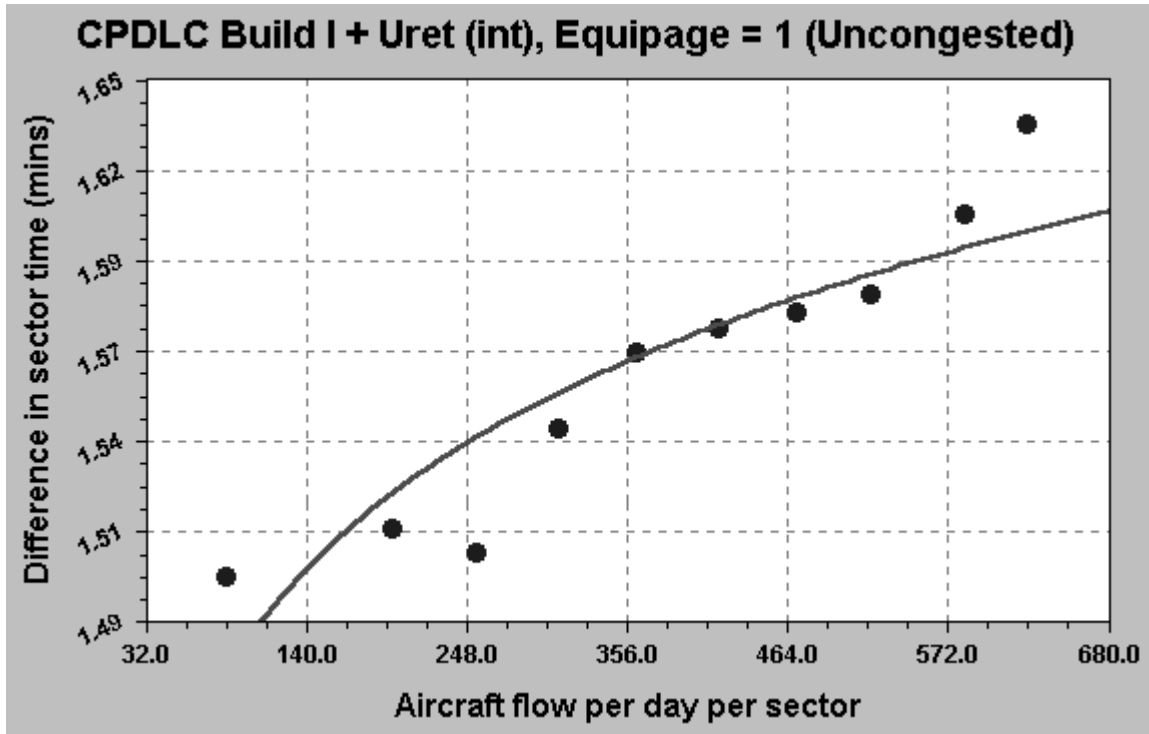


Figure 6.13 Power fit between delta and aircraft density for CPDLC Build I with integrated URET at 100 percent Equipage (Uncongested)

Figure 6.13 shows a sample power fit relationship between delta for CPDLC Build I with integrated URET and aircraft flow per day per sector for 100 percent equipage level. The R-square for the fit is 0.87.

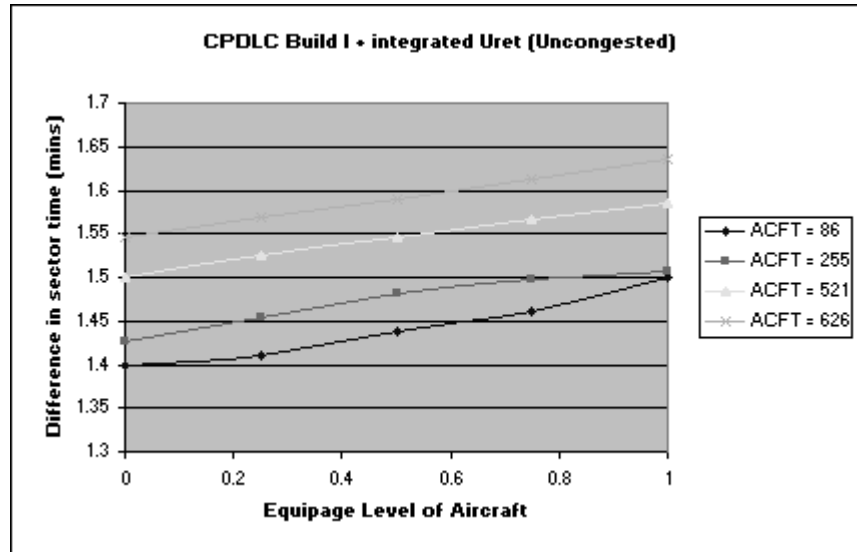


Figure 6.14 Sector time difference per aircraft for CPDLC Build I with integrated URET v/s Equipage Level (Uncongested)

A linear fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build I with integrated URET and equipage level since the R-square varies in the range 0.98 to 0.99 for varying ADS.

$$y = ax + b \tag{6.6}$$

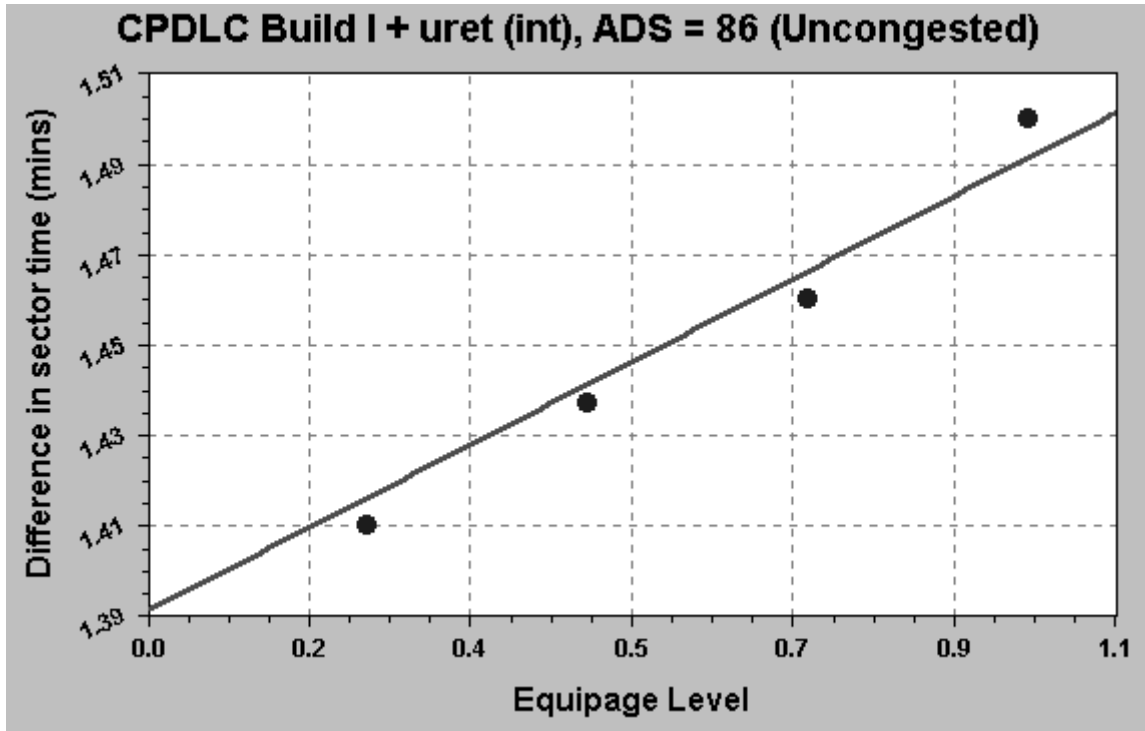


Figure 6.15 Linear fit between delta and equipage level for CPDLC Build I with integrated URET at ADS = 86 (Uncongested)

Figure 6.15 shows a sample linear fit relationship between delta for CPDLC Build I with integrated URET and equipage level for aircraft flow per day per sector for of 86. The R-square for the fit is 0.98.

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build I with integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = (ax_1 + b)x_2^c \quad (6.7)$$

Figure 6.17 shows the regression benefit surface for CPDLC Build I with integrated URET (uncongested region).

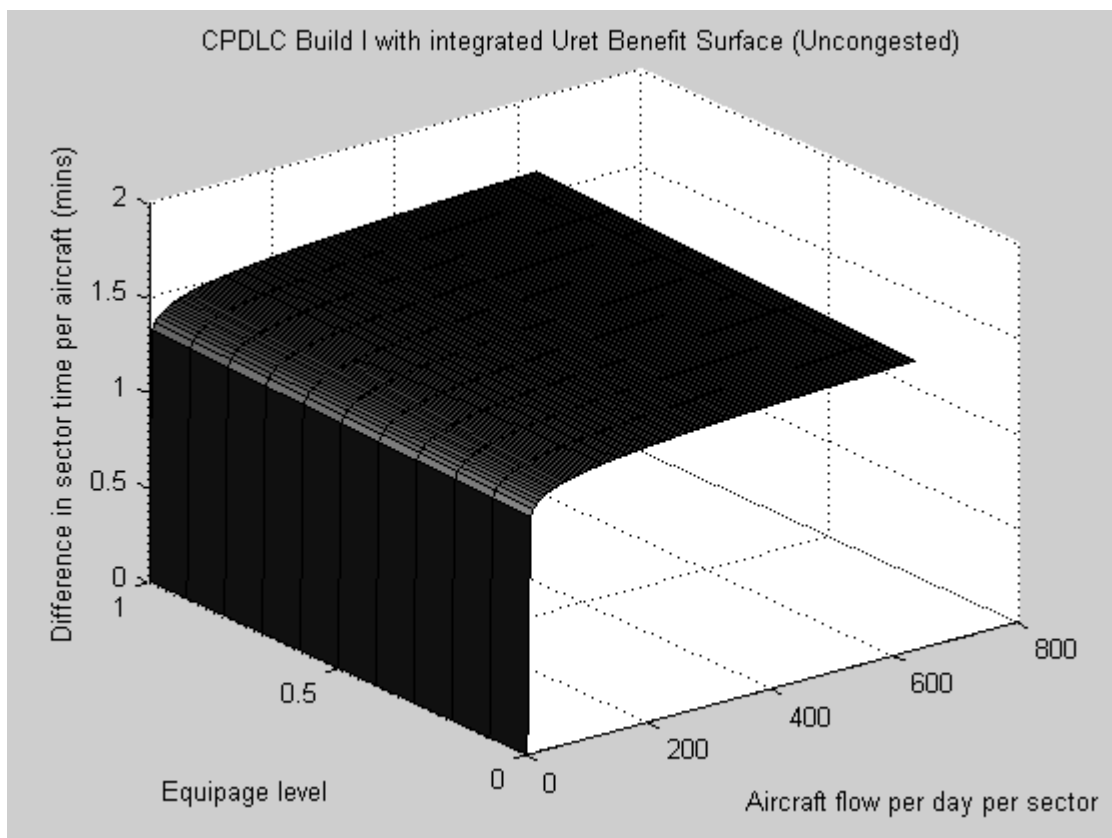


Figure 6.16 Regression surface for CPDLC Build I with integrated URET (Uncongested Case)

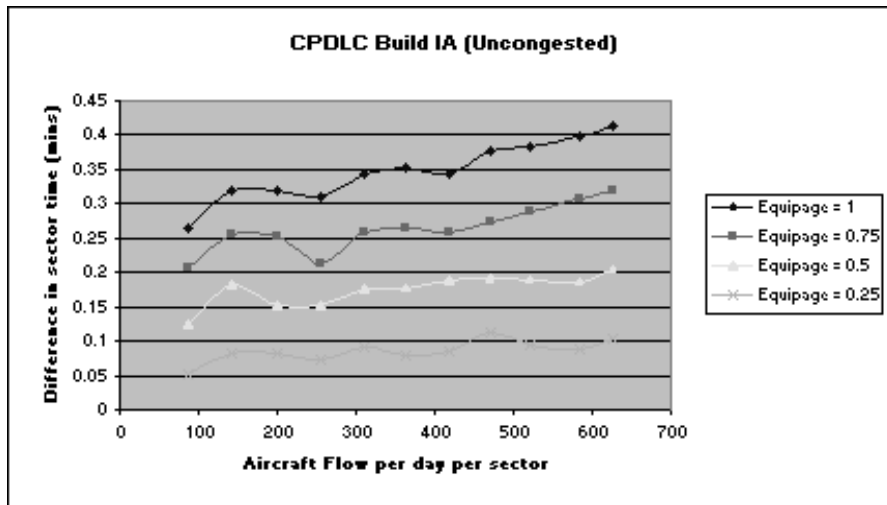


Figure 6.17 Sector time difference per aircraft for CPDLC Build IA (Uncongested)

Figure 6.18 shows a power fit relationship between delta per aircraft for CPDLC Build IA and aircraft flow per day per sector for equipage level of 1. The R-square for the fit is 0.87.

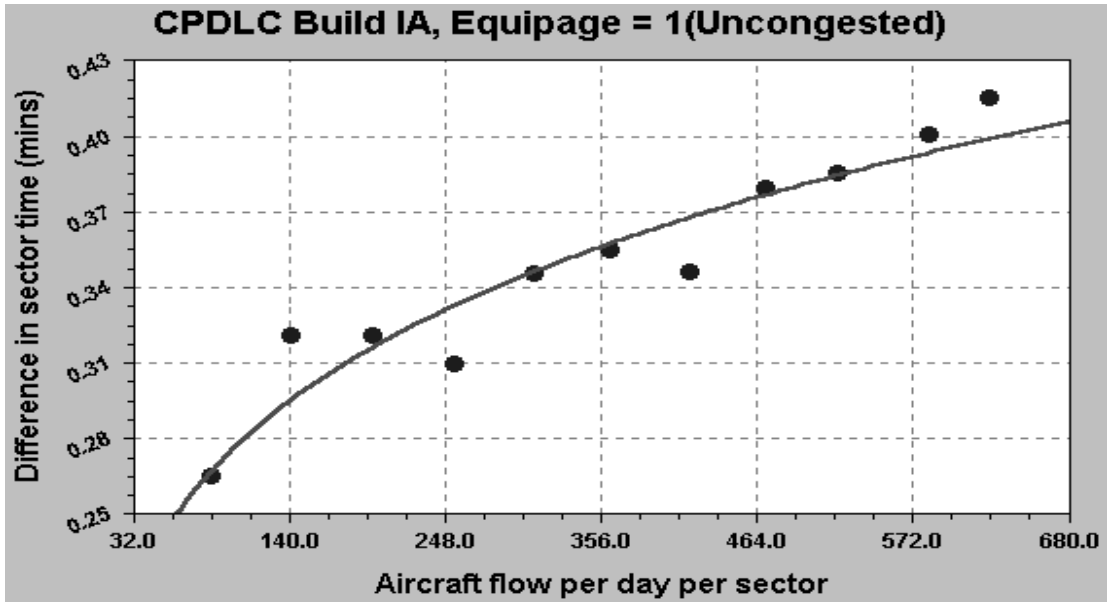


Figure 6.18 Power fit between delta and aircraft density for CPDLC Build IA at 100 percent Equipage (Uncongested)

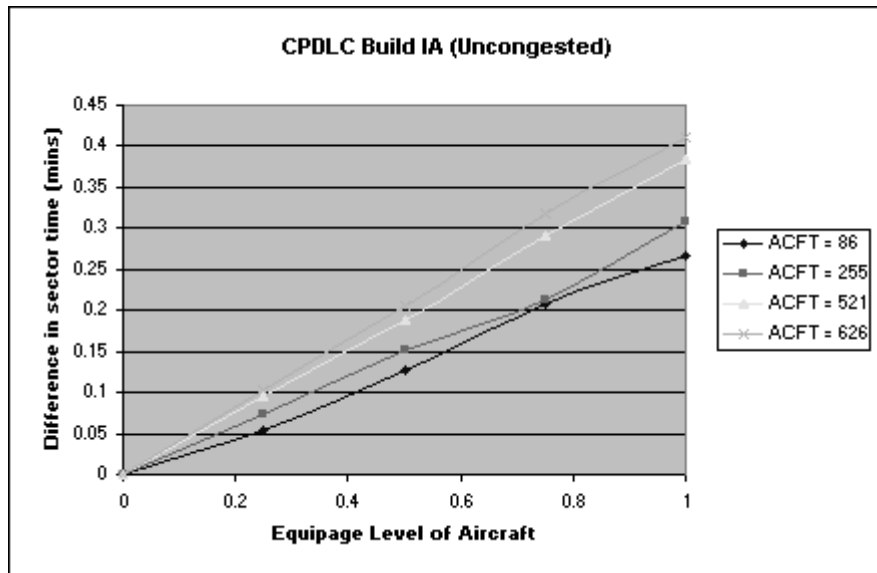


Figure 6.19 Sector time difference per aircraft for CPDLC Build IA v/s Equipage Level (Uncongested)

Figure 6.20 shows a linear fit relationship between delta for CPDLC Build I with integrated URET and equipage level for aircraft flow per day per sector for of 86. The R-square for the fit is 0.99.

$$y = ax \tag{6.8}$$

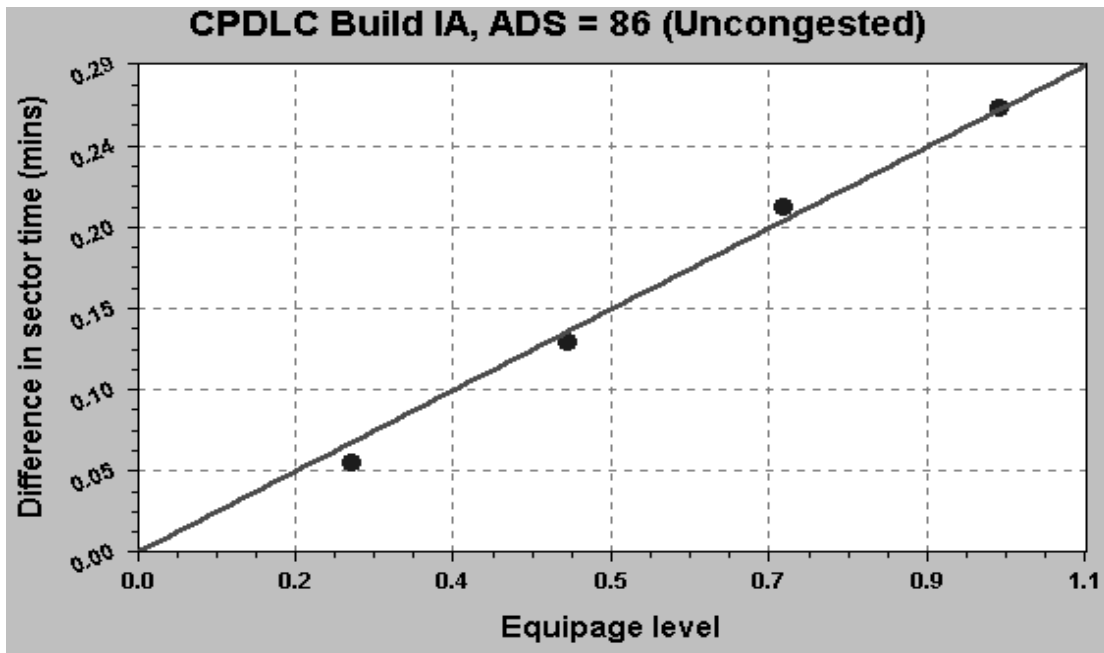


Figure 6.20 Linear fit between delta and equipage level for CPDLC Build IA at ADS = 86 (Uncongested)

After determining the relationship of equipage level (EI_a) and ADS with sector time difference per aircraft for CPDLC Build IA, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = ax_1x_2^b \tag{6.9}$$

Figure 6.21 shows the regression benefit surface for CPDLC Build IA (uncongested region).

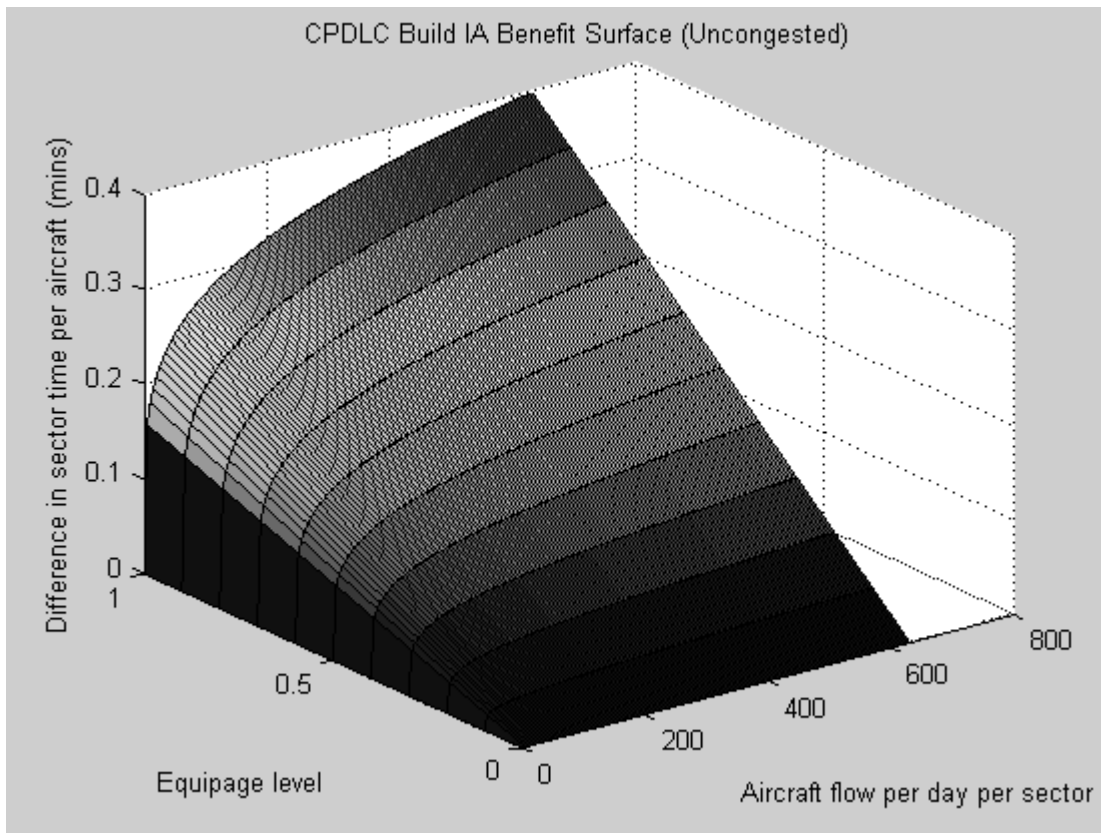


Figure 6.21 Regression Surface for CPDLC Build IA (Uncongested)

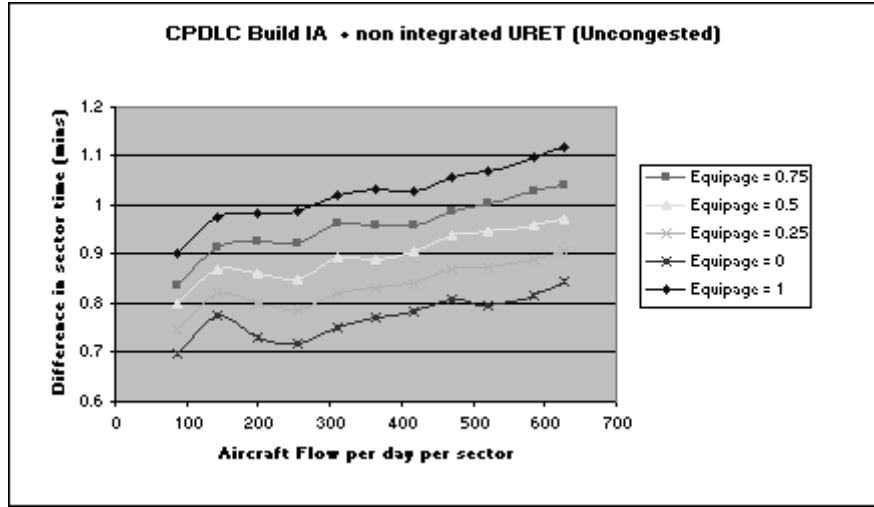


Figure 6.22 Sector time difference per aircraft for CPDLC Build IA and non integrated URET (Uncongested)

A power fit of the form shown in the equation 6.1 is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build IA with non integrated URET and ADS.

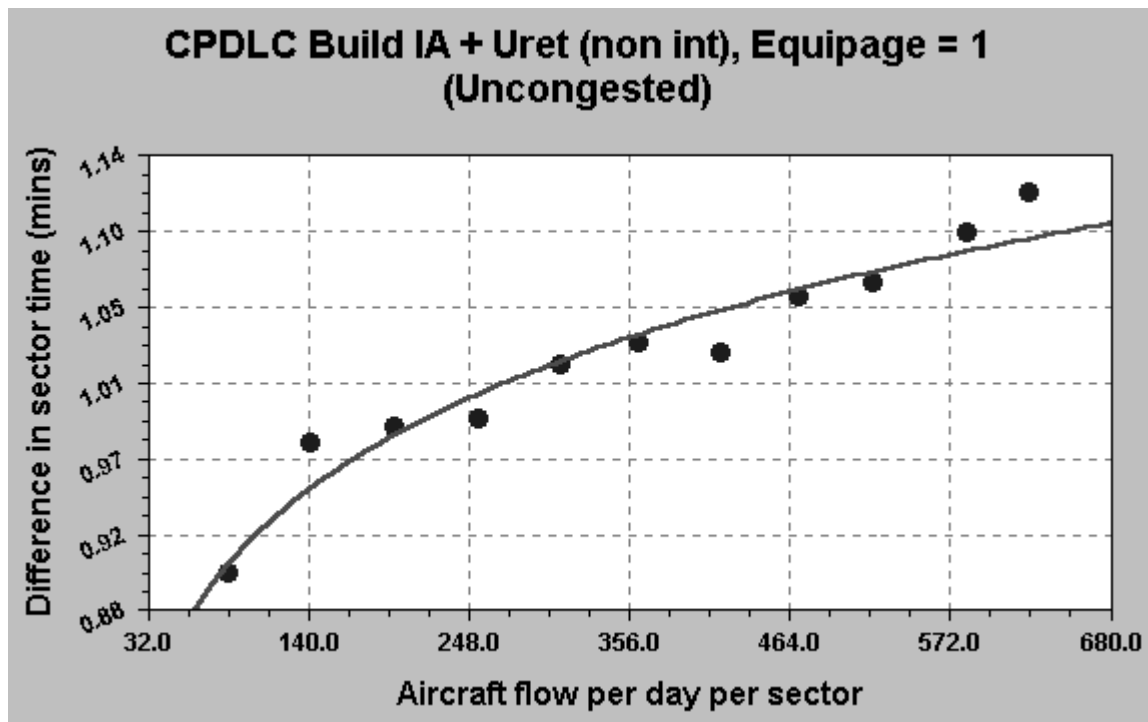


Figure 6.23 Power fit between delta and aircraft density for CPDLC Build IA with non integrated URET at 100 percent Equipage (Uncongested)

Figure 6.23 shows a sample power fit relationship between delta for CPDLC Build IA with non integrated URET and aircraft flow per day per sector for equipage level of 1. The R-square for the fit is 0.94.

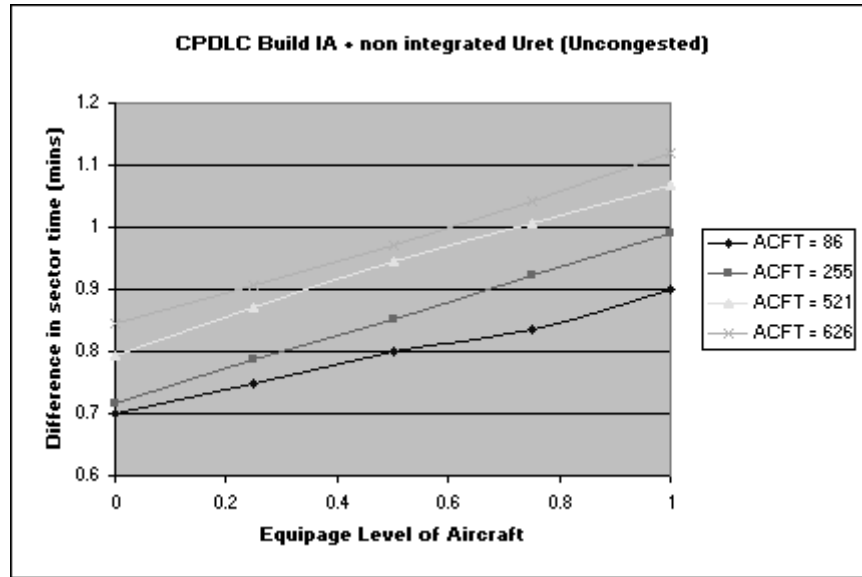


Figure 6.24 Sector time difference per aircraft for CPDLC Build IA with non integrated URET v/s Equipage Level (Uncongested)

A linear fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build IA with non integrated URET and equipage level.

$$y = ax + b \tag{6.10}$$

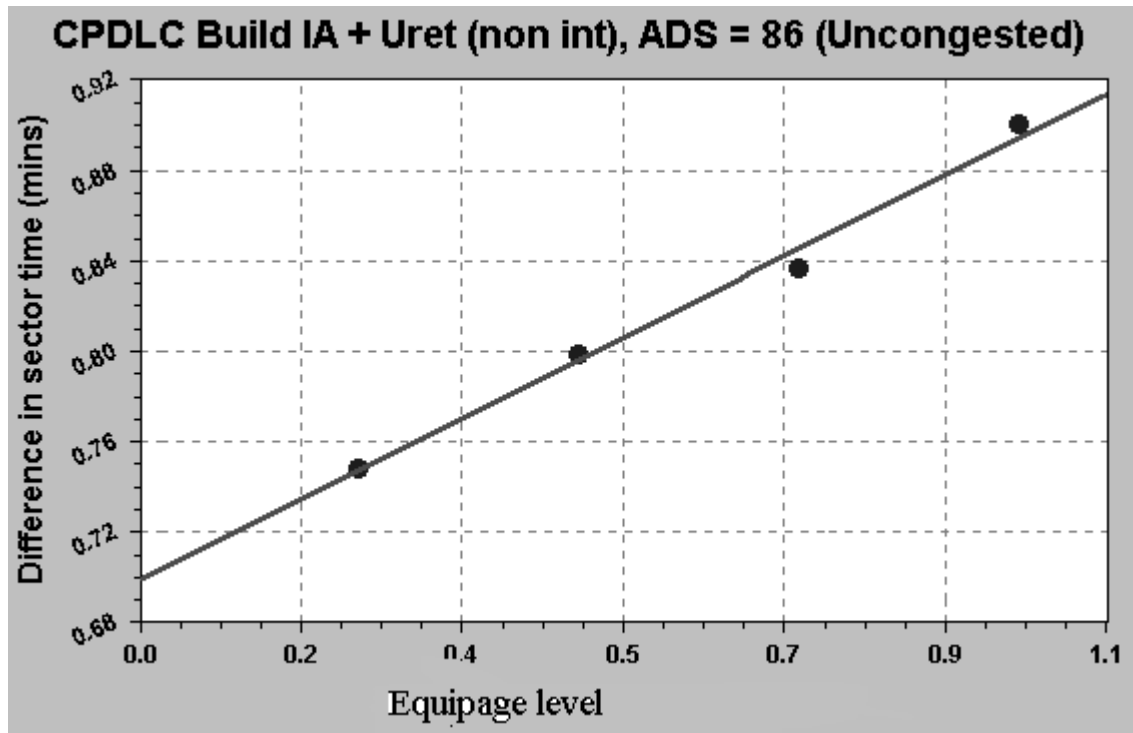


Figure 6.25 Linear fit between delta and equipage level for CPDLC Build IA with non integrated URET at ADS = 86 (Uncongested)

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build IA with non integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = (ax_1 + b)x_2^c \quad (6.11)$$

Figure 6.26 shows the regression benefit surface for CPDLC Build IA with non integrated URET (uncongested region).

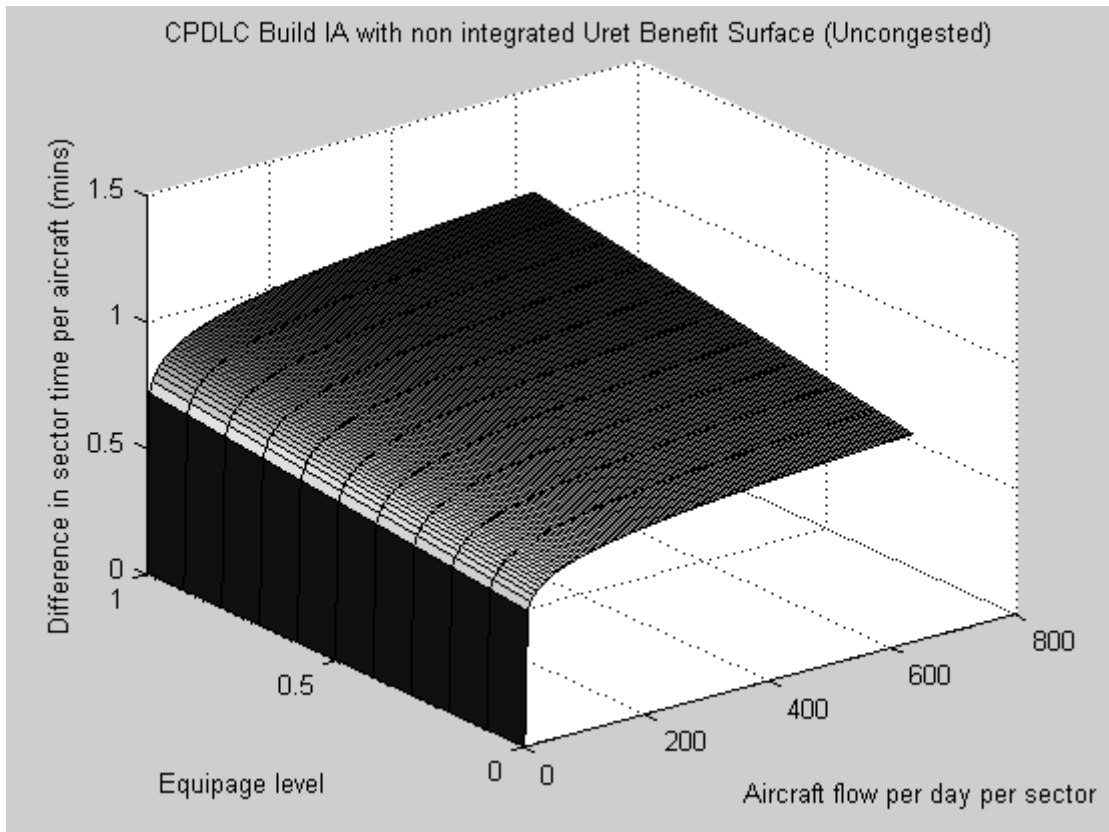


Figure 6.26 Regression Surface for CPDLC Build IA with non integrated URET (Uncongested Case)

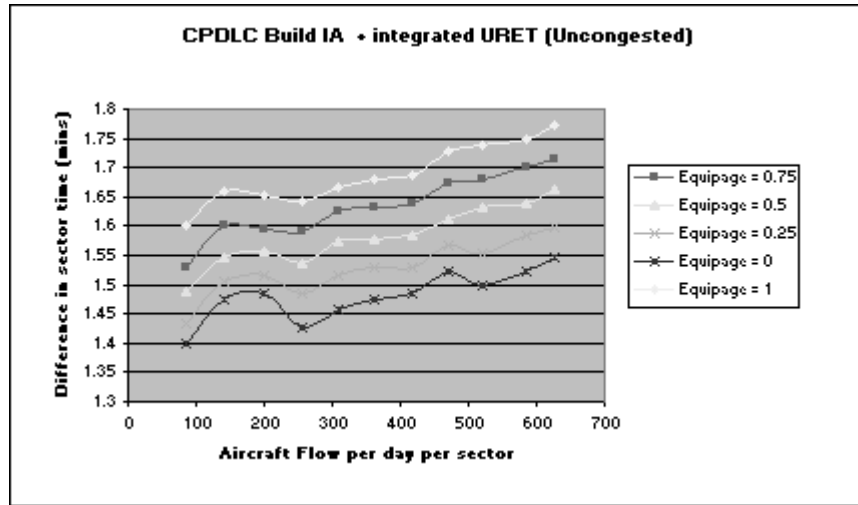


Figure 6.27 Sector time difference per aircraft for CPDLC Build IA and integrated URET (Uncongested)

A power fit of the form shown in the equation 6.1 is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build IA with integrated URET and ADS.

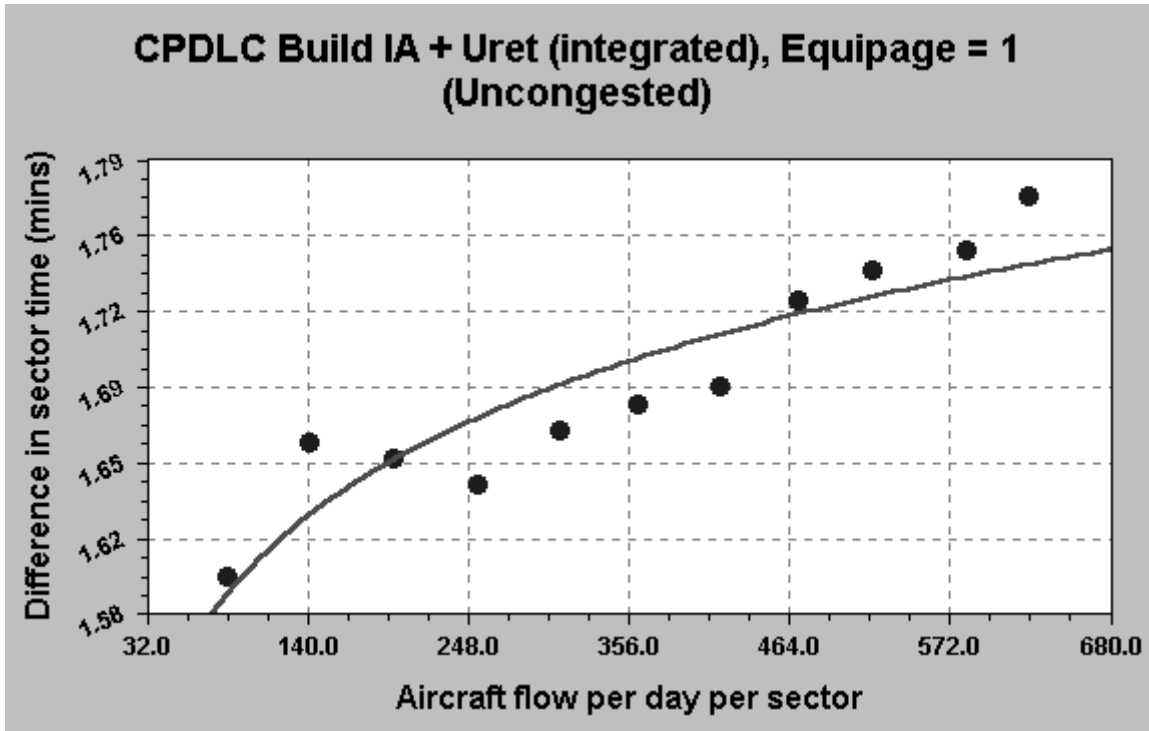


Figure 6.28 Power fit between delta and aircraft density for CPDLC Build IA with integrated URET at 100 percent Equipage (Uncongested)

Figure 6.28 shows a sample power fit relationship between delta for CPDLC Build IA with integrated URET and aircraft flow per day per sector for equipage level of 1. The R-square for the fit is 0.91.

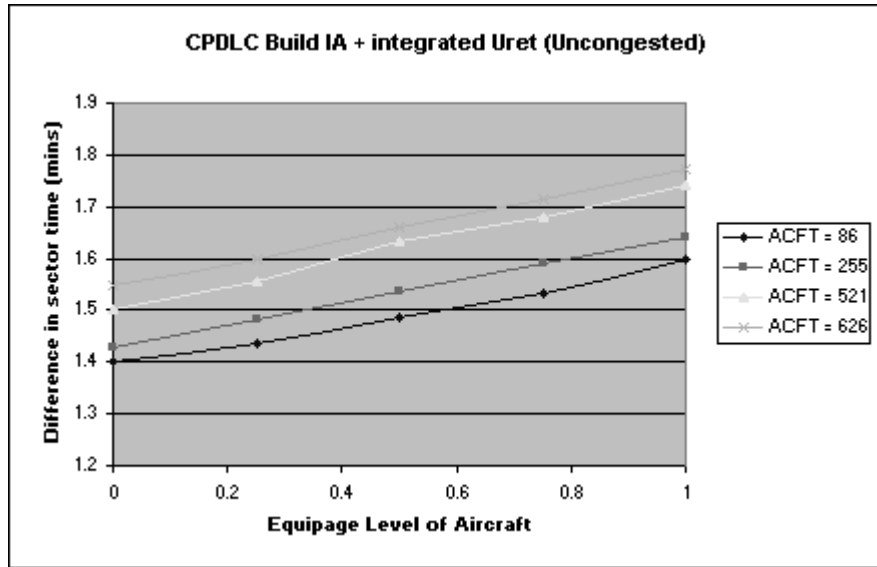


Figure 6.29 Sector time difference per aircraft for CPDLC Build IA with integrated URET v/s Equipage Level (Uncongested)

A linear fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build IA with integrated URET and equipage level.

$$y = ax + b \tag{6.12}$$

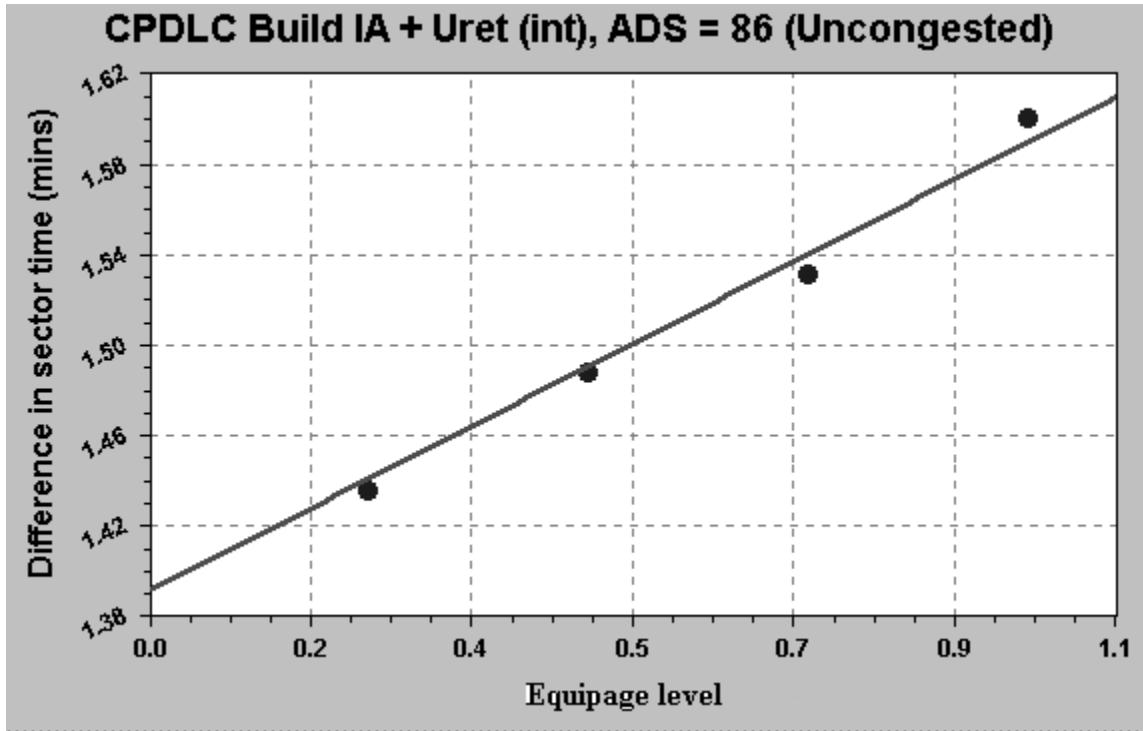


Figure 6.30 Linear fit between delta and equipage level for CPDLC Build IA with integrated URET at ADS = 86 (Uncongested)

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build IA with integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = (ax_1 + b)x_2^c \quad (6.13)$$

Figure 6.31 shows the regression benefit surface for CPDLC Build IA with integrated URET (uncongested region).

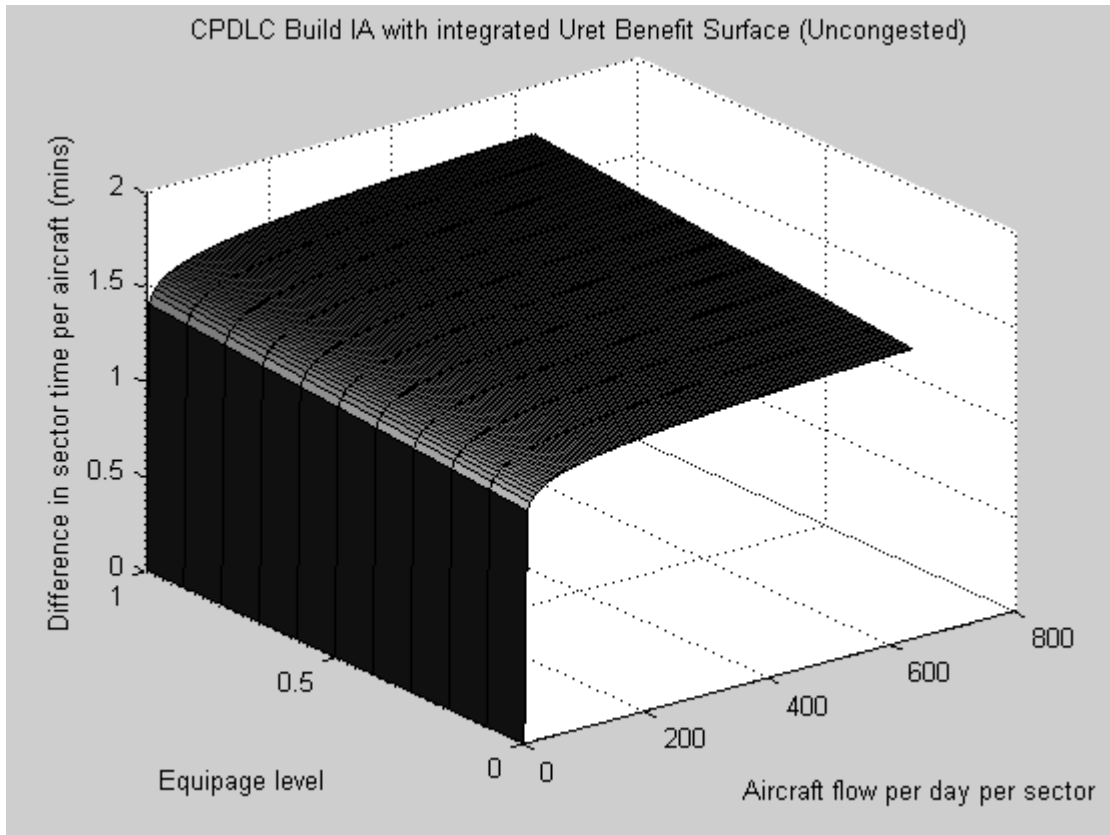


Figure 6.31 Regression Surface for CPDLC Build IA with integrated URET (Uncongested Case)

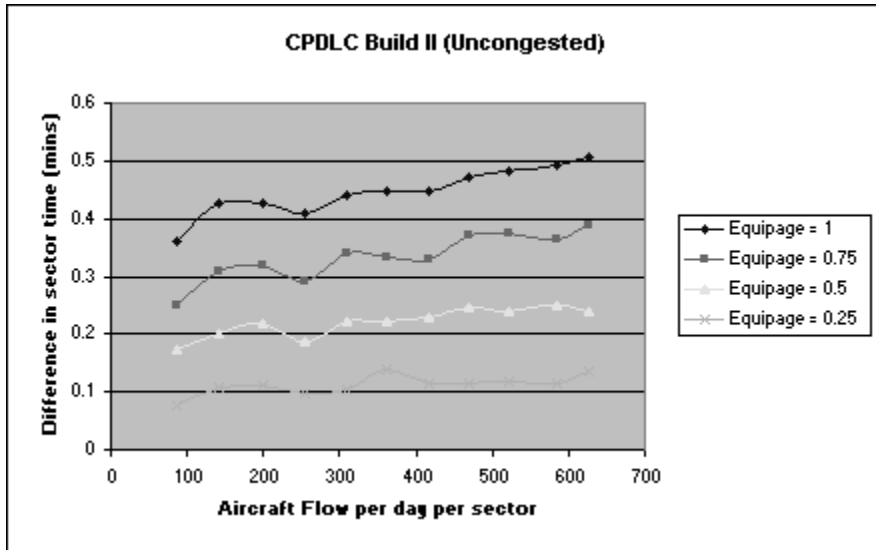


Figure 6.32 Sector time difference per aircraft for CPDLC Build II (Uncongested)

A power fit of the form shown in the equation 6.1 is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build II and ADS.

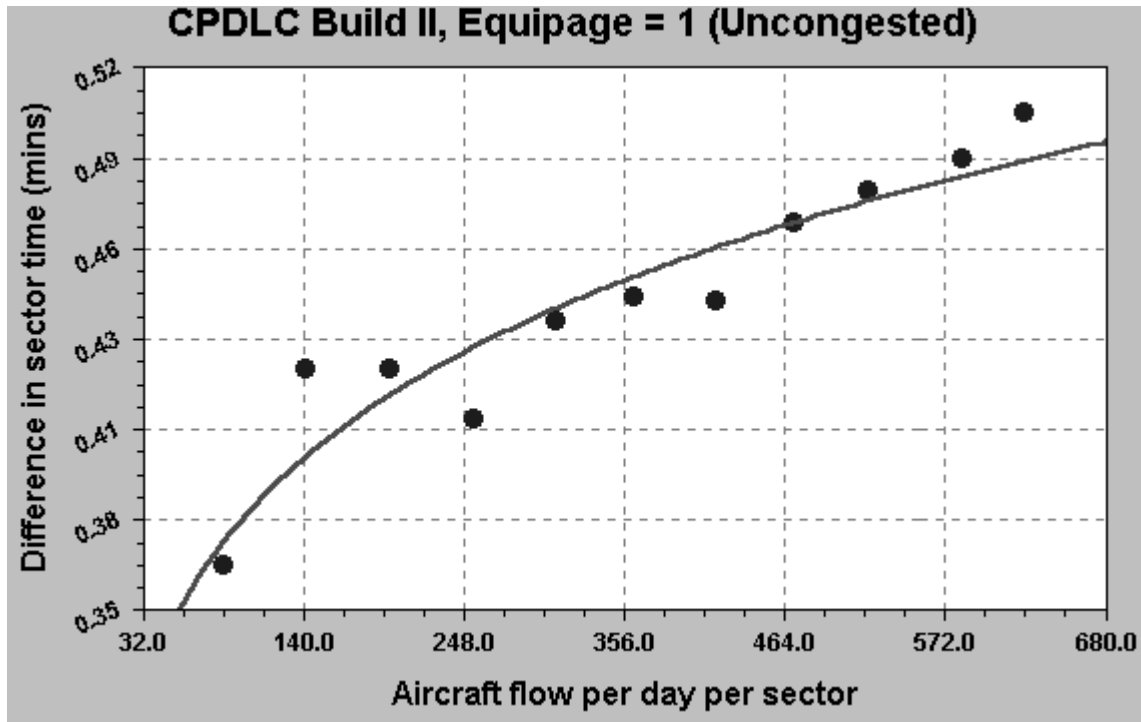


Figure 6.33 Power fit between delta and aircraft density for CPDLC Build II at 100 percent Equipage (Uncongested)

Figure 6.33 shows a sample power fit relationship between delta for CPDLC Build II and aircraft flow per day per sector for equipage level of 1. The R-square for the fit is 0.94.

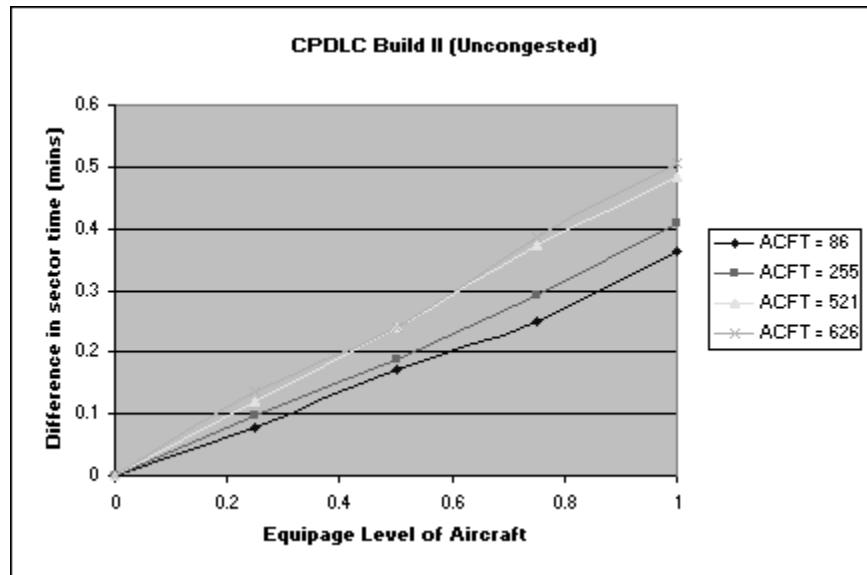


Figure 6.34 Sector time difference per aircraft for CPDLC Build II v/s Equipage level (Uncongested)

A linear fit of the form shown in the equation below is established to be a good fit between difference in sector time (delta) per aircraft for CPDLC Build II and equipage level.

$$y = ax \tag{6.14}$$

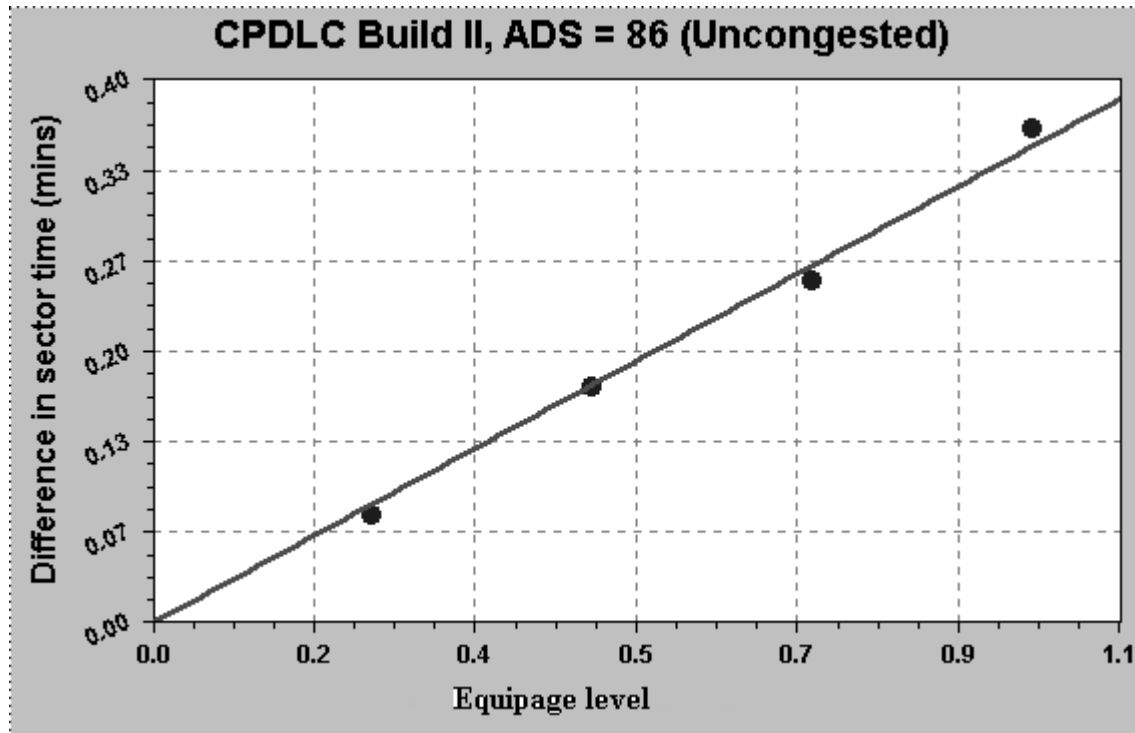


Figure 6.35 Linear fit between delta and equipage level for CPDLC Build II at ADS = 86 (Uncongested)

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build II, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = ax_1x_2^b \quad (6.15)$$

Figure 6.36 shows the regression benefit surface for CPDLC Build II (uncongested region).

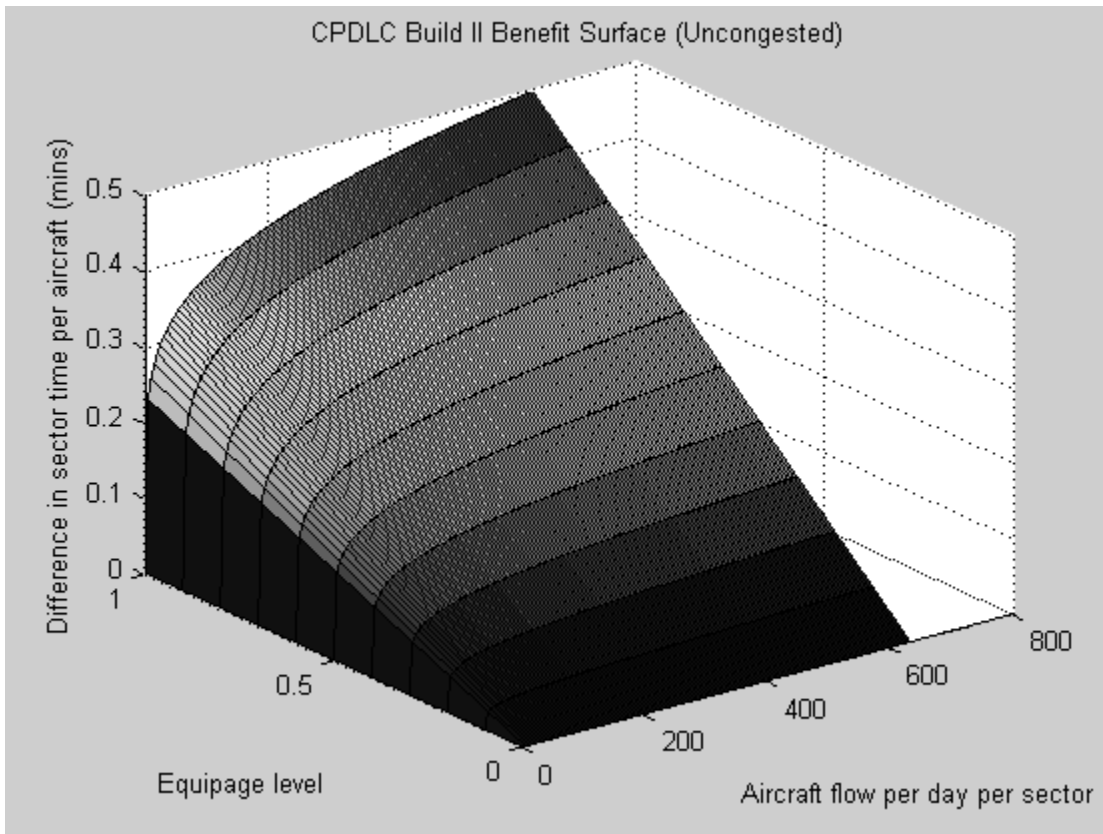


Figure 6.36 Regression Surface for CPDLC Build II (Uncongested Case)

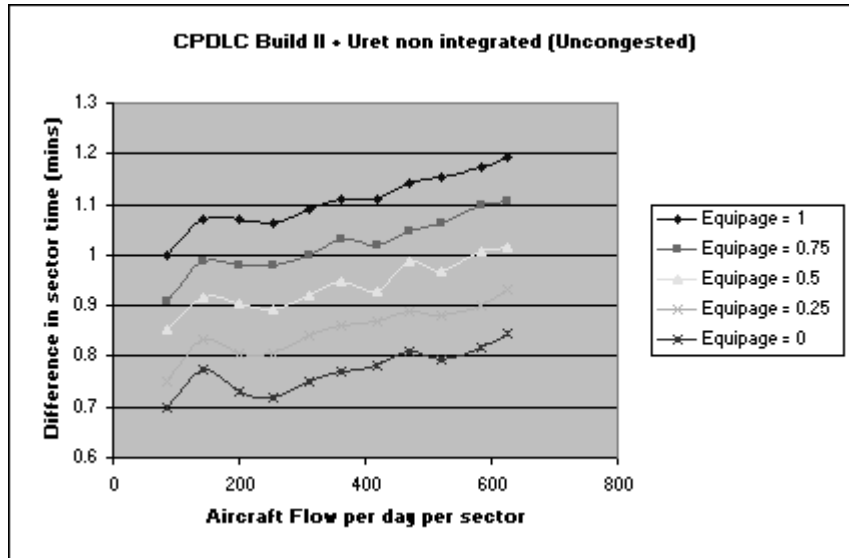


Figure 6.37 Sector time difference per aircraft for CPDLC Build II and non integrated URET (Uncongested)

A power fit of the form shown in the equation 6.1 is established to be a good fit between difference in sector time (delta) per aircraft for CPDLC Build II with non integrated URET and ADS.

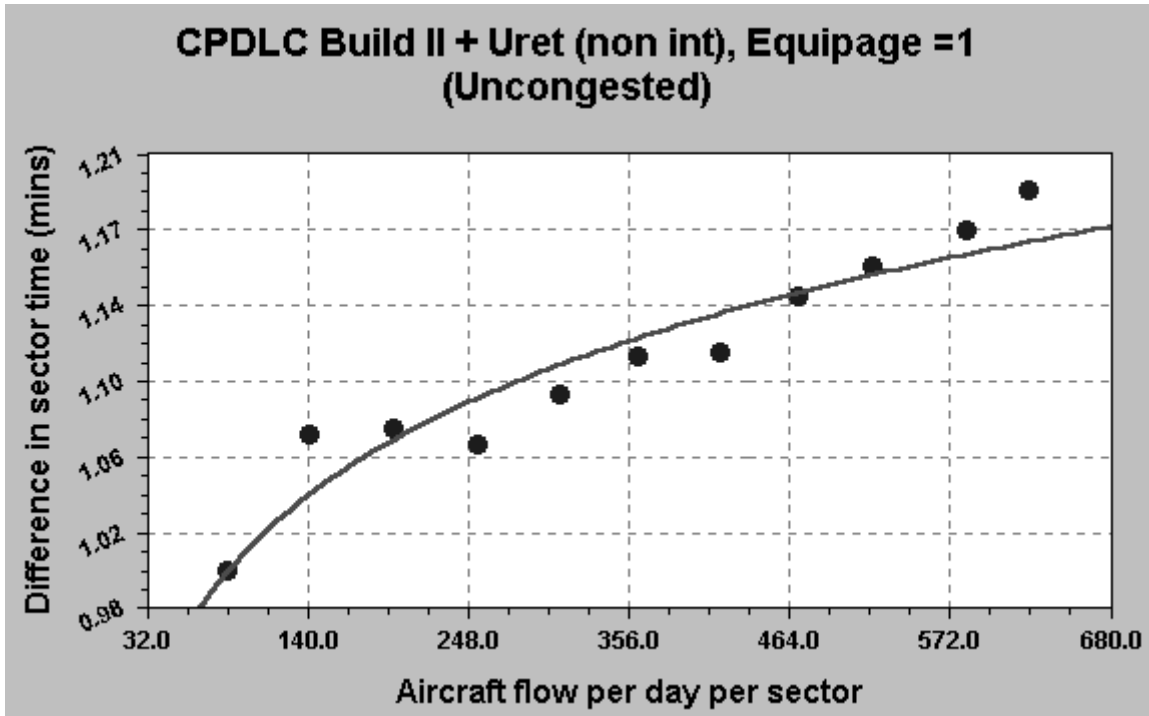


Figure 6.38 Power fit between delta and aircraft density for CPDLC Build II with non integrated URET at 100 percent Equipage (Uncongested)

Figure 6.38 shows a sample power fit relationship between delta for CPDLC Build II with non integrated URET and aircraft flow per day per sector for equipage level of 1. The R-square for the fit is 0.95.

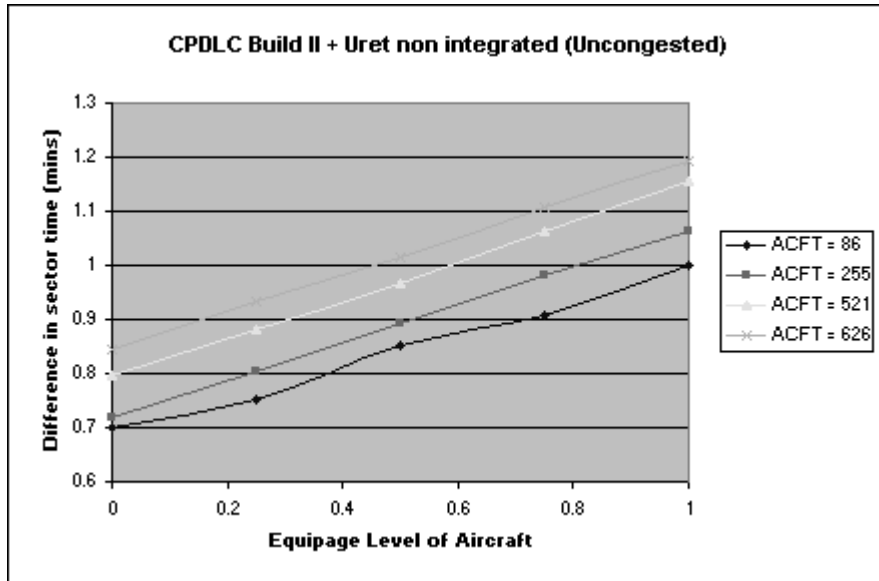


Figure 6.39 Sector time difference per aircraft for CPDLC Build II with non integrated URET v/s Equipage level (Uncongested)

A linear fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build II with non integrated URET and equipage level.

$$y = ax + b \tag{6.16}$$

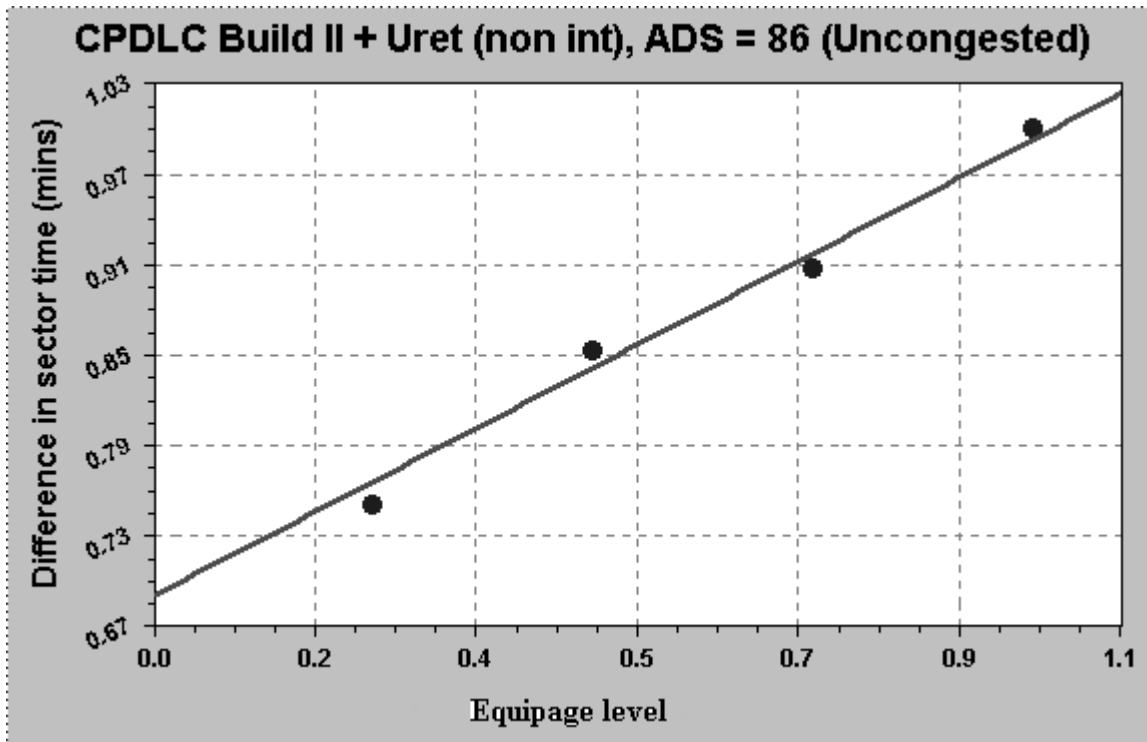


Figure 6.40 Linear fit between delta and equipage level for CPDLC Build II with non integrated URET at ADS = 86 (Uncongested)

After determining the relationship of equipage level (El_a) and ADS with sector traversal time difference per aircraft for CPDLC Build II with non integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = (ax_1 + b)x_2^c \quad (6.17)$$

Figure 6.41 shows the regression benefit surface for CPDLC Build II with non integrated URET (uncongested region).

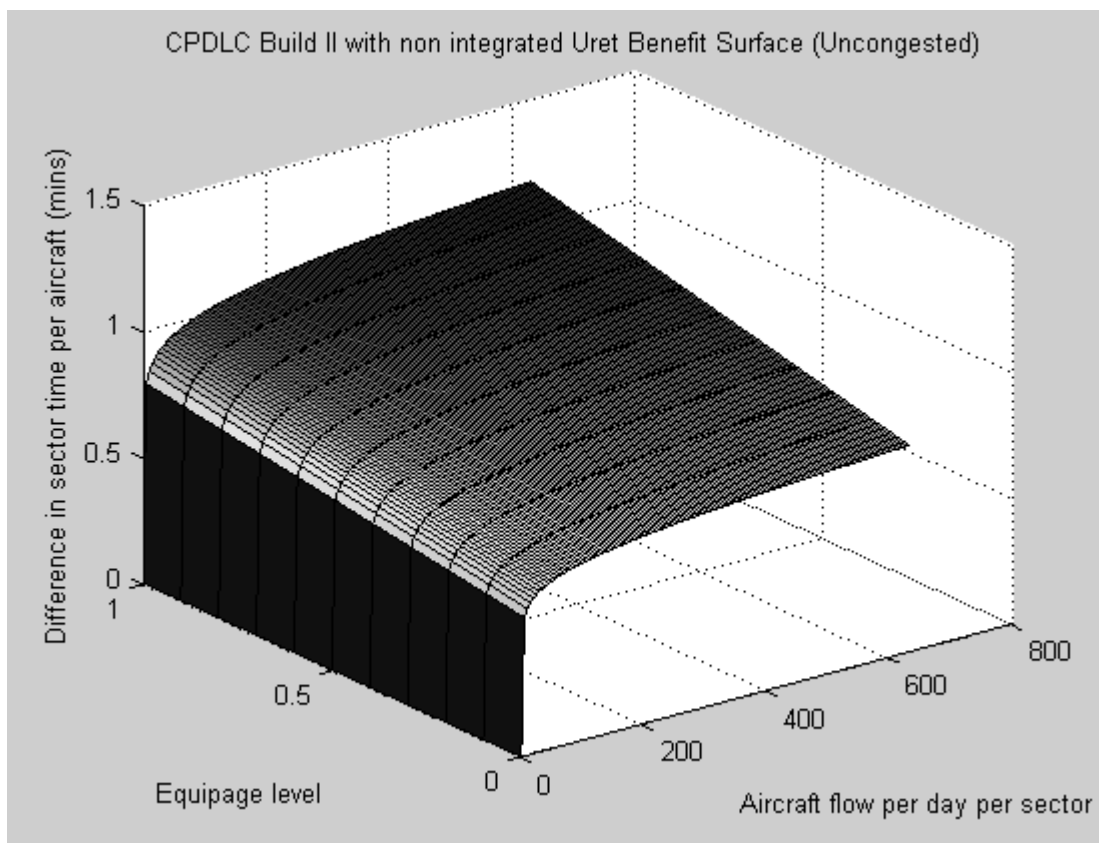


Figure 6.41 Regression surface for CPDLC Build II with non integrated URET (Uncongested case)

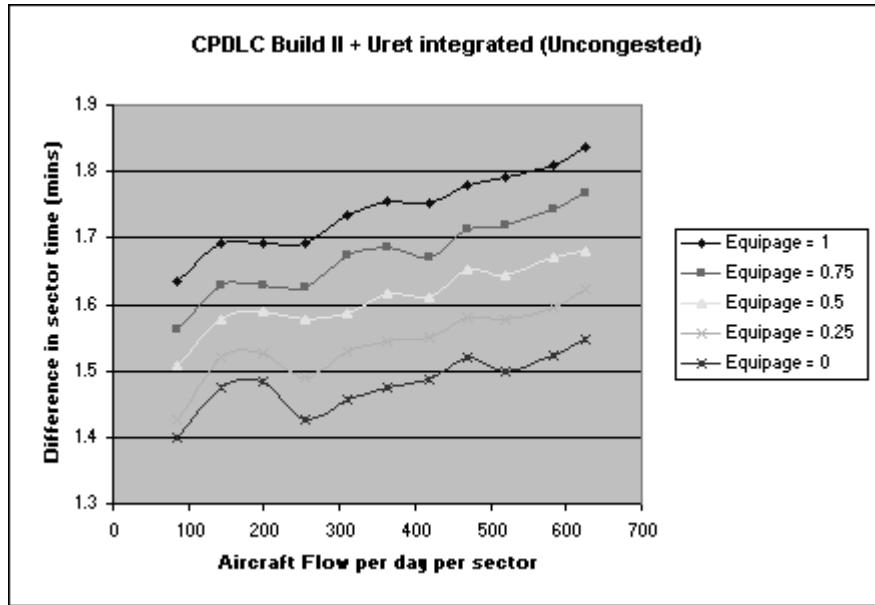


Figure 6.42 Sector time difference per aircraft for CPDLC Build II and integrated URET (Uncongested)

A power fit of the form shown in the equation 6.1 is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build II with integrated URET and ADS.

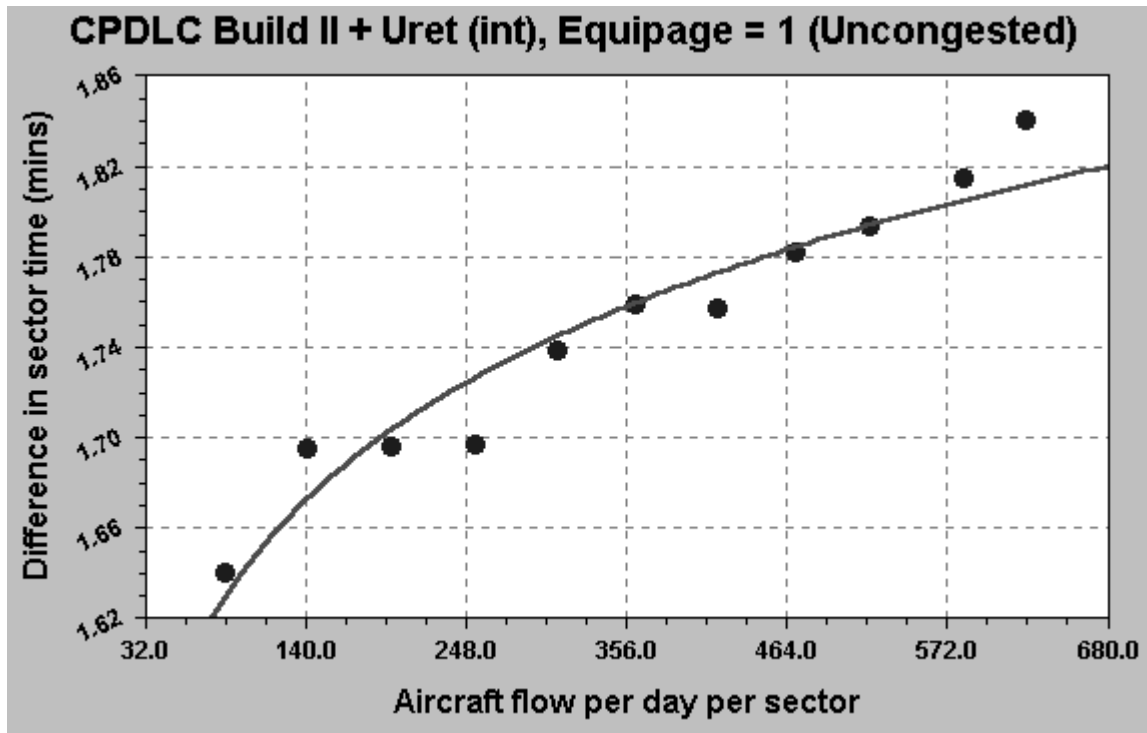


Figure 6.43 Power fit between delta and aircraft density for CPDLC Build II with integrated URET at 100 percent Equipage (Uncongested)

Figure 6.43 shows a sample power fit relationship between delta for CPDLC Build II with integrated URET and aircraft flow per day per sector for equipage level of 1. The R-square for the fit is 0.96.

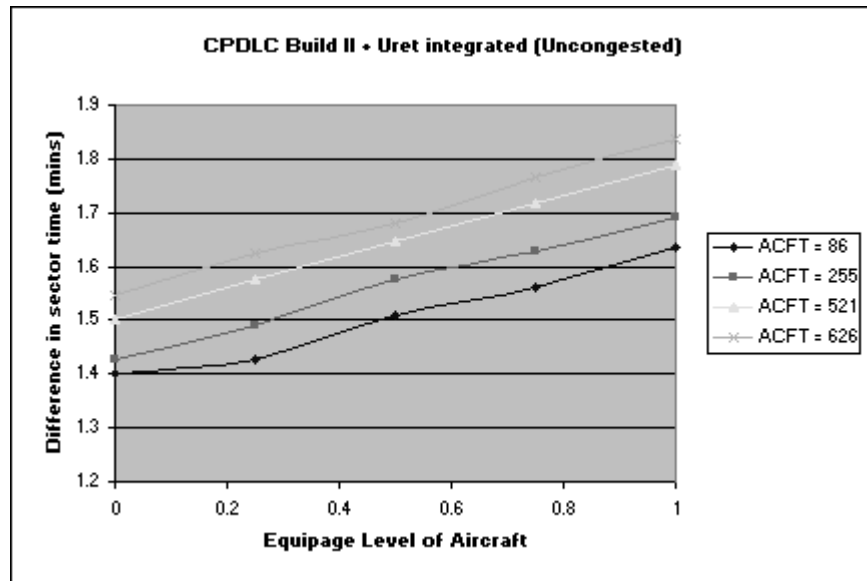


Figure 6.44 Sector time difference per aircraft for CPDLC Build II with integrated URET v/s Equipage level (Uncongested)

A linear fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build II with integrated URET and equipage level.

$$y = ax + b \tag{6.18}$$

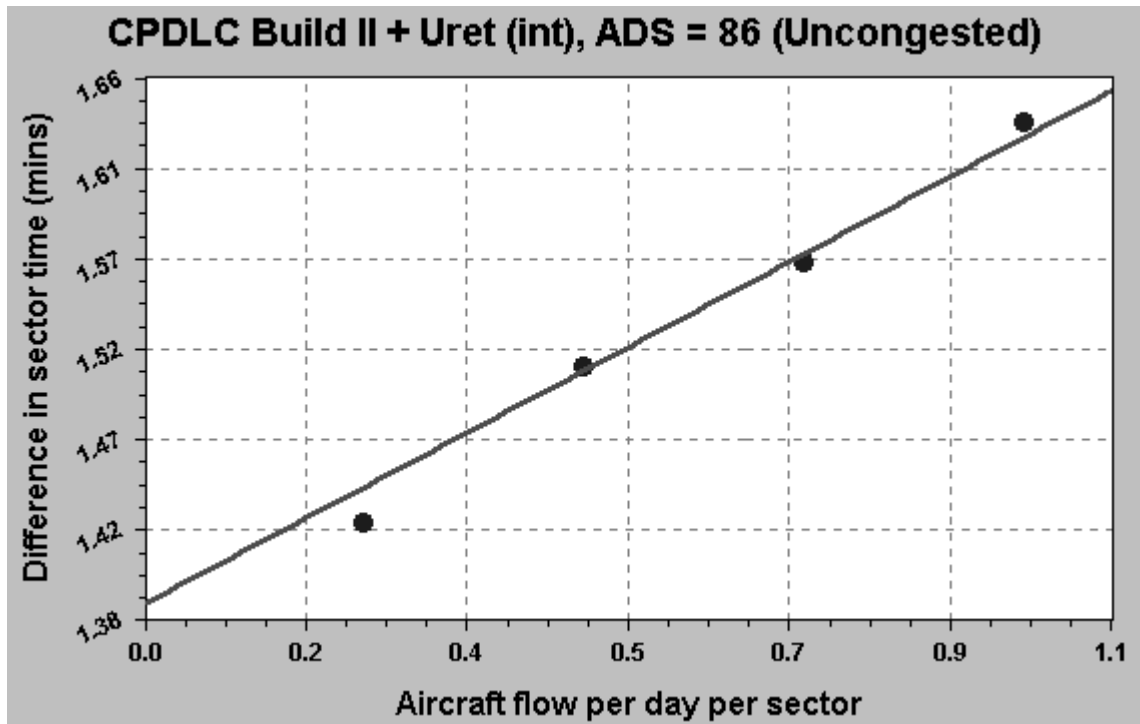


Figure 6.45 Linear fit between delta and equipage level for CPDLC Build II with integrated URET at ADS = 86 (Uncongested)

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build II with integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = (ax_1 + b)x_2^c \quad (6.19)$$

Figure 6.46 shows the regression benefit surface for CPDLC Build II with integrated URET (uncongested region).

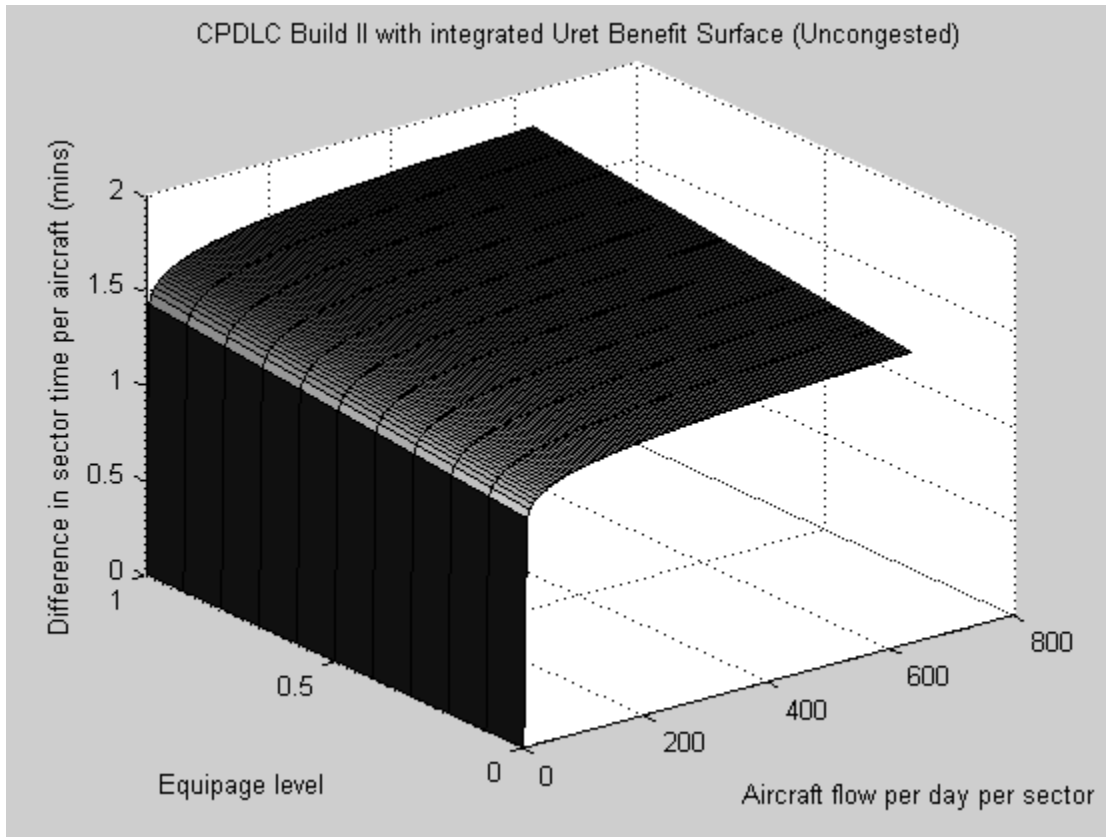


Figure 6.46 Regression Surface for CPDLC Build II with integrated URET (Uncongested)

		Value	Confidence Interval		R-square
CPDLC Build I	a	0.53774	0.36273	0.71276	0.9724
	b	0.1487	0.093792	0.2036	
CPDLC Build I + uret non	a	0.0701	0.058678	0.081524	0.8702
	b	0.50323	0.46828	0.5382	
	c	0.074324	0.062523	0.086119	
CPDLC Build I + uret int	a	0.061578	0.049565	0.073591	0.8528
	b	1.1715	1.1308	1.2122	
	c	0.040681	0.034754	0.046607	
CPDLC Build IA	a	0.11471	0.095137	0.13429	0.9906
	b	0.19265	0.16367	0.22163	
CPDLC Build IA + uret non	a	0.15063	0.13841	0.16284	0.9677
	b	0.46149	0.43448	0.48849	
	c	0.089403	0.07951	0.099295	
CPDLC Build IA + uret int	a	0.16029	0.14702	0.17357	0.948
	b	1.1366	1.0967	1.1765	
	c	0.045839	0.039857	0.051822	
CPDLC Build II	a	0.17577	0.15399	0.19755	0.9948
	b	0.16107	0.13997	0.18218	
CPDLC Build II + uret non	a	0.20816	0.19227	0.22405	0.9753
	b	0.47889	0.44958	0.50819	
	c	0.082703	0.072371	0.093035	
CPDLC Build II + uret int	a	0.19738	0.18385	0.2109	0.9647
	b	1.1123	1.0739	1.1507	
	c	0.049578	0.043711	0.055445	

TABLE 6.1 Regression coefficients and confidence intervals (Uncongested)

After running the microscopic model with varying traffic density per day and equipage level of aircraft, 3-D surfaces were generated using non linear regression fits in MATLAB which quantified enroute time savings per sector as a function of equipage level and traffic flow per sector per day. Different surfaces were generated for each CPDLC Build with and without URET and PFAST in a integrated and non integrated scenario. The 3-D surfaces for each scenario were divided into two regions, one region uncongested traffic flow denoting all traffic flow upto saturation flow of an enroute sector and second region being the saturated region. The model was run for different air traffic flows per sector per day, equipage level of datalink equipped aircraft and CPDLC Build level and curves showing the relationship between difference in airspace occupancy times for alternatives B, C and D as compared to

base alternative A were generated and these curves were embedded into the annual macroscopic model.

Congested Flow

Congested flow region denotes all air traffic flow per day per sector greater than approximately 630. This is mainly because the controller workload denoted by controller activity level reaches a saturation state at approximately the above specified air traffic density. Table 2 shows the coefficients of the regression surface models for all scenarios.

Figure 6.47 shows the mean sector traverse times for alternative A for different air traffic densities in the congested flow region.

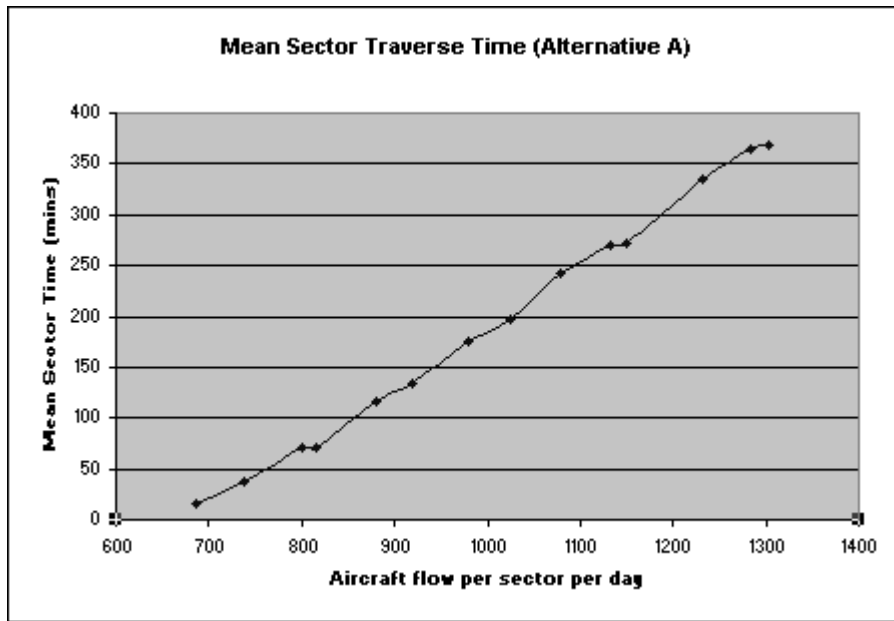


Figure 6.47 Mean Sector Traverse Times for Alternative A (Congested)

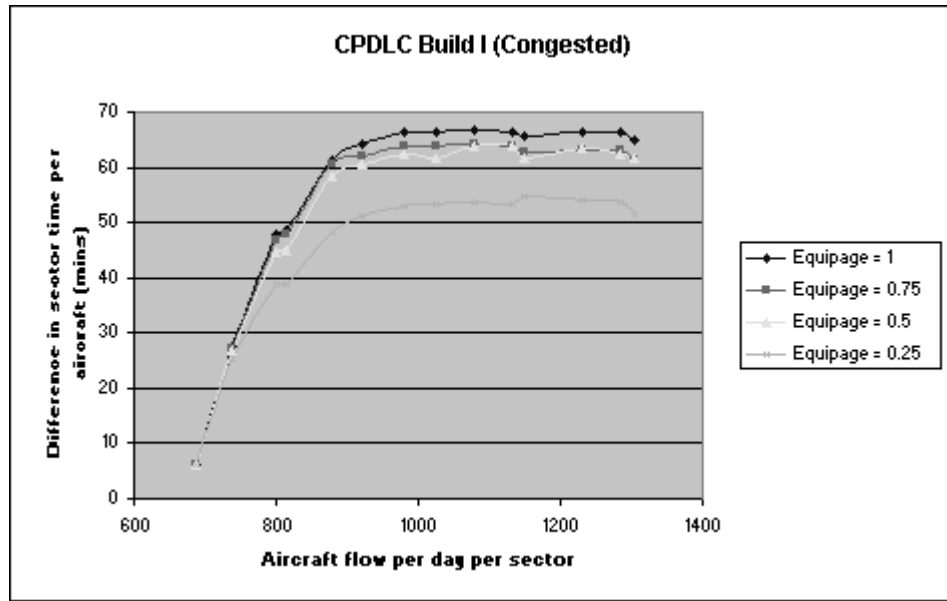


Figure 6.48 Sector time difference per aircraft for CPDLC Build I v/s ADS (Congested)

To get a general idea of the relationship between difference in sector time (delta) per aircraft for CPDLC Build I and aircraft density, curve fitting is done using a curve fitting software CurveExpert. An exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build I.

$$y = \frac{a}{(1 + ex^{(b-cx)})^d} \tag{6.20}$$

where y is the difference in sector traversal times per aircraft in minutes,

x is the aircraft flow per day per sector,

a, b, c, d are coefficients of the equation.

ex is the exponential form.

Figure 6.49 shows a sample exponential fit relationship between delta for CPDLC Build I and aircraft flow per day per sector for equipage level of 1. The R-square for the fit is 0.99.

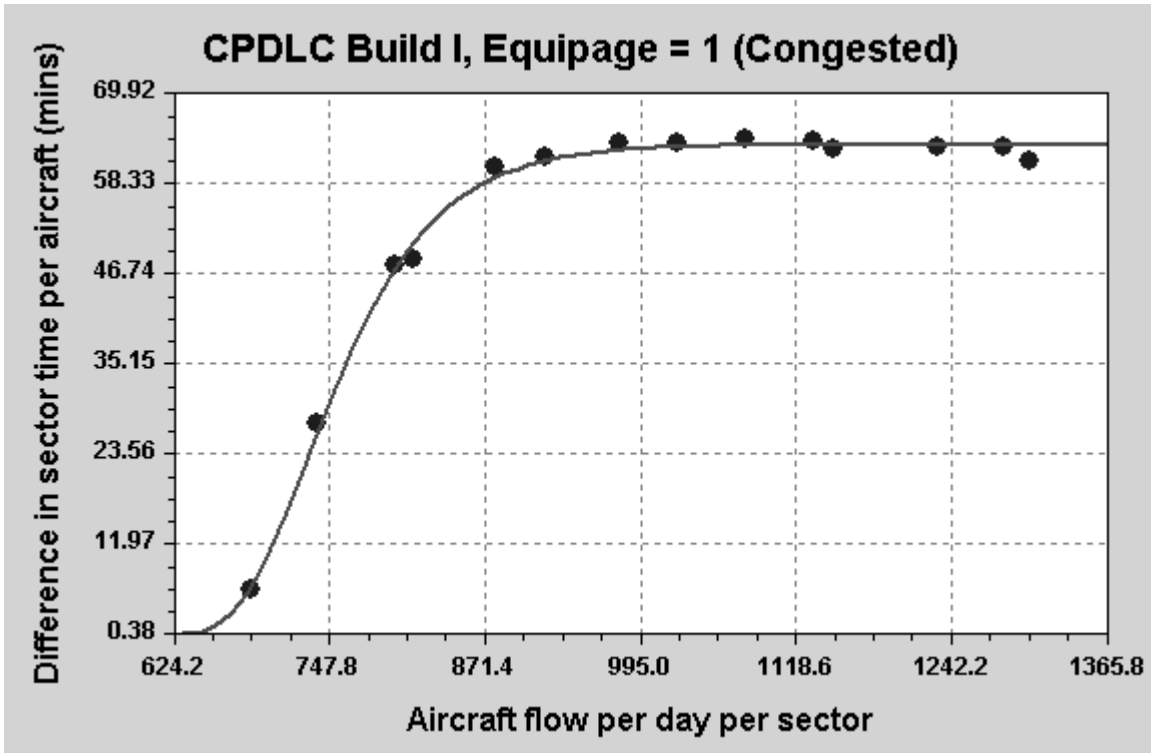


Figure 6.49 Non Linear fit between delta and aircraft density for CPDLC Build I at 100 percent equipage level (Congested)

Figure 6.50 shows the relationship between difference in sector traversal time for CPDLC Build I per aircraft and equipage level of aircraft for different aircraft flow per day per sector (ADS). ACFT denotes the aircraft flow per day per sector.

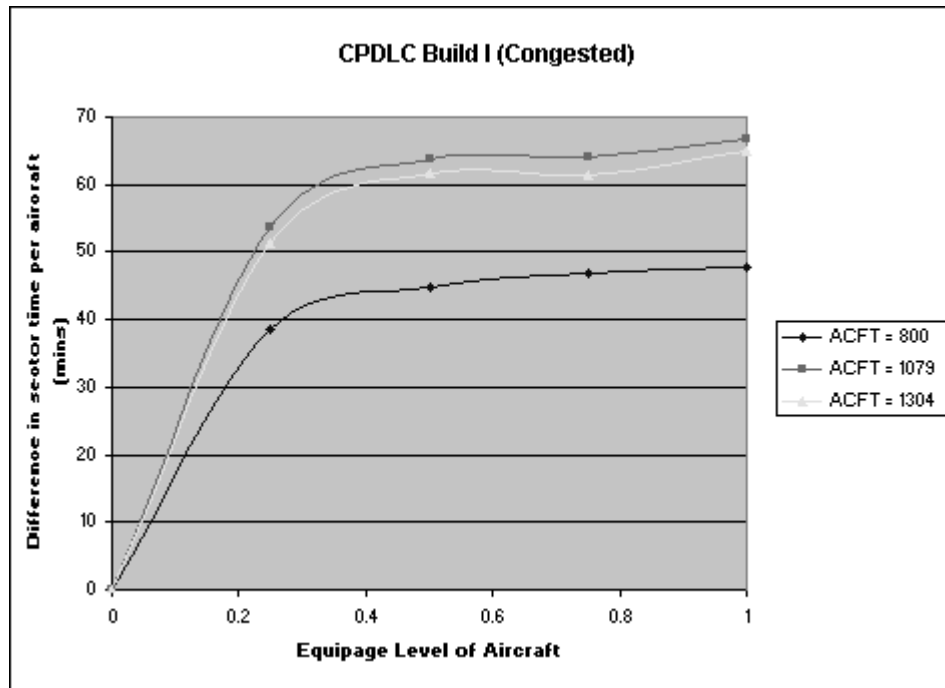


Figure 6.50 Sector time difference per aircraft for CPDLC Build I v/s Equipage Level (Congested)

A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build I and equipage level.

$$y = a(1 - e^{-bx}) \tag{6.21}$$

Figure 6.51 shows a sample exponential fit relationship between delta for CPDLC Build I and equipage level for aircraft flow per day per sector of 880. The R-square for the fit is 0.99.

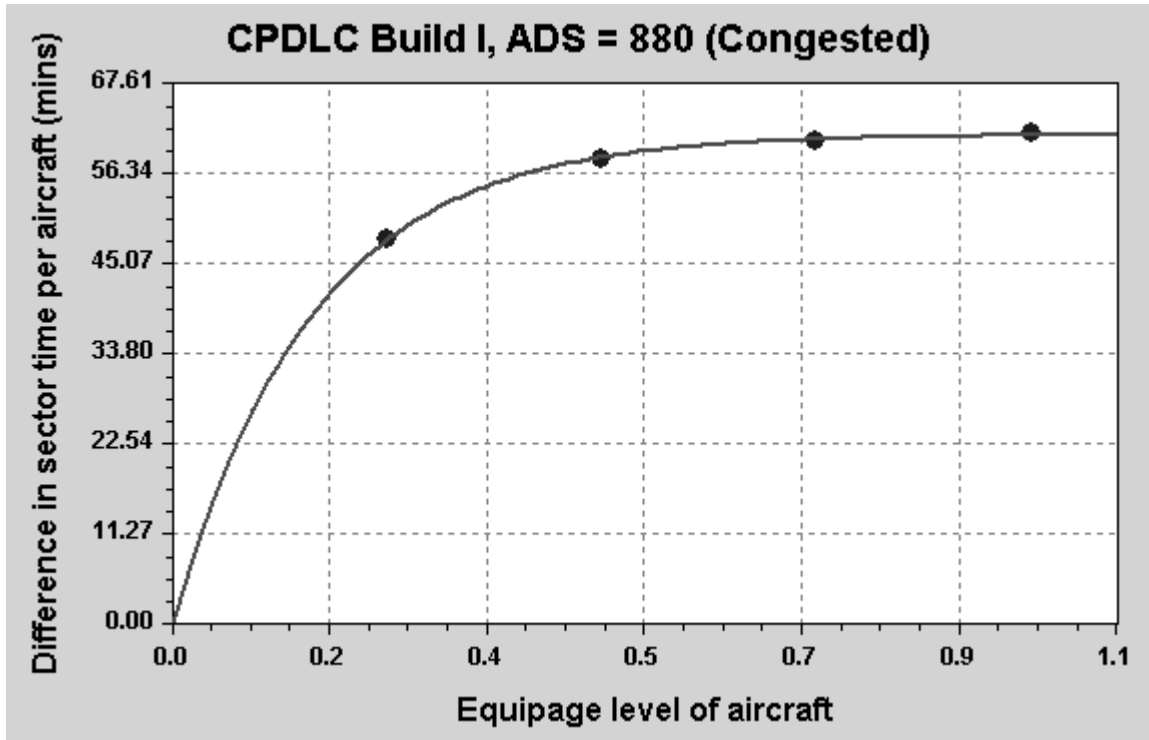


Figure 6.51 Exponential fit between delta and equipage level for CPDLC Build I at ADS = 880 (Congested)

After determining the relationship of equipage level (E_{I_a}) and ADS with sector traversal time difference per aircraft for CPDLC Build I, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = \frac{a(1 - e^{x_1 e})}{(1 + e^{(b - cx_2)})^d} \tag{6.22}$$

where x_1 is the equipage level,

x_2 is the aircraft flow per day per sector,

a, b, c, d, e are coefficients of the regression surface.

ex is the exponential form.

Two parameter non linear regression fitting is carried out in MATLAB using the entire output data set for CPDLC Build I

Figure 6.52 shows the regression surface for CPDLC Build I (Congested region).

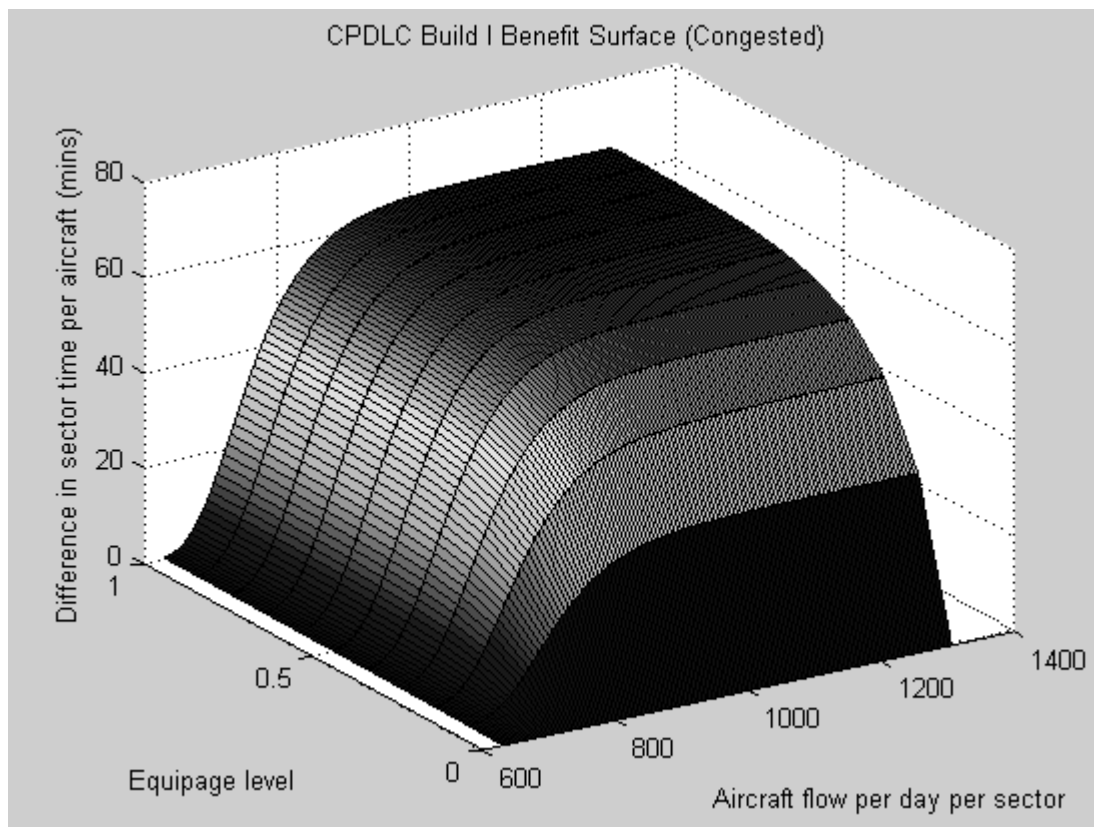


Figure 6.52 Regression Surface for CPDLC Build I (Congested)

Figure 6.53 shows the relationship between difference in sector traversal time per aircraft for CPDLC Build I with non integrated URET and aircraft flow per day per sector for varying equipage level of

aircraft.

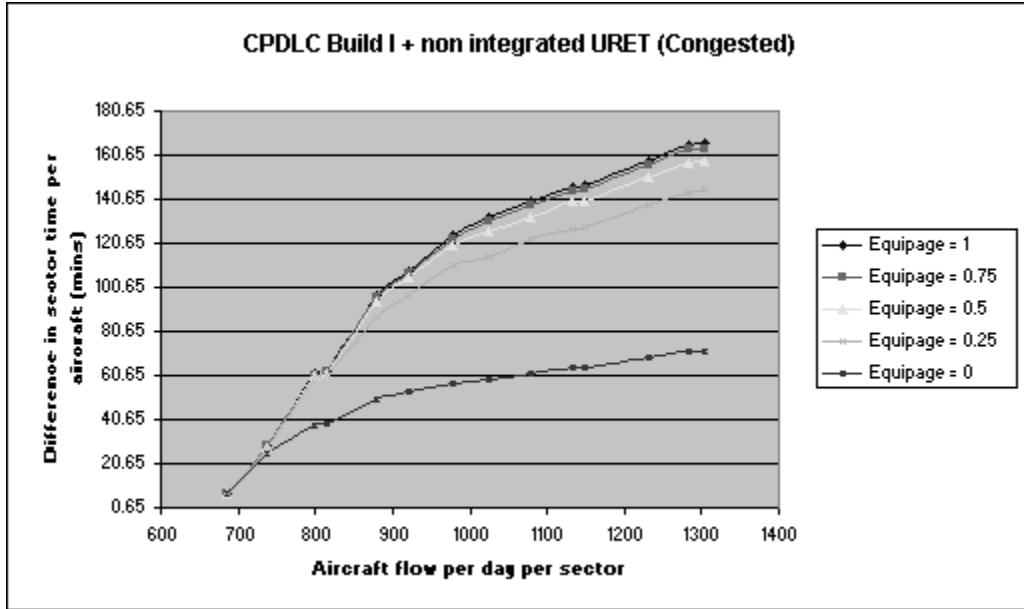


Figure 6.53 Sector traversal time difference per aircraft for CPDLC Build I and non integrated URET v/s ADS (Congested)

An exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build I with non integrated URET and ADS.

$$y = \frac{a}{(1 + e^{x^{(b-cx)}})^d} \tag{6.23}$$

Figure 6.54 shows a sample exponential fit relationship between delta for CPDLC Build I with non integrated URET and aircraft flow per day per sector for equipage level of 1. The R-square for the fit is 0.99.

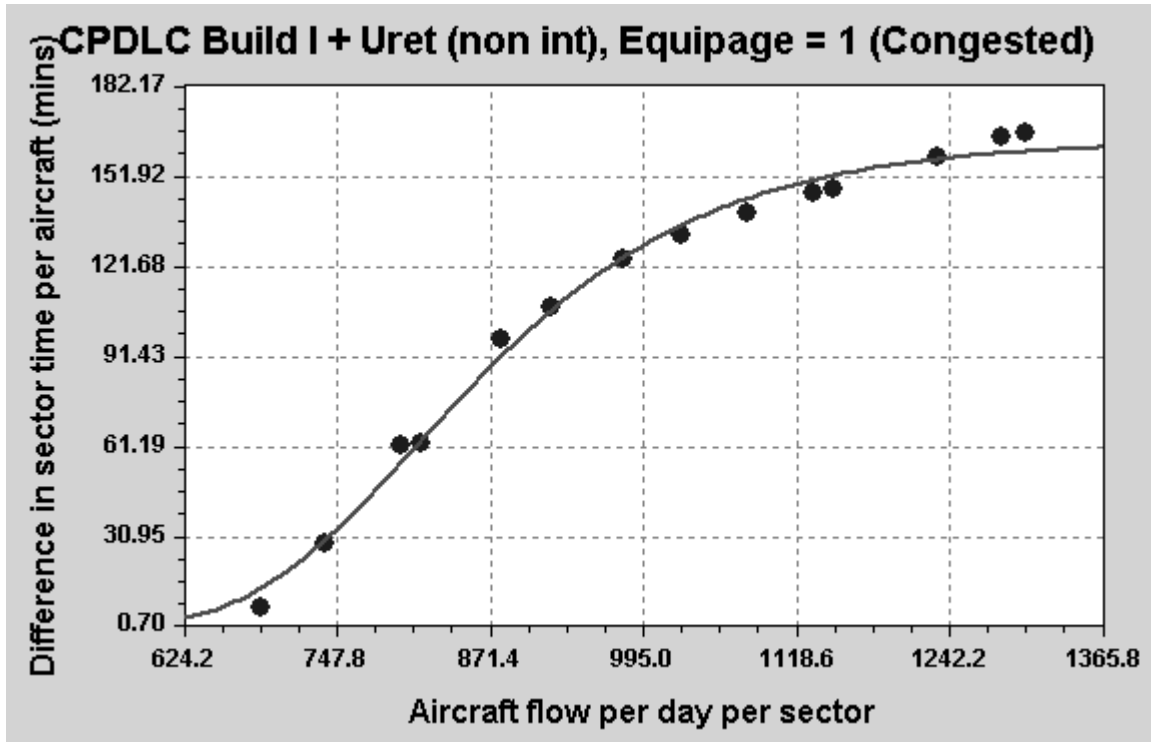


Figure 6.54 Non Linear fit between delta and aircraft density for CPDLC Build I with non integrated URET at 100 percent equipage level (Congested)

Figure 6.55 shows the relationship between difference in sector traversal time per aircraft for CPDLC Build I with non integrated URET and equipage level of aircraft for different aircraft flow per day per sector (ADS).

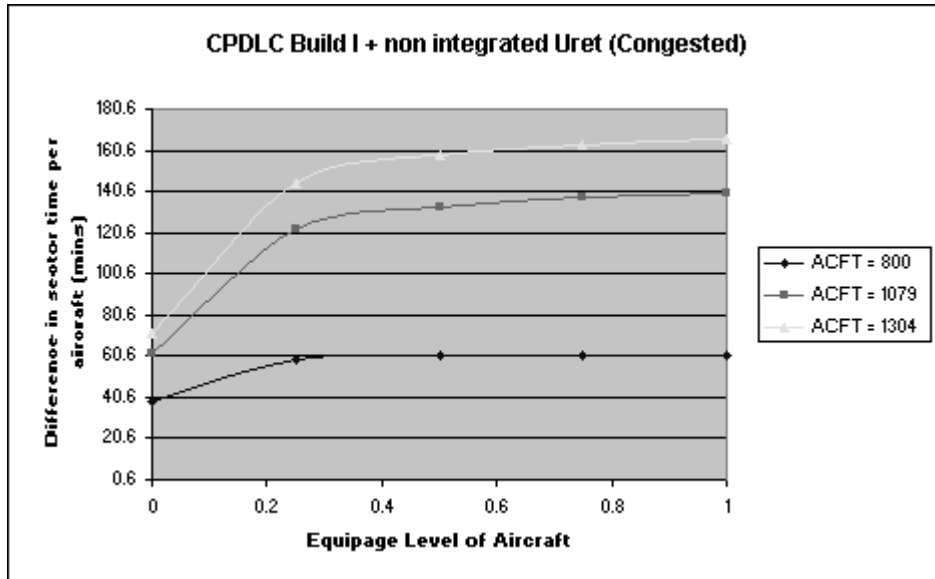


Figure 6.55 Sector time difference per aircraft for CPDLC Build I with non integrated URET v/s Equipage Level (Congested)

An exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build I with non integrated URET and equipage level.

$$y = a(b - e^{-cx}) \tag{6.24}$$

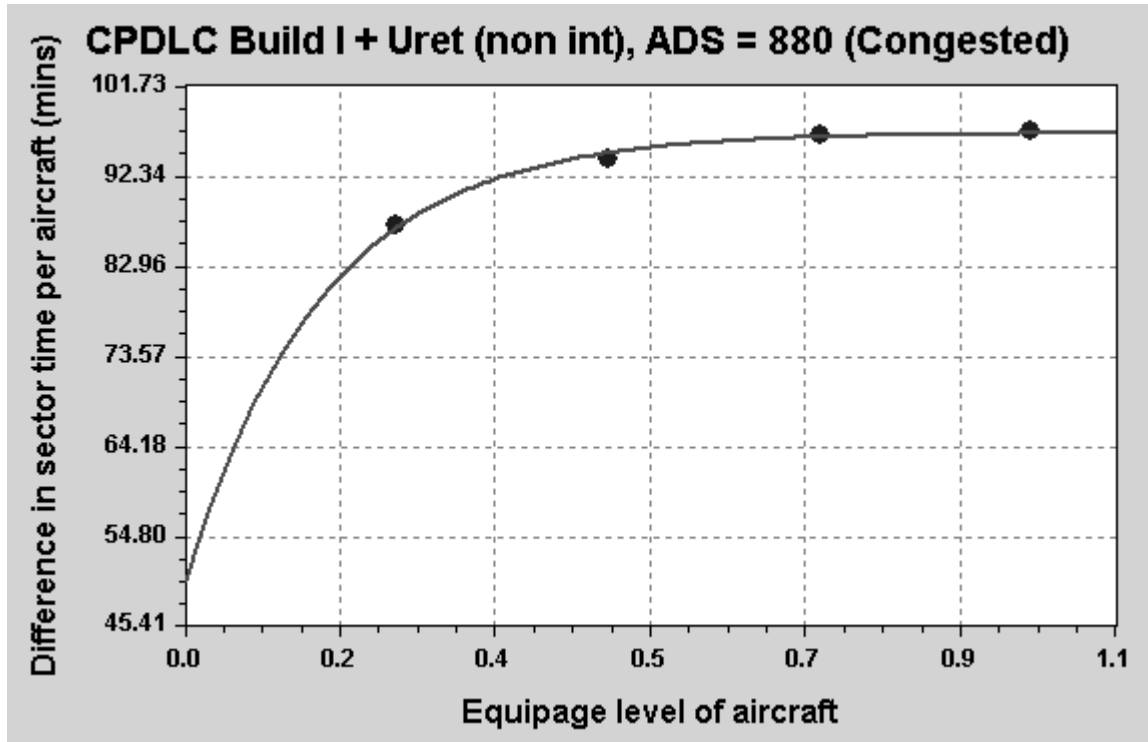


Figure 6.56 Exponential fit between delta and equipage level for CPDLC Build I with non integrated URET at ADS = 880 (Congested)

Figure 6.56 shows a sample exponential fit relationship between delta for CPDLC Build I with non integrated URET and equipage level for aircraft flow per day per sector for of 880. The R-square for the fit is 0.99.

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build I with non integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = \frac{a(e - ex^{-x1f})}{(1 + ex^{(b-cx2)})^d} \quad (6.25)$$

Figure 6.57 shows the regression surface CPDLC Build I with non integrated URET (uncongested region).

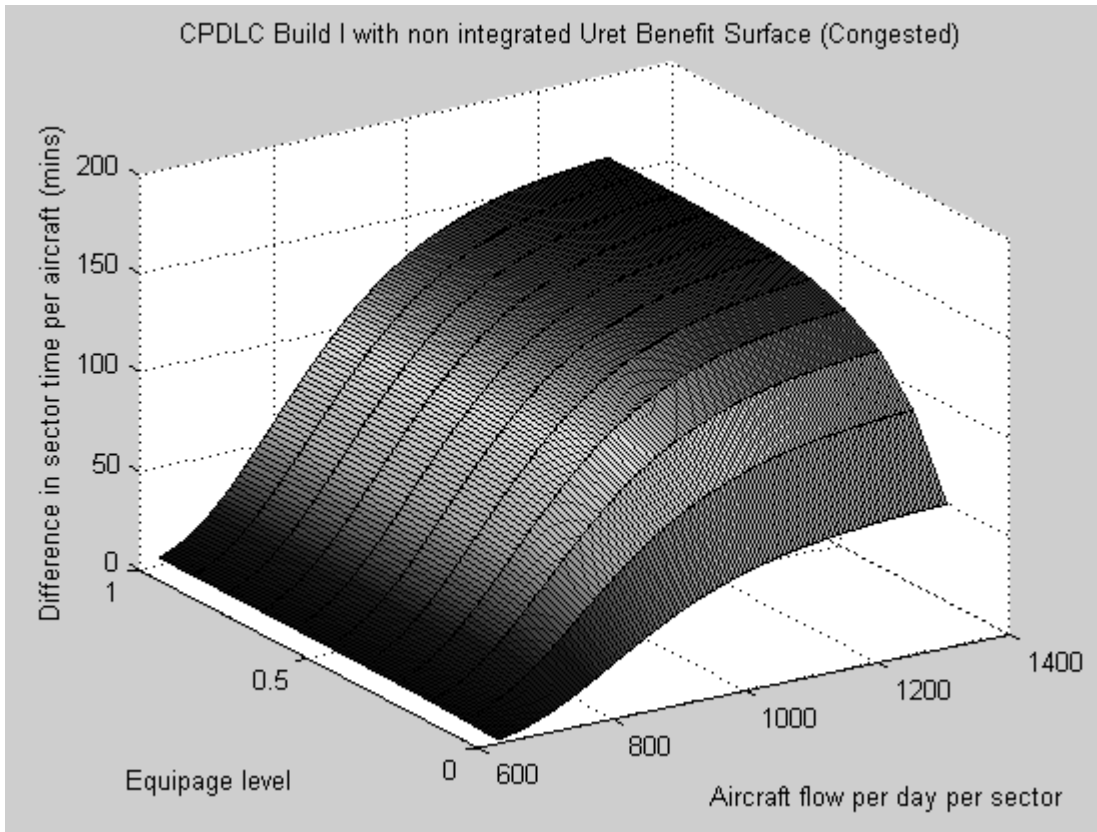


Figure 6.57 Regression surface for CPDLC Build I with non integrated URET (Congested)

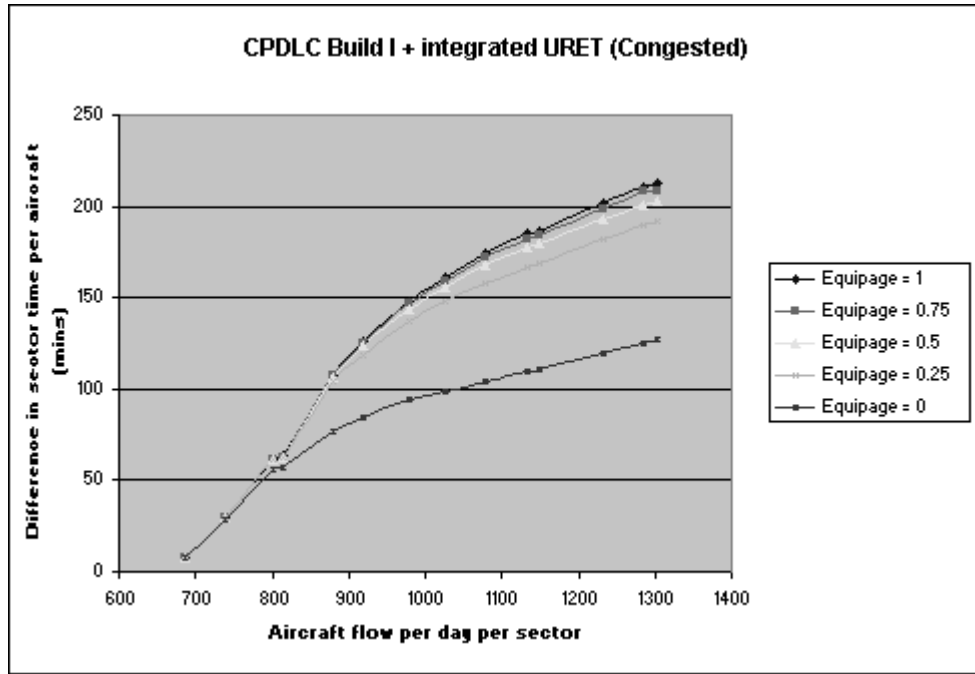


Figure 6.58 Sector time difference per aircraft for CPDLC Build I and integrated URET (Congested)

From the figure 6.58 and using CurveExpert, an exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build I with integrated URET.

$$y = \frac{a}{(1 + e^{(b-cx)})^d} \tag{6.26}$$

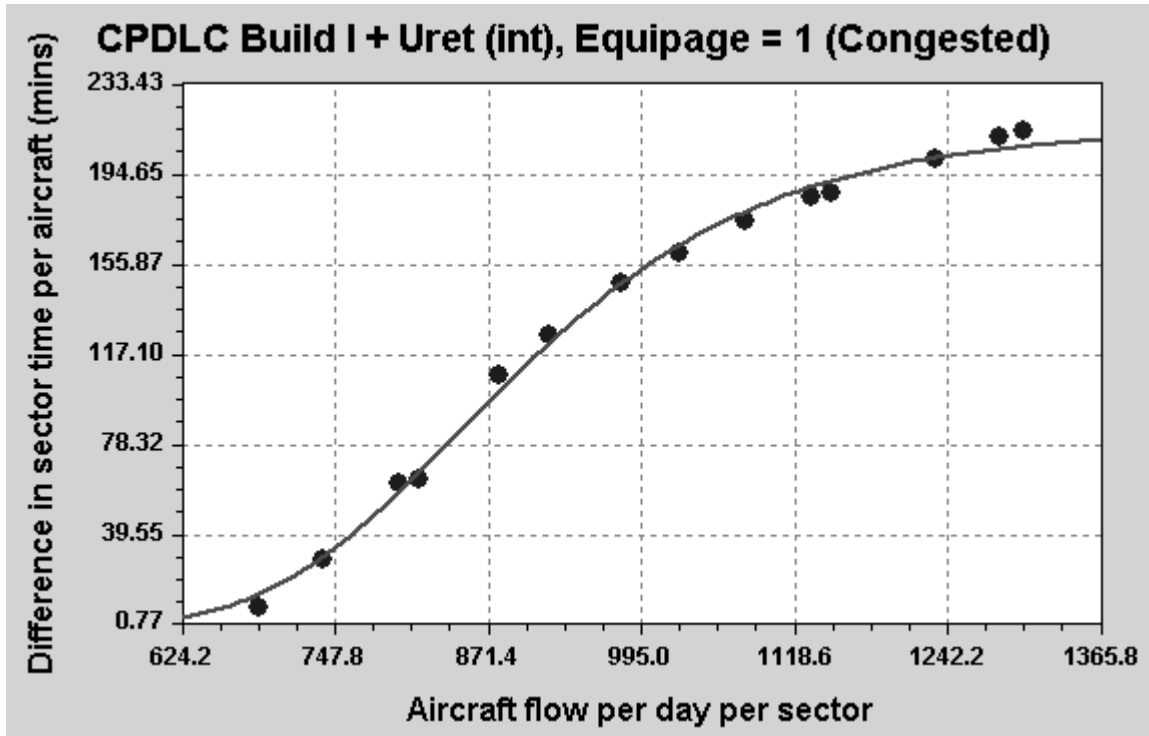


Figure 6.59 Non Linear fit between delta and aircraft density for CPDLC Build I with integrated URET at 100 percent equipage level (Congested)

Figure 6.59 shows a sample exponential fit relationship between delta for CPDLC Build I with integrated URET and aircraft flow per day per sector for equipage level of 1.

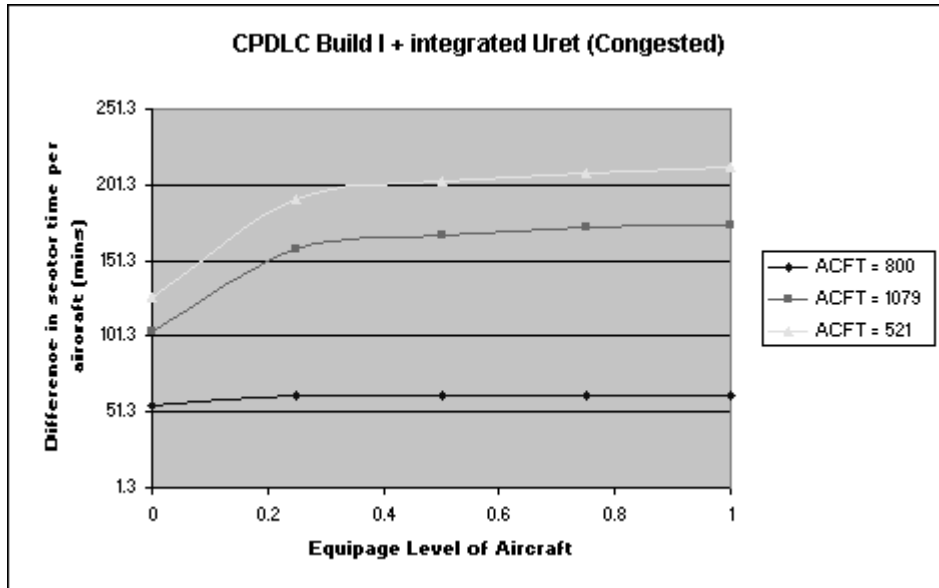


Figure 6.60 Sector time difference per aircraft for CPDLC Build I with integrated URET v/s Equipage Level (Congested)

A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build I with integrated URET and equipage level.

$$y = a(b - e^{-cx}) \tag{6.27}$$

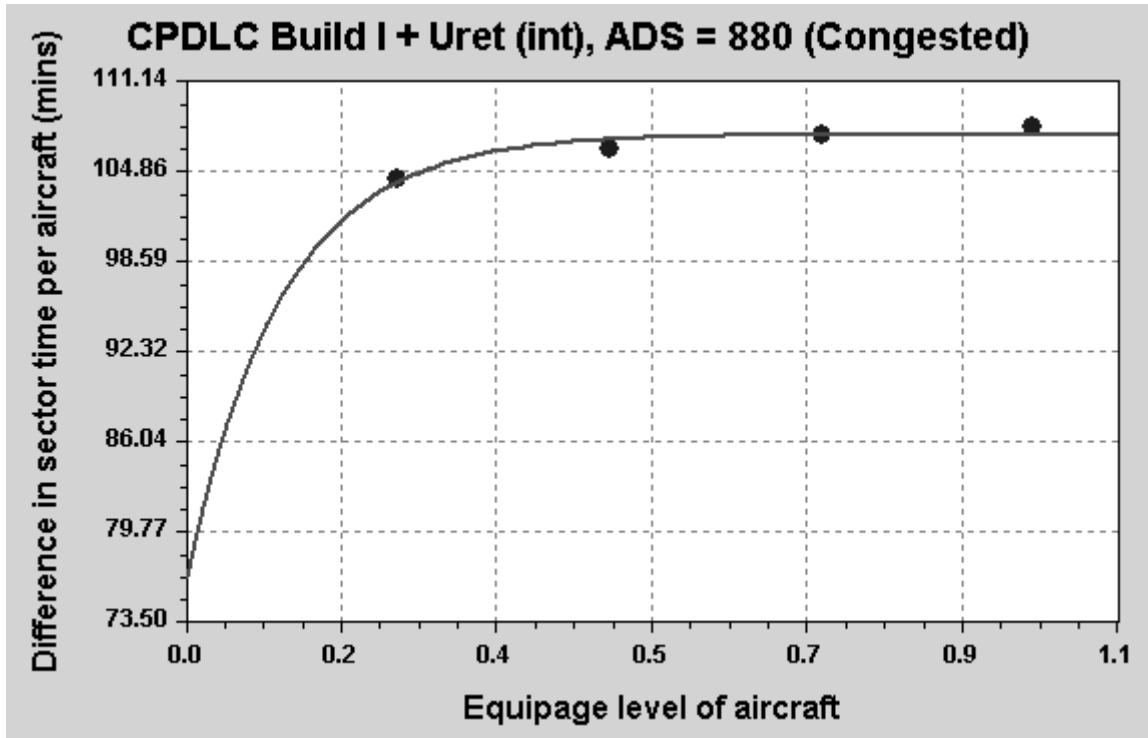


Figure 6.61 Exponential fit between delta and equipage level for CPDLC Build I with integrated URET at ADS = 880 (Congested)

Figure 6.61 shows a exponential fit relationship between delta for CPDLC Build I with integrated URET and equipage level for aircraft flow per day per sector for of 880. The R-square for the fit is 0.98.

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build I with integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = \frac{a(e - ex^{-x1f})}{(1 + ex^{(b-cx2)})^d} \tag{6.28}$$

Figure 6.62 shows the regression surface CPDLC Build I with integrated URET (uncongested region). The regression surface has a R-square of 0.9724

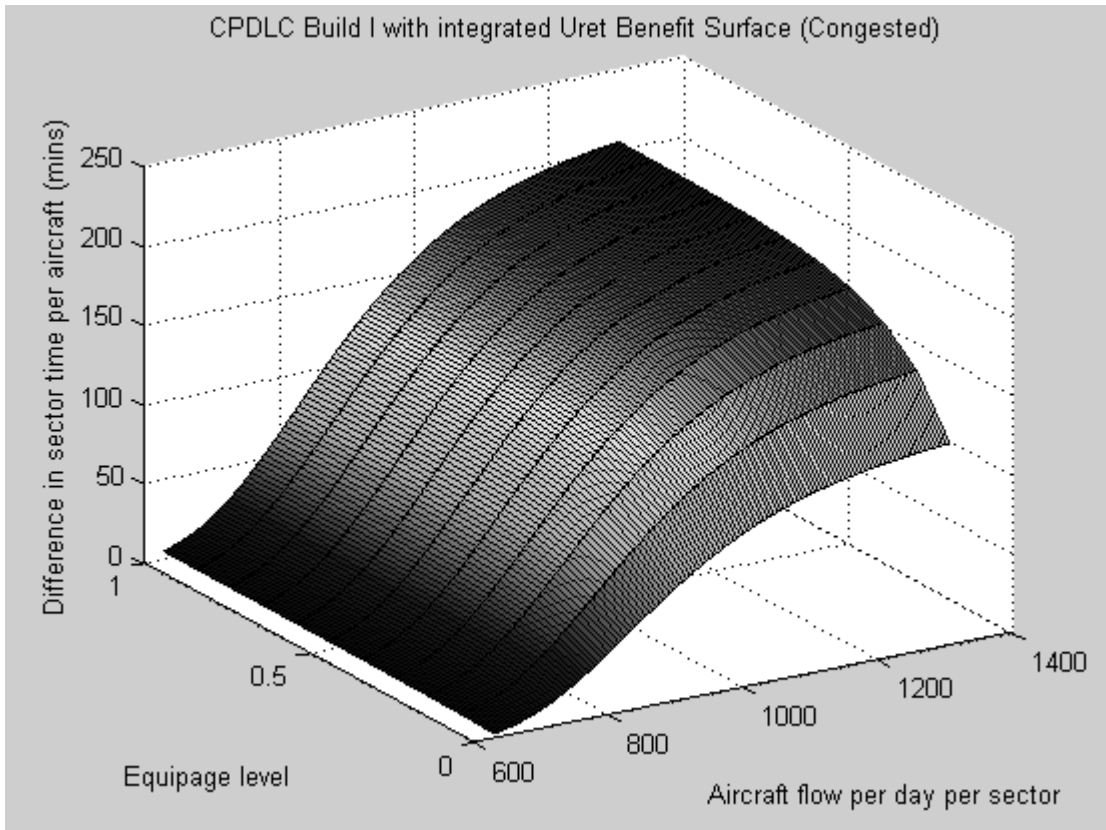


Figure 6.62 Regression surface for CPDLC Build I with integrated URET (Congested)

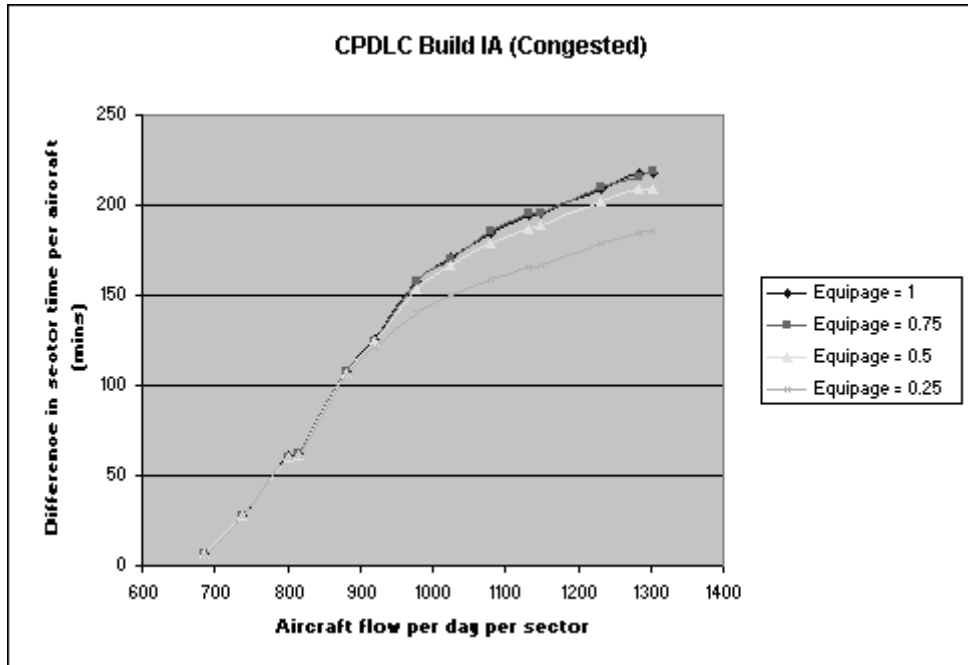


Figure 6.63 Sector time difference per aircraft for CPDLC Build IA (Congested)

A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build IA.

$$y = \frac{a}{(1 + e^{x^{(b-cx)}})^d} \tag{6.29}$$

Figure 6.64 shows a sample exponential fit relationship between delta for CPDLC Build IA and aircraft flow per day per sector for equipage level of 1.

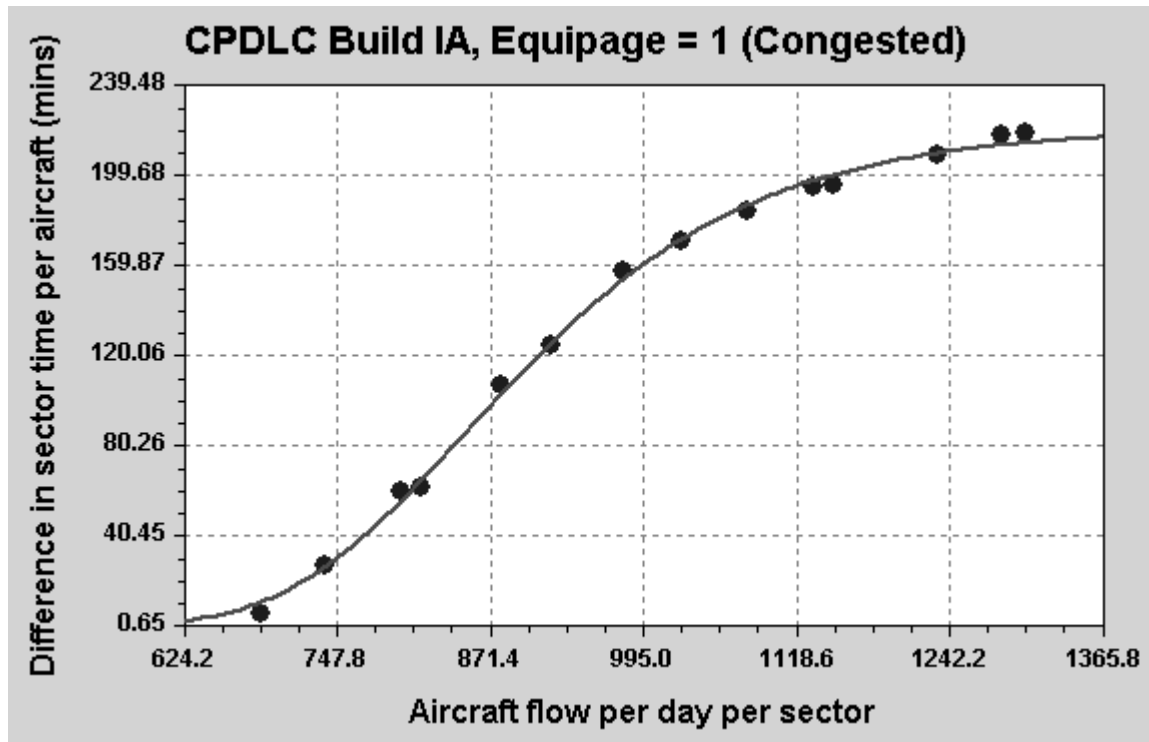


Figure 6.64 Non Linear fit between delta and aircraft density for CPDLC Build IA at 100 percent equipage level (Congested)

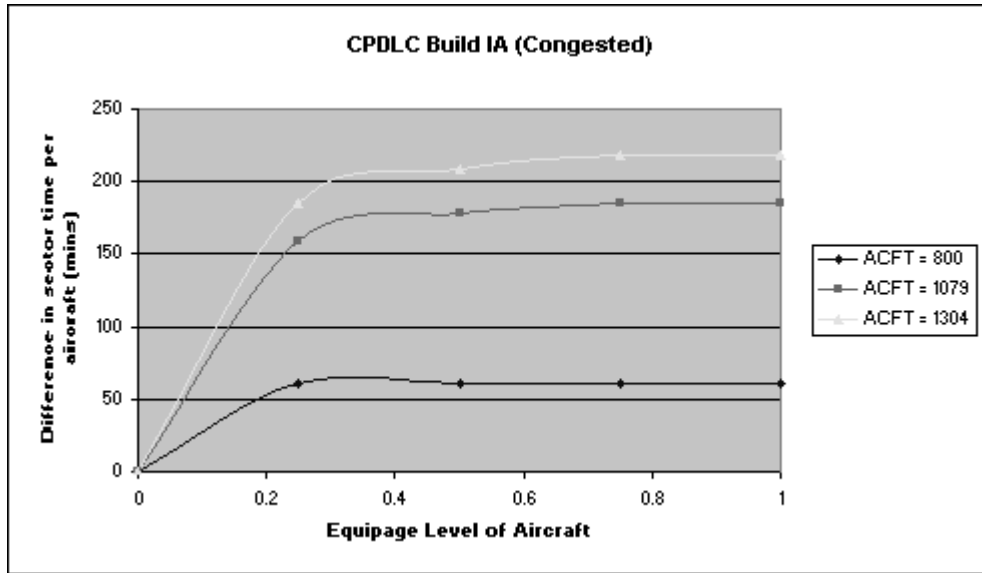


Figure 6.65 Sector time difference per aircraft for CPDLC Build IA v/s Equipage Level (Uncongested)

An exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build IA and equipage level.

$$y = a(1 - e^{-bx}) \tag{6.30}$$

Figure 6.66 shows a sample exponential fit relationship between delta for CPDLC Build IA and equipage level for aircraft flow per day per sector for of 880.

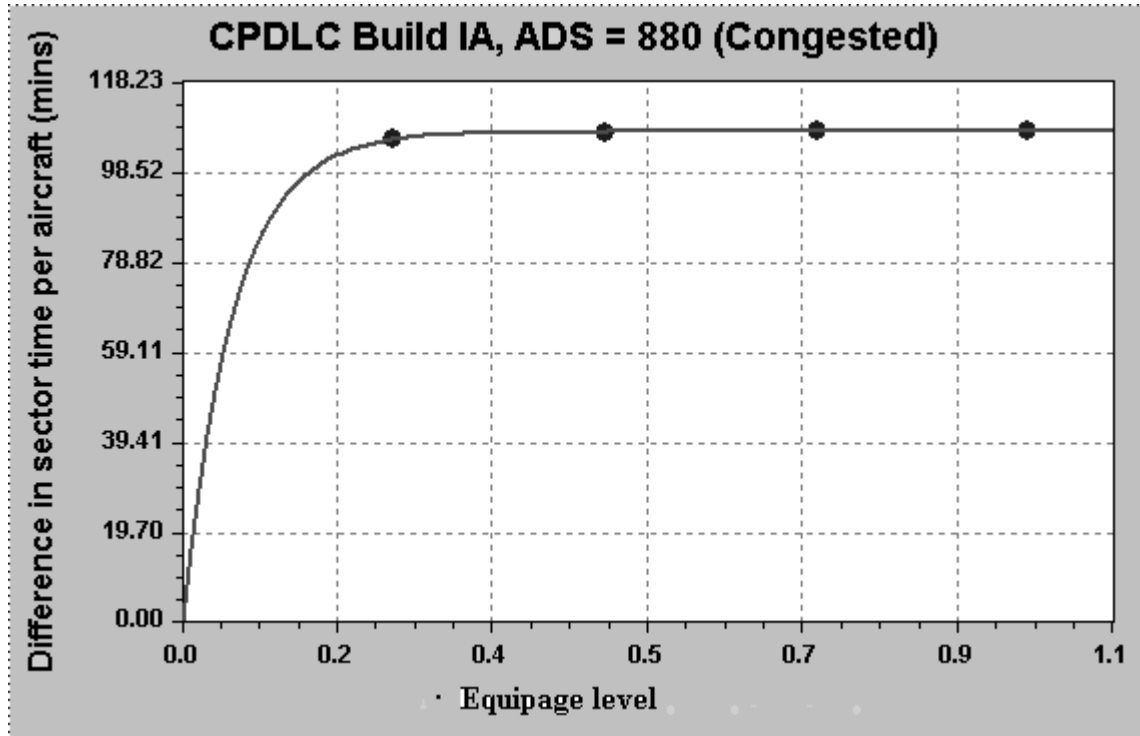


Figure 6.66 Exponential fit between delta and equipage level for CPDLC Build IA at ADS = 880 (Congested)

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build IA, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = \frac{a(1 - e^{-x^1e})}{(1 + e^{(b-cx^2)})^d} \quad (6.31)$$

Figure 6.67 shows the regression surface CPDLC Build IA (Congested region).

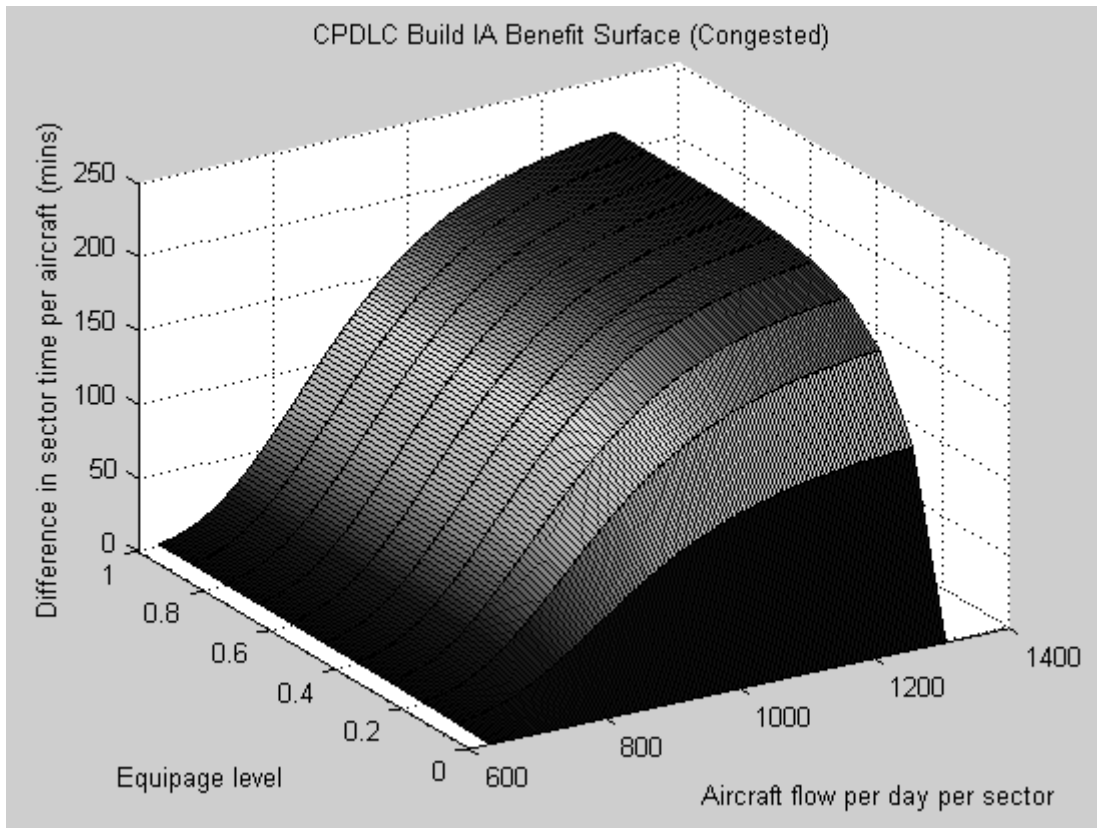


Figure 6.67 Regression Surface for CPDLC Build IA (Congested)

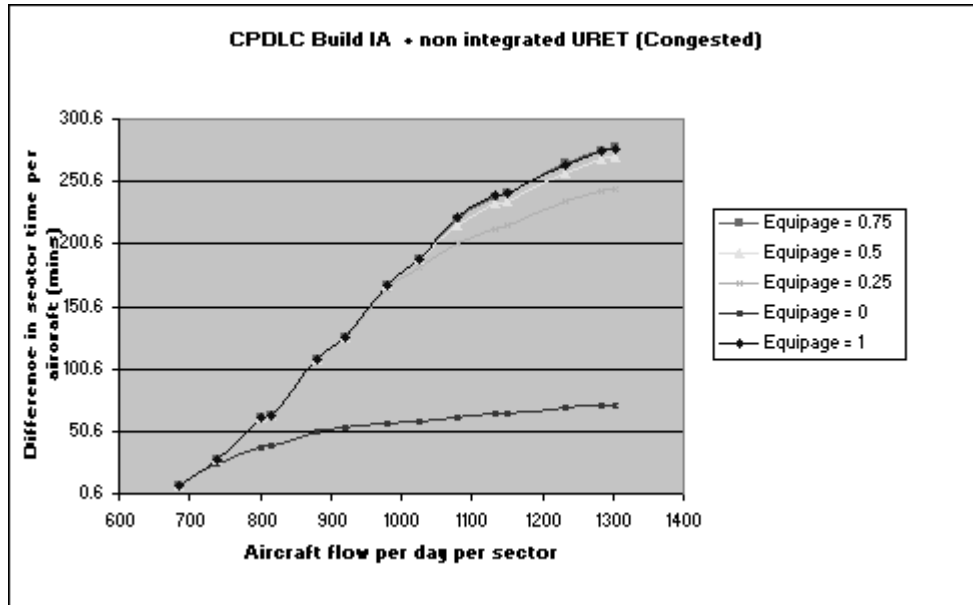


Figure 6.68 Sector traversal time difference per aircraft for CPDLC Build IA and non integrated URET (Uncongested)

A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build IA with non integrated URET.

$$y = \frac{a}{(1 + e^{(b-cx)})^d} \tag{6.32}$$

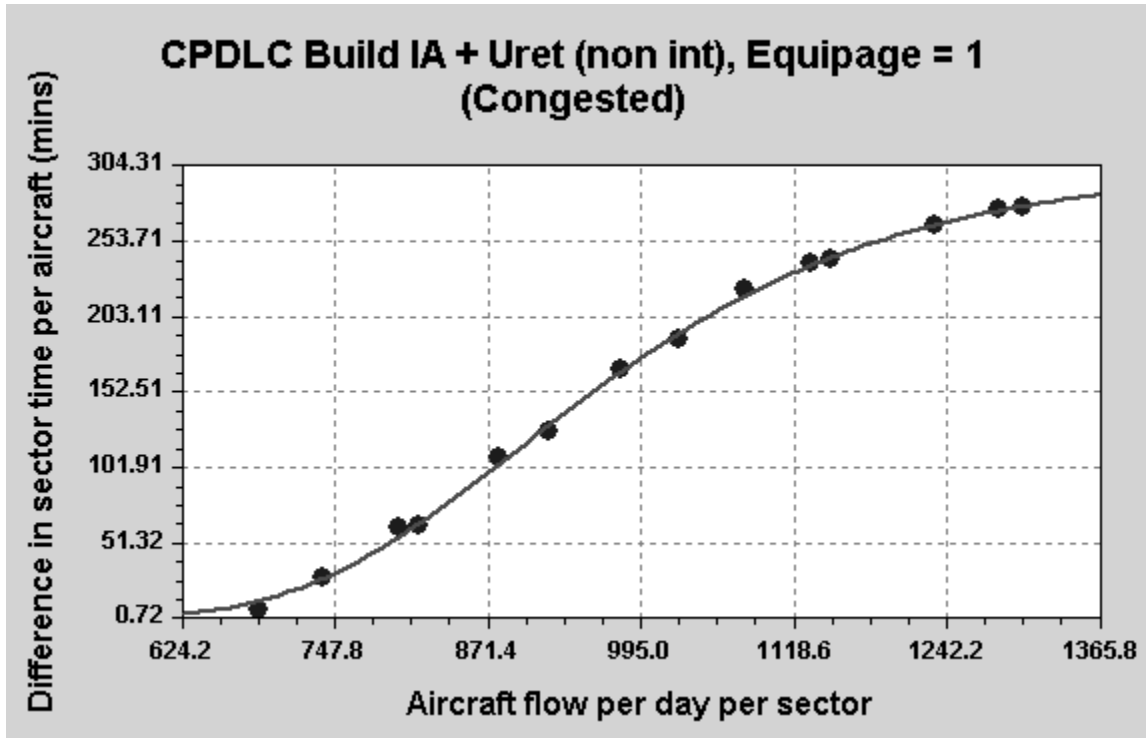


Figure 6.69 Non Linear fit between delta and aircraft density for CPDLC Build IA with non integrated URET at 100 percent equipage level (Congested)

Figure 6.69 shows a sample exponential fit relationship between delta for CPDLC Build IA with non integrated URET and aircraft flow per day per sector for equipage level of 1.

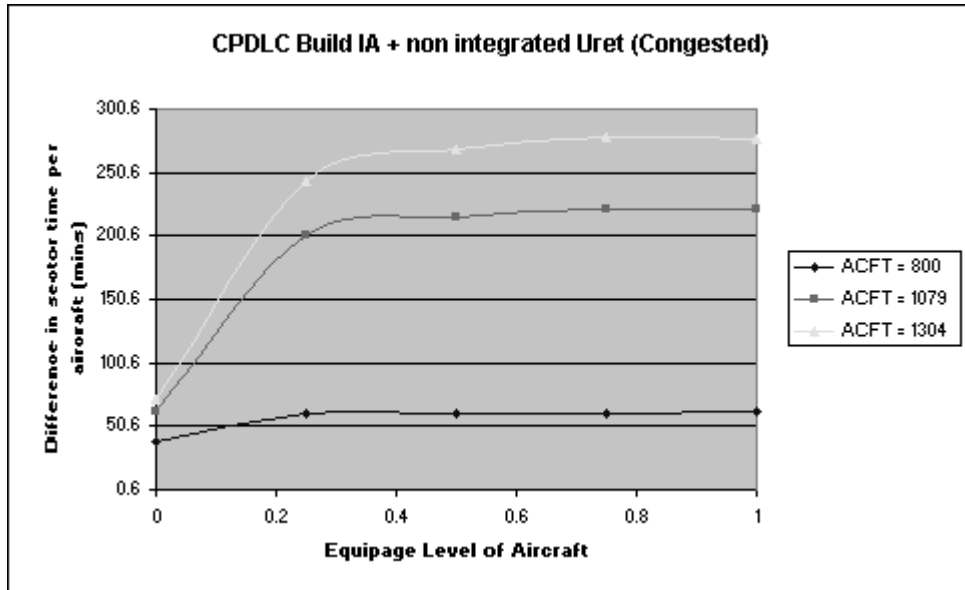


Figure 6.70 Sector time difference per aircraft for CPDLC Build IA with non integrated URET v/s Equipage Level (Congested)

A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build IA with non integrated URET and equipage level.

$$y = a(b - ex^{-cx}) \tag{6.33}$$

Figure 6.71 shows a sample exponential fit relationship between delta for CPDLC Build IA with non integrated URET and equipage level for aircraft flow per day per sector for of 880.

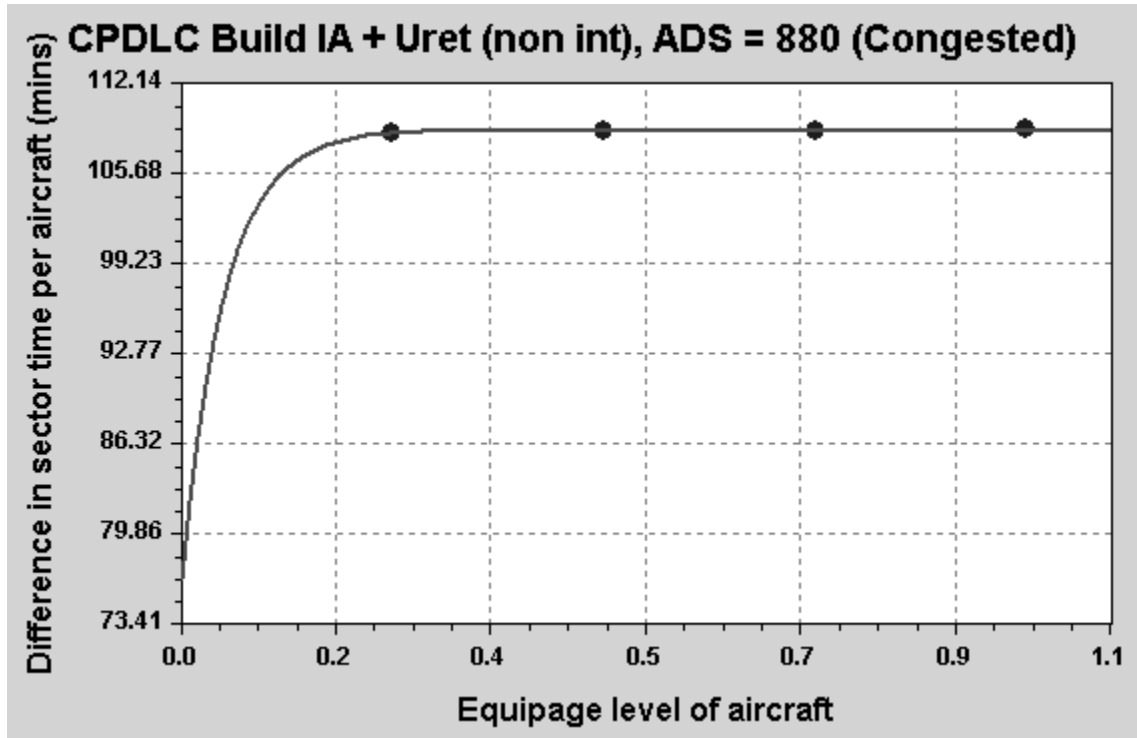


Figure 6.71 Exponential fit between delta and equipage level for CPDLC Build IA with non integrated URET at ADS = 880 (Congested)

After determining the relationship of equipage level (EI_a) and ADS with sector traverse time difference per aircraft for CPDLC Build I, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = \frac{a(e - ex^{-x1f})}{(1 + ex^{(b-cx2)})^d} \quad (6.34)$$

Two parameter non linear regression fitting is carried out in MATLAB using the entire output data set

for CPDLC Build IA with non integrated URET and coefficient values are obtained as shown in Table 6.2.

Figure 6.72 shows the regression surface CPDLC Build IA with non integrated URET (Congested region).

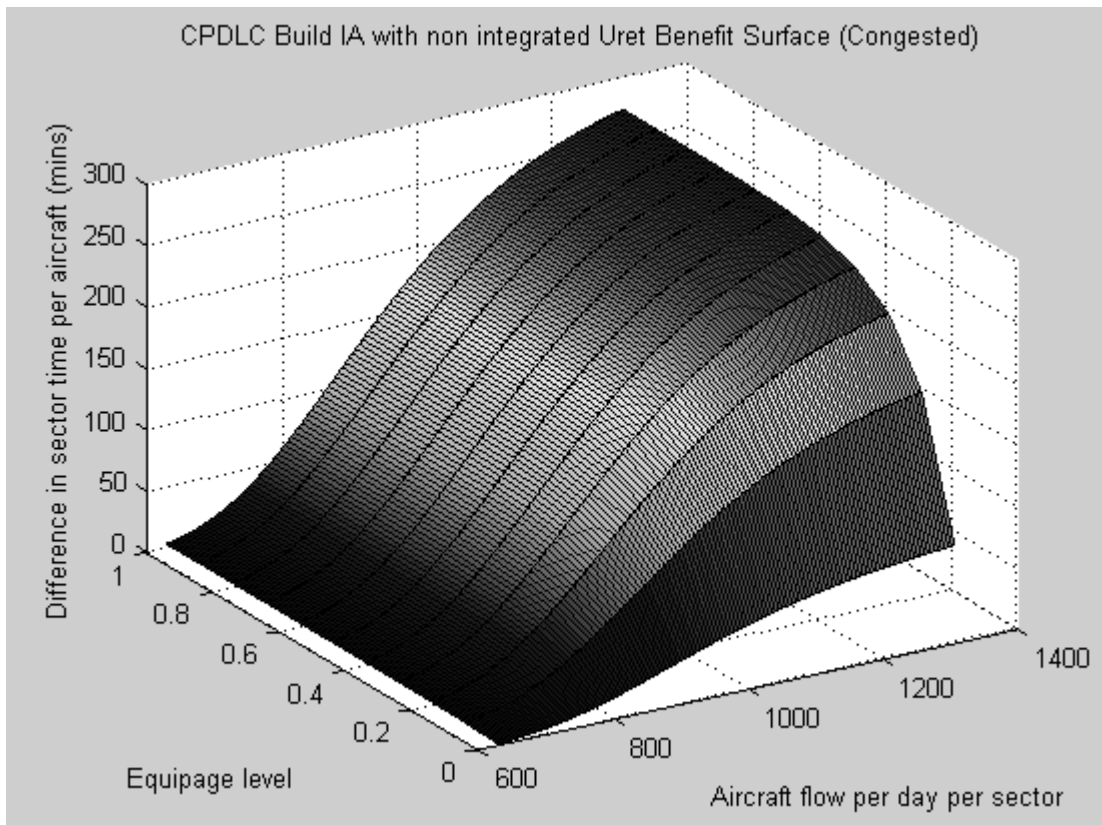


Figure 6.72 Regression surface for CPDLC Build IA with non integrated URET (Congested)

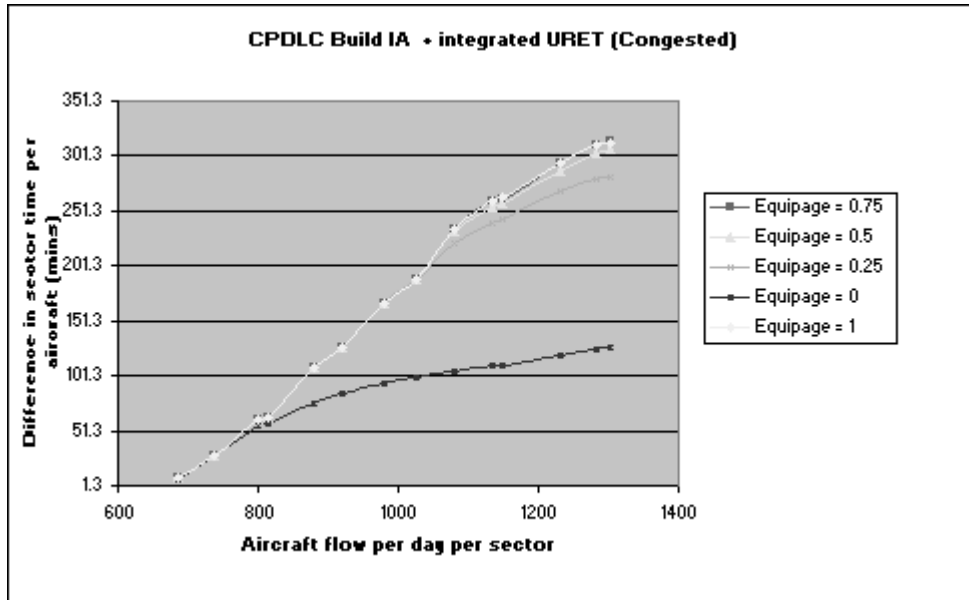


Figure 6.73 Sector time difference per aircraft for CPDLC Build IA and integrated URET (Congested)
 A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) for CPDLC Build IA with integrated URET.

$$y = \frac{a}{(1 + e^{x^{(b-cx)}})^d} \tag{6.35}$$

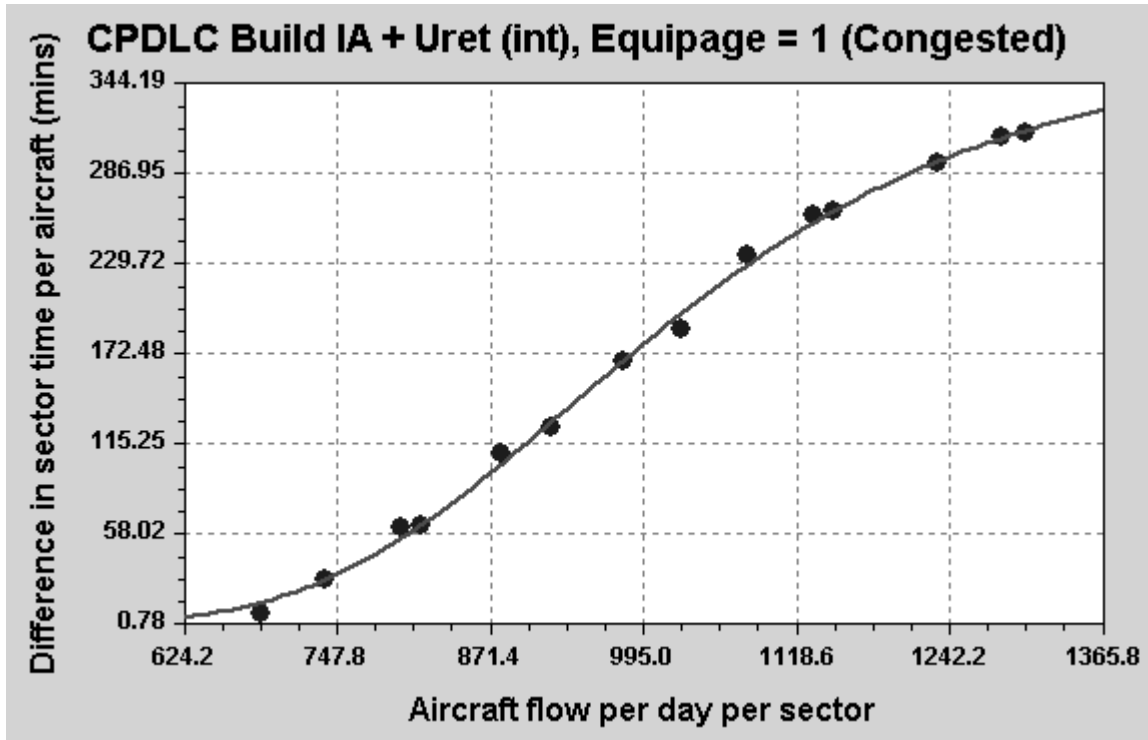


Figure 6.74 Non Linear fit between delta and aircraft density for CPDLC Build IA with integrated URET at 100 percent equipage level (Congested)

Figure 6.74 shows a sample exponential fit relationship between delta for CPDLC Build IA with integrated URET and aircraft flow per day per sector for equipage level of 1. The R-square for the fit is 0.99.

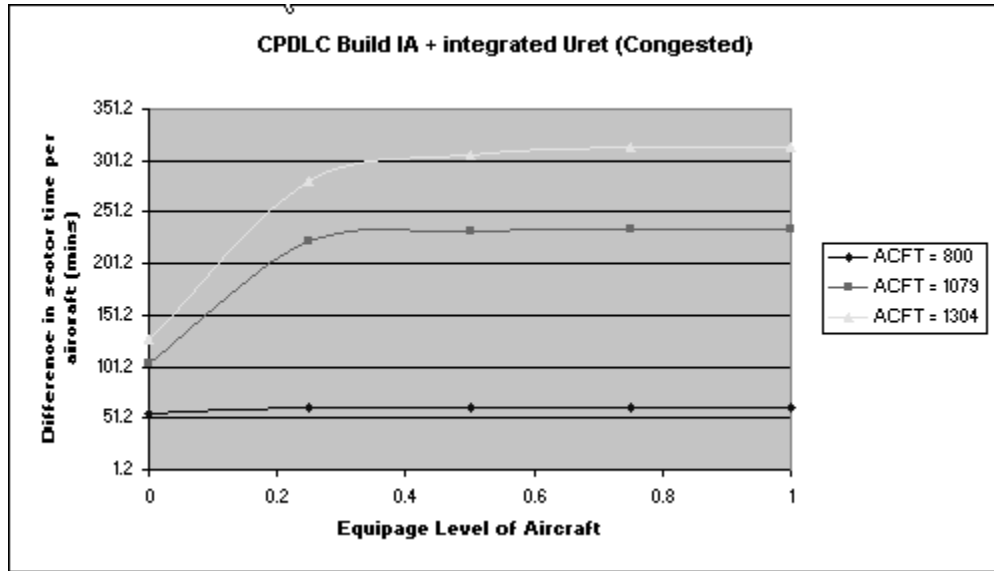


Figure 6.75 Sector time difference per aircraft for CPDLC Build IA with integrated URET v/s Equipage Level (Uncongested)

An exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build IA with integrated URET and equipage level.

$$y = a(b - e^{-cx}) \tag{6.36}$$

Figure 6.76 shows a sample exponential fit relationship between Δ for CPDLC Build IA with integrated URET and equipage level for aircraft flow per day per sector for of 880.

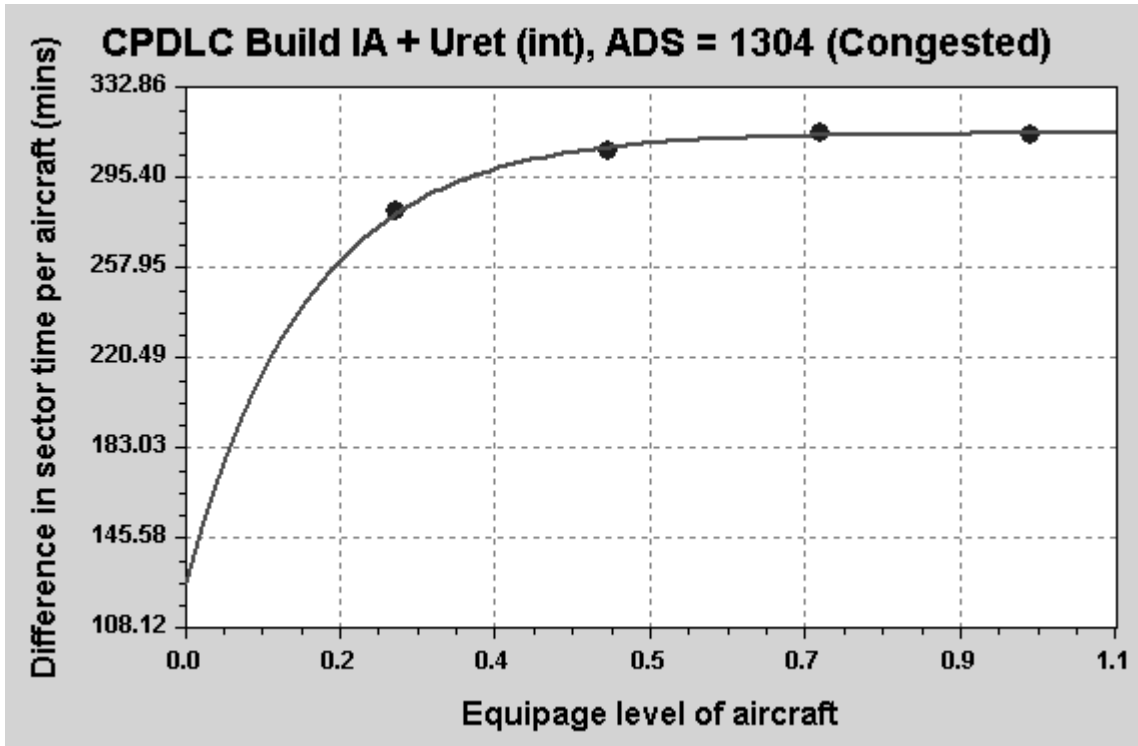


Figure 6.76 Exponential fit between delta and equipage level for CPDLC Build IA with integrated URET at ADS = 1304 (Congested))

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build IA with integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = \frac{a(e - ex^{-x1f})}{(1 + ex^{(b-cx2)})^d} \tag{6.37}$$

Two parameter non linear regression fitting is carried out in MATLAB using the entire output data set

for CPDLC Build IA with integrated URET and coefficient values are obtained as shown in Table 6.2.

Figure 6.77 shows the regression surface CPDLC Build IA with integrated URET (Congested region).

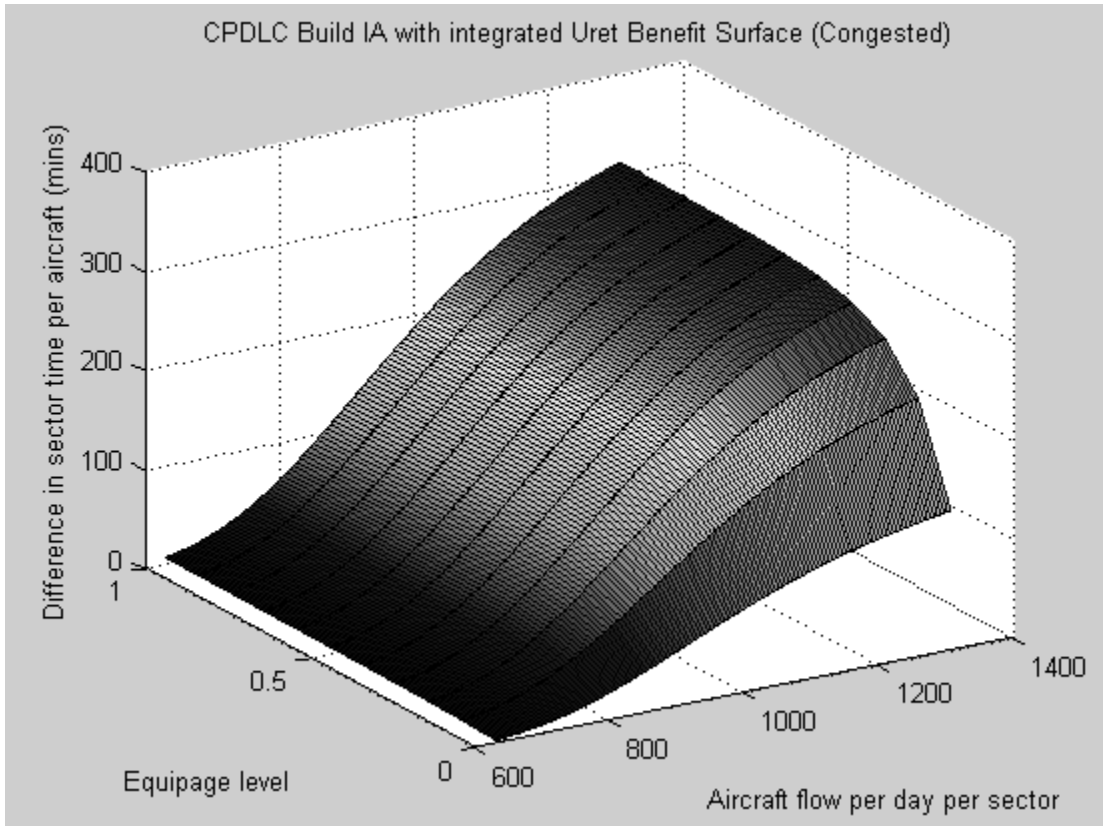


Figure 6.77 Regression surface for CPDLC Build IA with integrated URET (Congested)

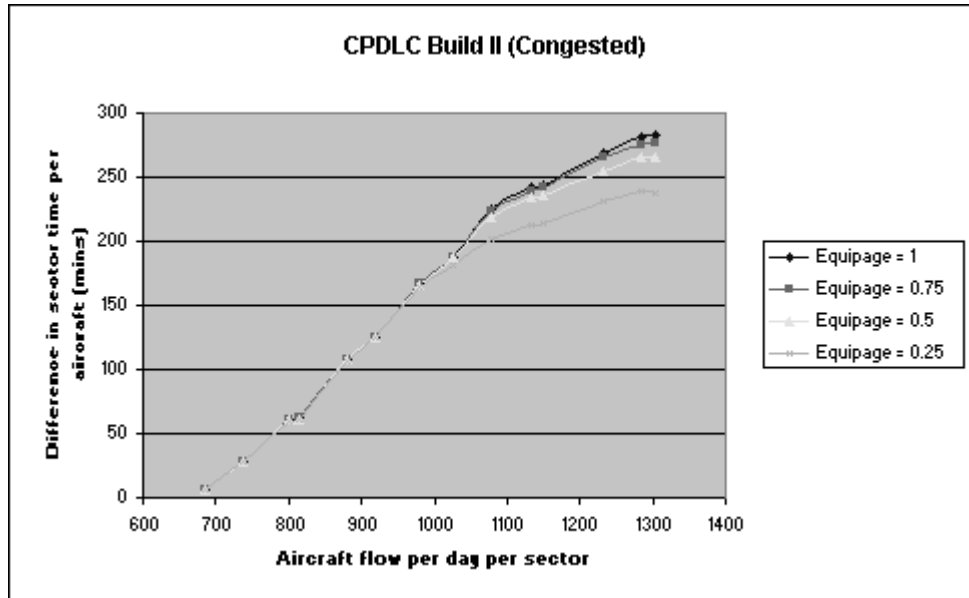


Figure 6.78 Sector time difference per aircraft for CPDLC Build II (Uncongested)

A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build II.

$$y = \frac{a}{(1 + e^{x(b-c)})^d} \tag{6.38}$$

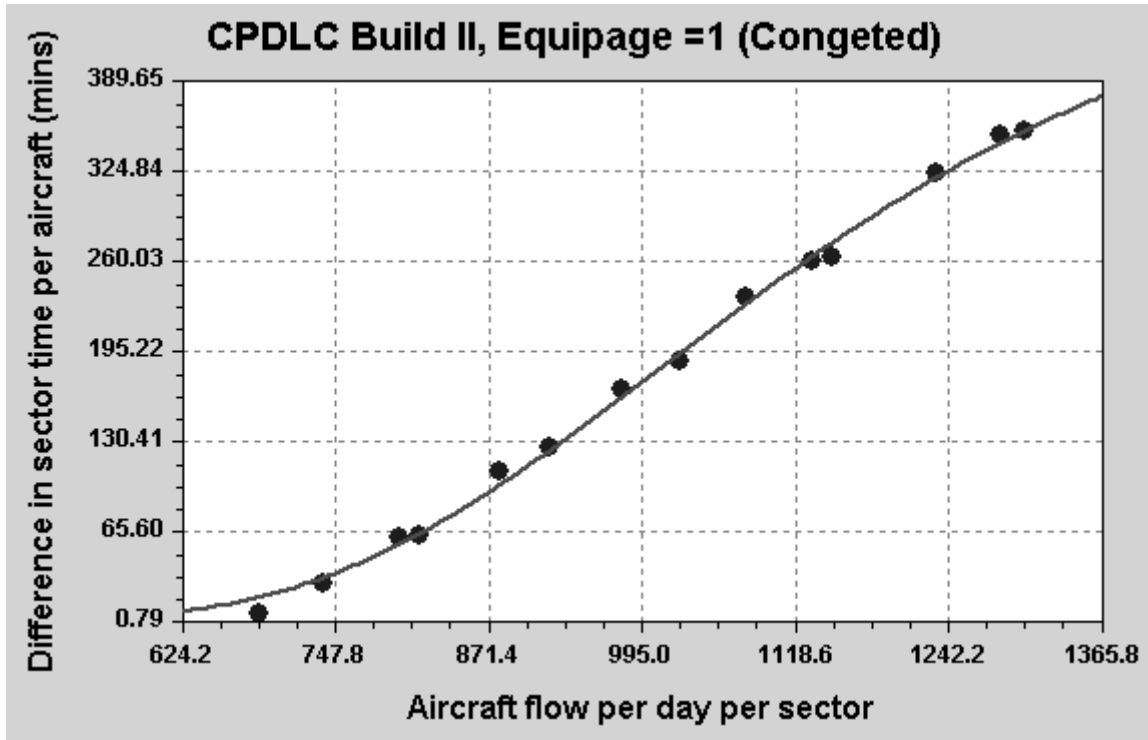


Figure 6.79 Non Linear fit between delta and aircraft density for CPDLC Build II at 100 percent equipage level (Congested)

Figure 6.79 shows a sample exponential fit relationship between delta for CPDLC Build II and aircraft flow per day per sector for equipage level of 1.

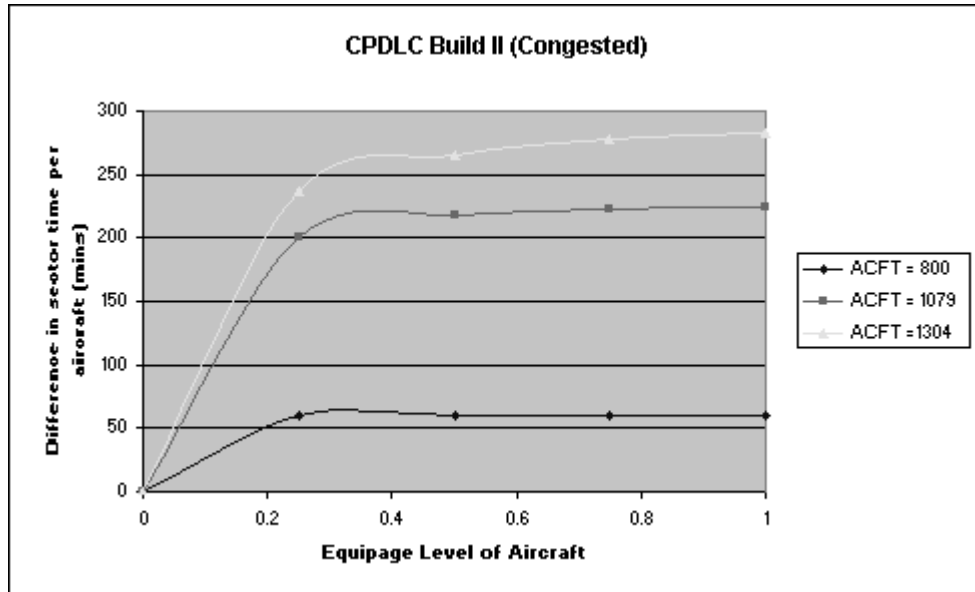


Figure 6.80 Sector time difference per aircraft for CPDLC Build II v/s Equipage level (Uncongested)

A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (Δ) per aircraft for CPDLC Build II and equipage level.

$$y = a(1 - e^{-bx}) \tag{6.39}$$

Figure 6.81 shows a sample exponential fit relationship between Δ for CPDLC Build II and equipage level for aircraft flow per day per sector for of 880.

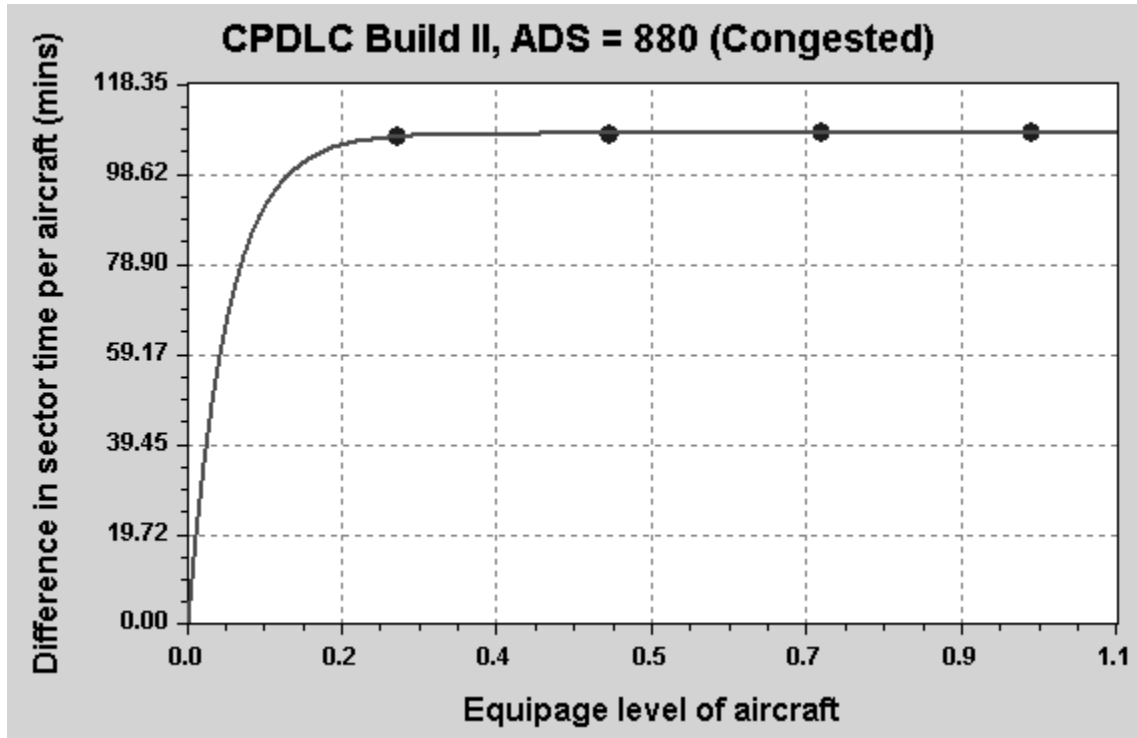


Figure 6.81 Exponential fit between delta and equipage level for CPDLC Build II at ADS = 880 (Congested)

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build I, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = \frac{a(1 - e^{-x1e})}{(1 + e^{(b - cx2)})^d} \quad (6.40)$$

Two parameter non linear regression fitting is carried out in MATLAB using the entire output data set for CPDLC Build II and coefficient values are obtained as shown in Table 6.2.

Figure 6.82 shows the regression surface for CPDLC Build II (Congested region).

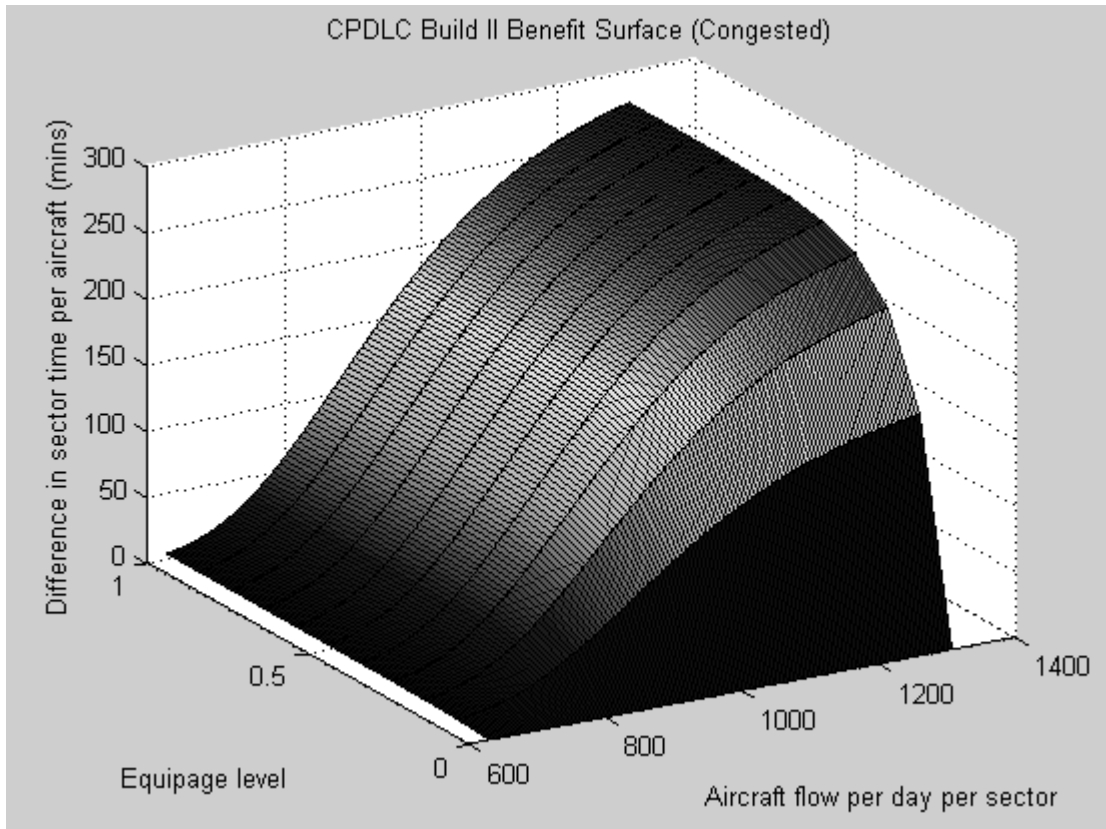


Figure 6.82 Regression Surface for CPDLC Build II (Congested)

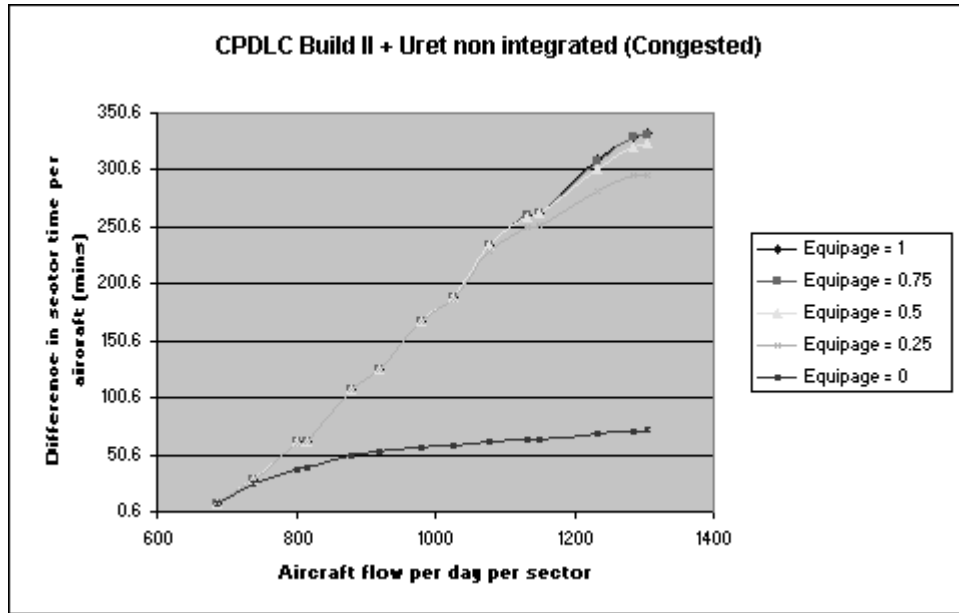


Figure 6.83 Sector traversal time difference per aircraft for CPDLC Build II and non integrated URET (Congested)

An exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build II with non integrated URET.

$$y = \frac{a}{(1 + e^{x^{(b-cx)}})^d} \tag{6.41}$$

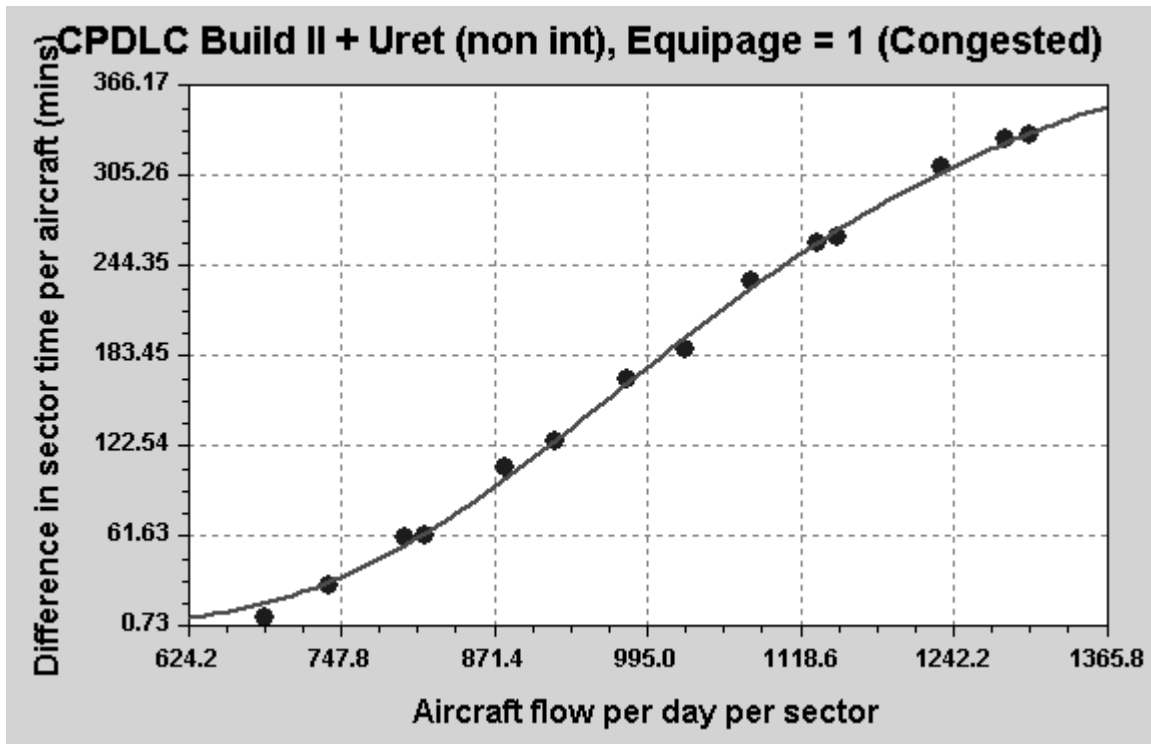


Figure 6.84 Non Linear fit between delta and aircraft density for CPDLC Build II with non integrated URET at 100 percent equipage level (Congested)

Figure 6.84 shows a sample exponential fit relationship between delta for CPDLC Build II with non integrated URET and aircraft flow per day per sector for equipage level of 1.

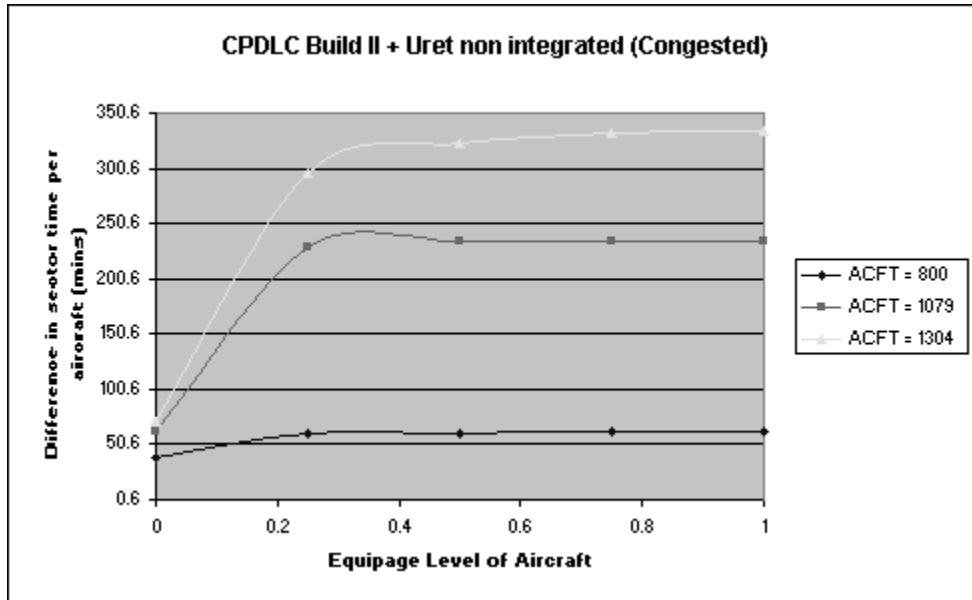


Figure 6.85 Sector time difference per aircraft for CPDLC Build II with non integrated URET v/s Equipage level (Congested)

A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector time (delta) per aircraft for CPDLC Build II with non integrated URET and equipage level.

$$y = a(b - ex^{-cx}) \tag{6.42}$$

Figure 6.87 shows a sample exponential fit relationship between delta for CPDLC Build II with non integrated URET and equipage level for aircraft flow per day per sector for of 880. The R-square for the fit is 0.99.

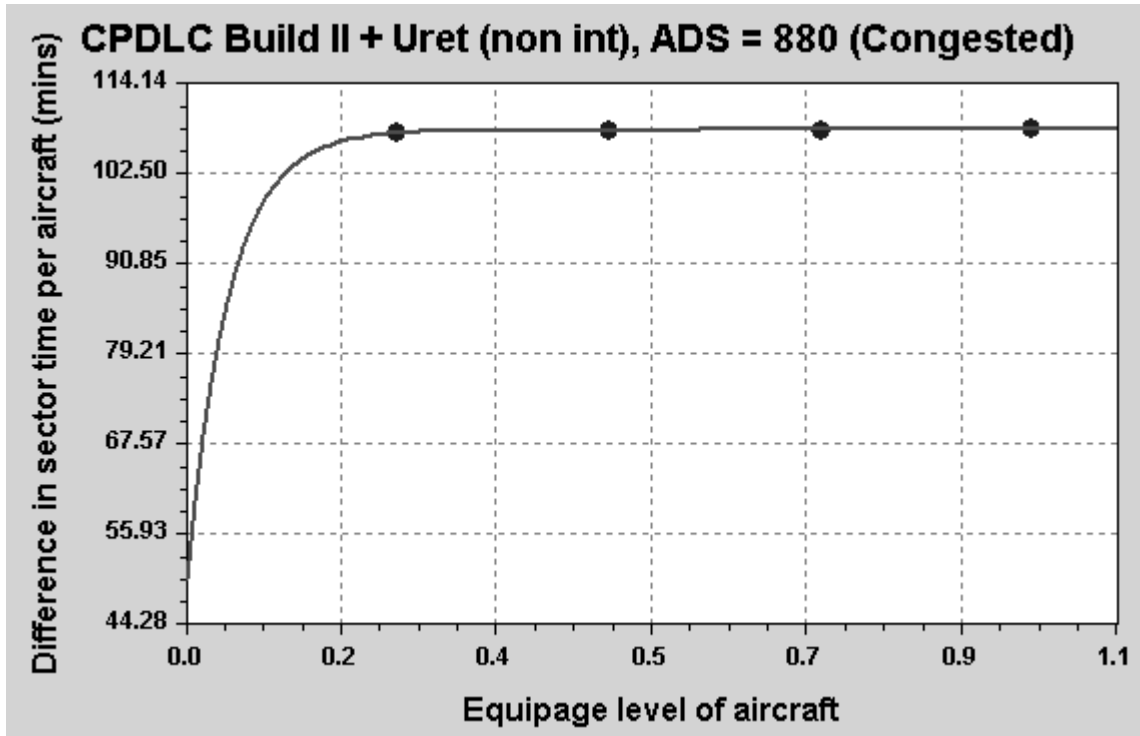


Figure 6.86 Exponential fit between delta and equipage level for CPDLC Build II with non integrated URET at ADS = 880 (Congested)

After determining the relationship of equipage level (EI_a) and ADS with sector traversal time difference per aircraft for CPDLC Build II with non integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = \frac{a(e - ex^{-x1f})}{(1 + ex^{(b-cx2)})^d} \tag{6.43}$$

Two parameter non linear regression fitting is carried out in MATLAB using the entire output data set for CPDLC Build II with non integrated URET and coefficient values are obtained as shown in Table 6.2.

Figure 6.87 shows the regression surface CPDLC Build II with non integrated URET (Congested re-

gion).

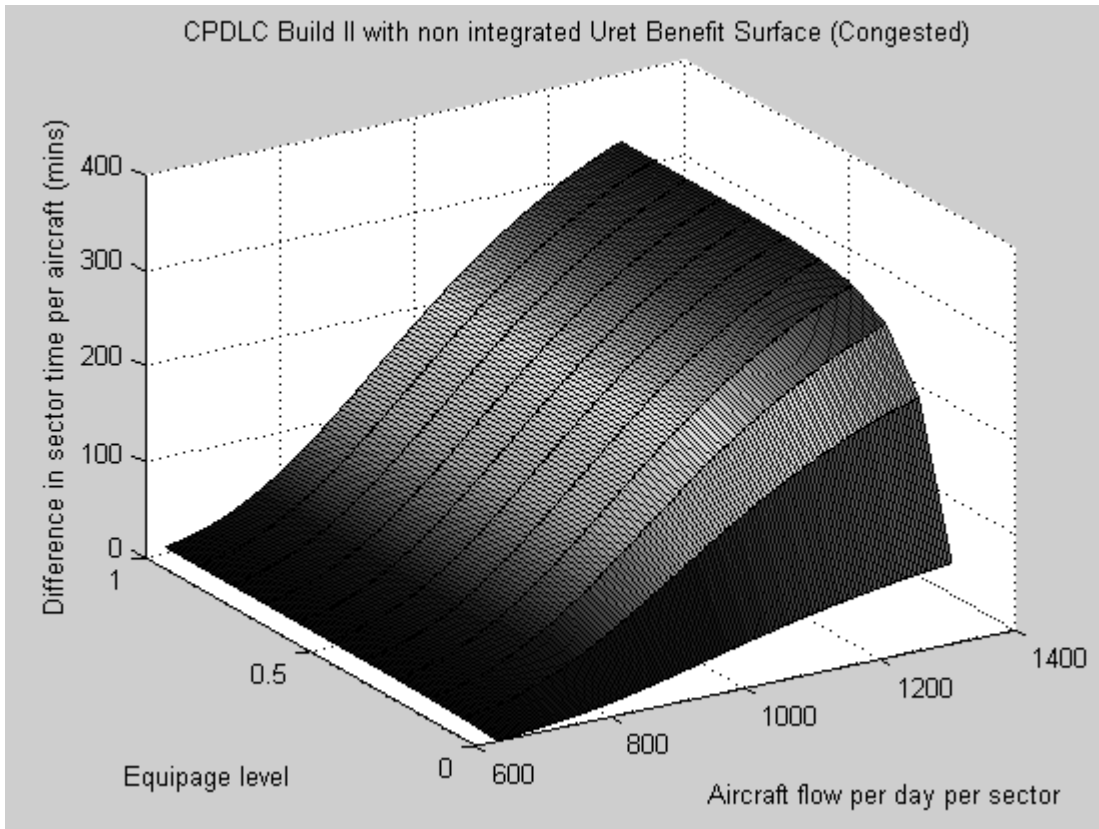


Figure 6.87 Regression Surface for CPDLC Build II with non integrated URET (Congested)

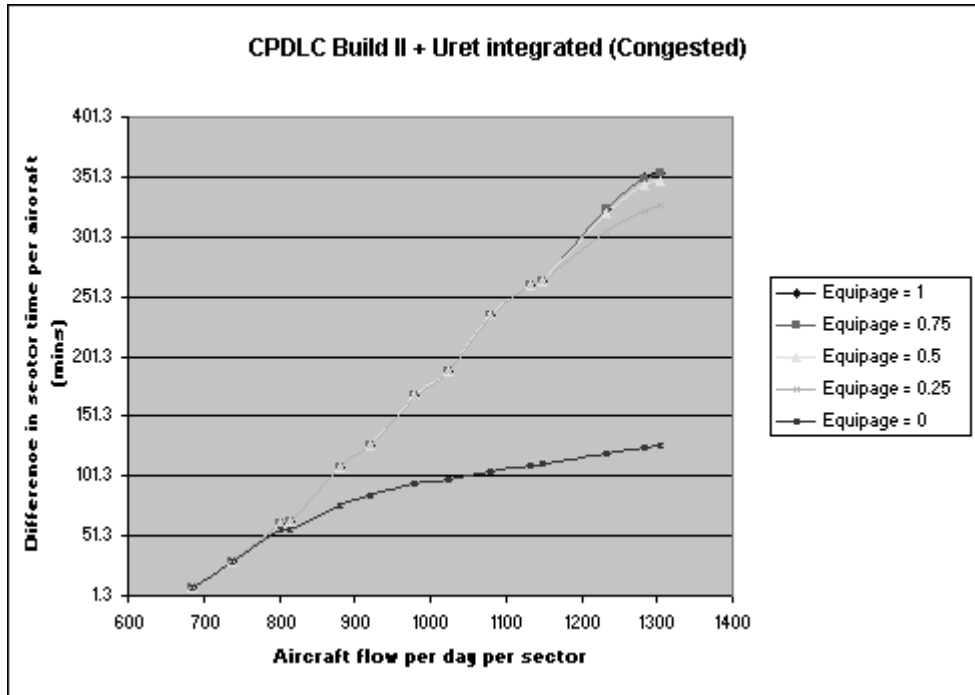


Figure 6.88 Sector time difference per aircraft for CPDLC Build II and integrated URET (Congested)
 A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build II with integrated URET.

$$y = \frac{a}{(1 + e^{x(b-c)})^d} \tag{6.44}$$

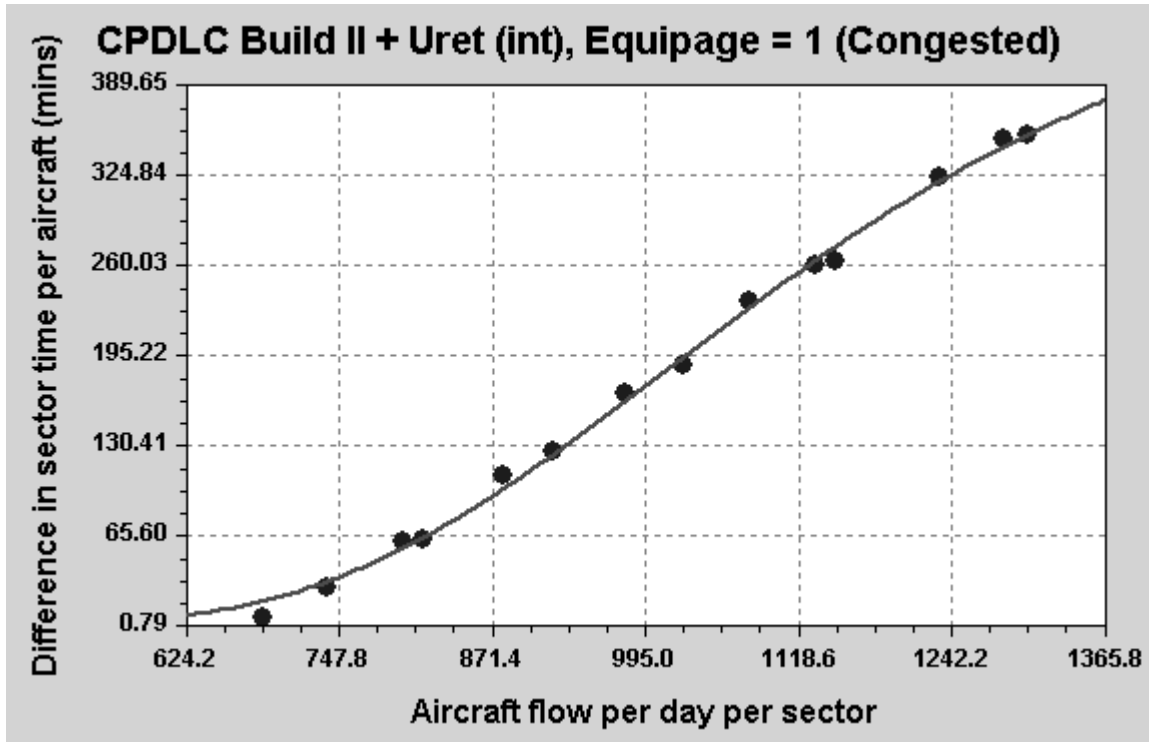


Figure 6.89 Non Linear fit between delta and aircraft density for CPDLC Build II with integrated URET at 100 percent equipage level (Congested)

Figure 6.89 shows a sample exponential fit relationship between delta for CPDLC Build II with integrated URET and aircraft flow per day per sector for equipage level of 1. The R-square for the fit is 0.98.

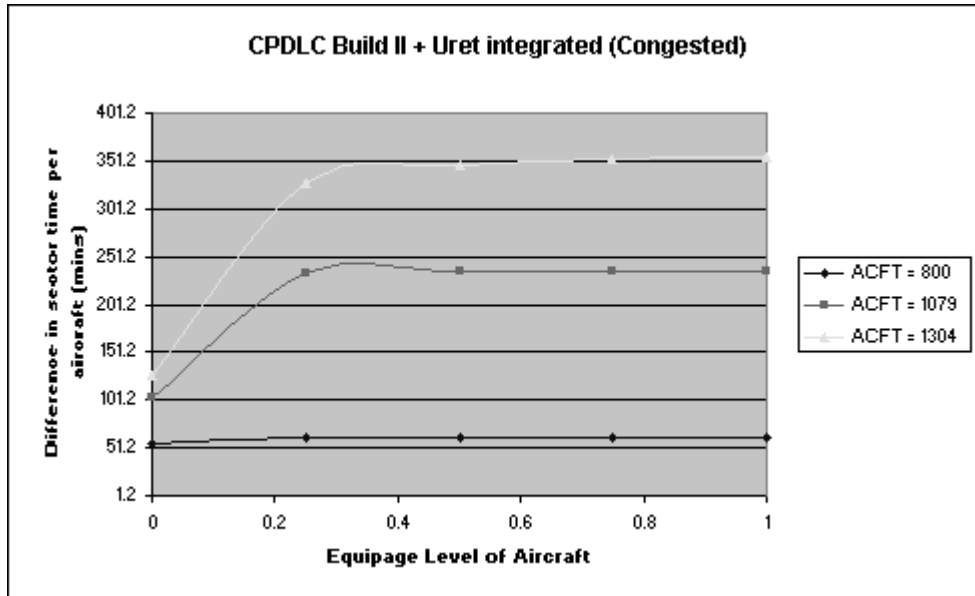


Figure 6.90 Sector time difference per aircraft for CPDLC Build II with integrated URET v/s Equipage level (Congested)

A exponential fit of the form shown in the equation below is established to be a good fit between difference in sector traversal time (delta) per aircraft for CPDLC Build II with integrated URET and equipage level.

$$y = a(b - ex^{-cx}) \tag{6.45}$$

Figure 6.91 shows a sample exponential fit relationship between delta for CPDLC Build II with integrated URET and equipage level for aircraft flow per day per sector for of 880. The R-square for the fit is 0.99.

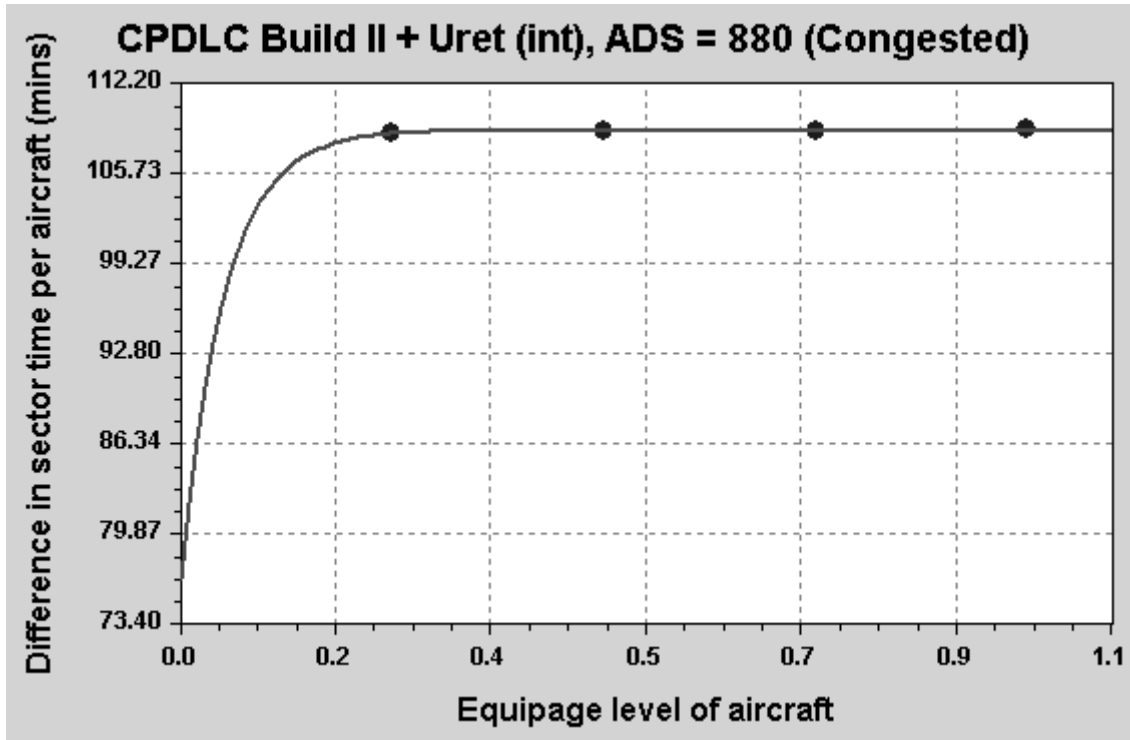


Figure 6.91 Exponential fit between delta and equipage level for CPDLC Build II with integrated URET at ADS = 880 (Congested)

After determining the relationship of equipage level (EI_a) and ADS with sector time difference per aircraft for CPDLC Build II with integrated URET, a non-linear two parameter regression surface is constructed which is of the form as shown in the equation below.

$$y = \frac{a(e - ex^{-x1f})}{(1 + ex^{(b-cx2)})^d} \quad (6.46)$$

Two parameter non linear regression fitting is carried out in MATLAB using the entire output data set for CPDLC Build II with integrated URET and coefficient values are obtained as shown in Table 6.2.

Figure 6.92 shows the regression surface CPDLC Build II with integrated URET (Congested region).

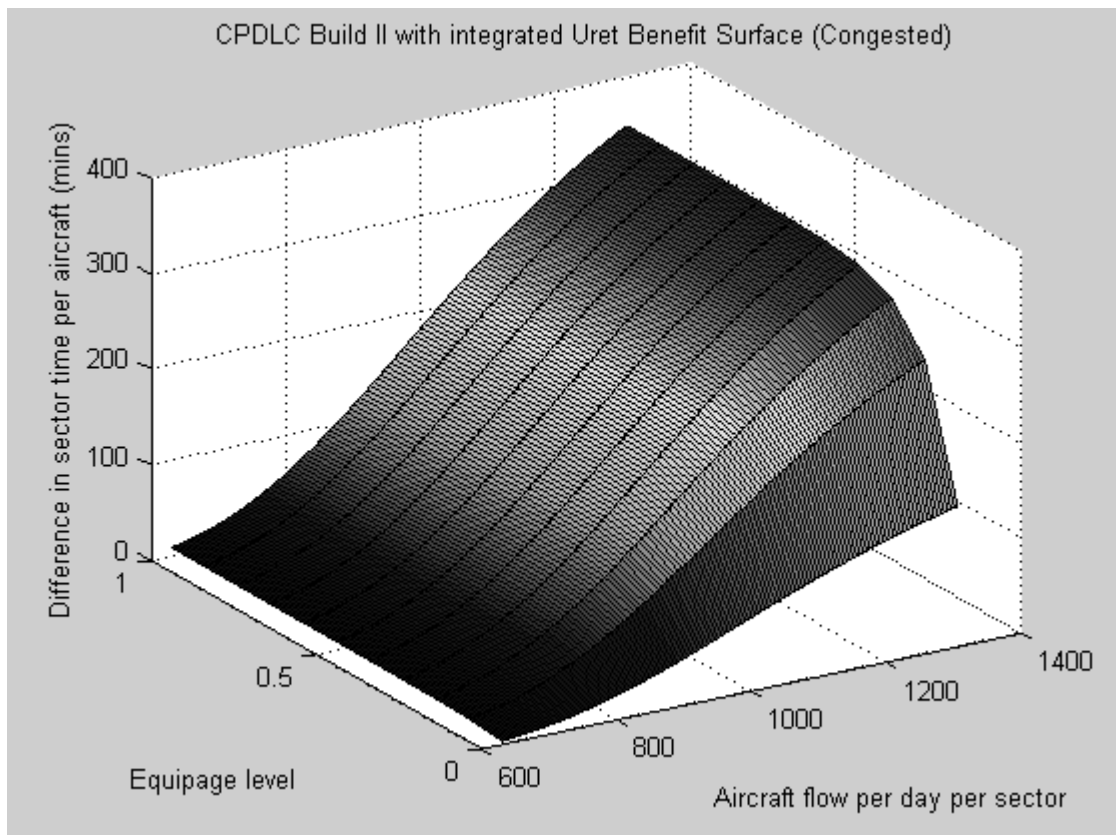


Figure 6.92 Regression surface for CPDLC Build II with integrated URET (Congested)

6.2 Enroute Sector Model

		Value	Confidence Interval		R-sq
CPDLC Build I	a	65.256	64.597	65.915	0.9974
	b	5.9903	-123.86	135.84	
	c	0.016397	0.014173	0.018621	
	d	409.59	-52086	52906	
	e	6.7854	6.4523	7.1186	
CPDLC Build I + uret non	a	87.482	82.81	92.154	0.9909
	b	-1.053	-455.94	453.83	
	c	0.0075565	0.0060814	0.0090315	
	d	1222.7	-5.53E+05	5.56E+05	
	e	1.8492	1.773	1.9255	
	f	6.0009	5.1167	6.8852	
CPDLC Build I + uret int	a	79.774	74.096	85.452	0.9927
	b	-1.5145	-437.21	434.18	
	c	0.0068684	0.0055777	0.0081592	
	d	1350.3	-5.85E+05	5.88E+05	
	e	2.6518	2.5002	2.8034	
	f	5.9458	4.7805	7.1111	
CPDLC Build IA	a	218.91	214.36	223.46	0.9979
	b	-0.73785	-233.49	232.02	
	c	0.0074383	0.0064679	0.0084087	
	d	1044.2	-2.41E+05	2.43E+05	
	e	8.2034	7.7077	8.6992	
CPDLC Build IA + uret non	a	211.02	198.84	223.2	0.9949
	b	-1.7725	-324.08	320.53	
	c	0.005863	0.0045874	0.0071386	
	d	1031.3	-3.30E+05	3.32E+05	
	e	1.4111	1.3719	1.4503	
	f	8.1801	7.1568	9.2033	
CPDLC Build IA + uret int	a	195.76	175.31	216.21	0.992
	b	-2.68	-586.51	581.15	
	c	0.0050241	0.003412	0.0066362	
	d	1441.3	-8.38E+05	8.41E+05	
	e	1.8234	1.7398	1.9071	
	f	8.2211	6.5532	9.889	
CPDLC Build II	a	298.28	288.16	308.4	0.998
	b	-1.3758	-168.58	165.83	
	c	0.0059854	0.0050955	0.0068753	
	d	785.08	-1.30E+05	1.31E+05	
	e	9.0257	8.4072	9.6442	
CPDLC Build II + uret non	a	295.09	261.97	328.2	0.9943
	b	-3.0484	-577.6	571.51	
	c	0.0045493	0.0030634	0.0060351	
	d	1538.8	-8.80E+05	8.83E+05	
	e	1.3476	1.3076	1.3877	
	f	9.9509	8.2669	11.635	
CPDLC Build II + uret int	a	265.37	213.64	317.11	0.9905
	b	-3.6092	-866.89	859.67	
	c	0.0039331	0.0020397	0.0058266	
	d	1739	-1.50E+06	1.50E+06	
	e	1.7314	1.646	1.8167	
	f	10.834	7.4379	14.229	

TABLE 6.2 Regression coefficients and confidence intervals (Congested)

6.2.2 Controller Workload Metrics

Controller workload is measured by two metrics namely Controller Activity Level (CAL) and Controller Utilization (CU).

Controller Utilization

Controller Utilization is a measure of how busy a controller remains throughout the day in routine and conflict tasks. It is a ratio of the total time spent by a controller in routine and conflicts to the total time available which is a single day's period.

Figure 6.93 shows the controller utilization for alternative A as a function of the aircraft flow per day per sector. As seen from the figure when the aircraft flow per day per sector becomes greater than 900 the controller utilization becomes greater than 1 which means that more than a days time is required to resolve conflicts and routine tasks.

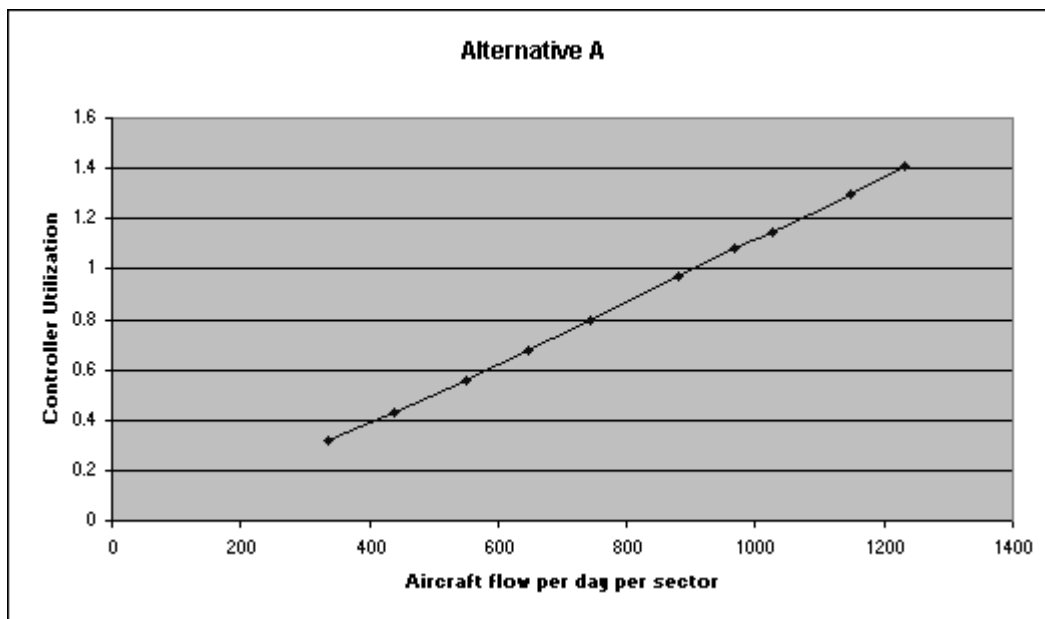


Figure 6.93 Controller utilization versus aircraft density for alternative A

Figure 6.94 shows the percentage reduction in the controller utilization for 100 percent equipage level of aircraft for different scenarios. From the figure it can be seen that the percentage reduction remains fairly constant for varying aircraft flow per day per sector meaning that the actual reduction in the time

that the controller spends in resolving routine and conflicts tasks reduces linearly with increase in aircraft flow per day per sector.

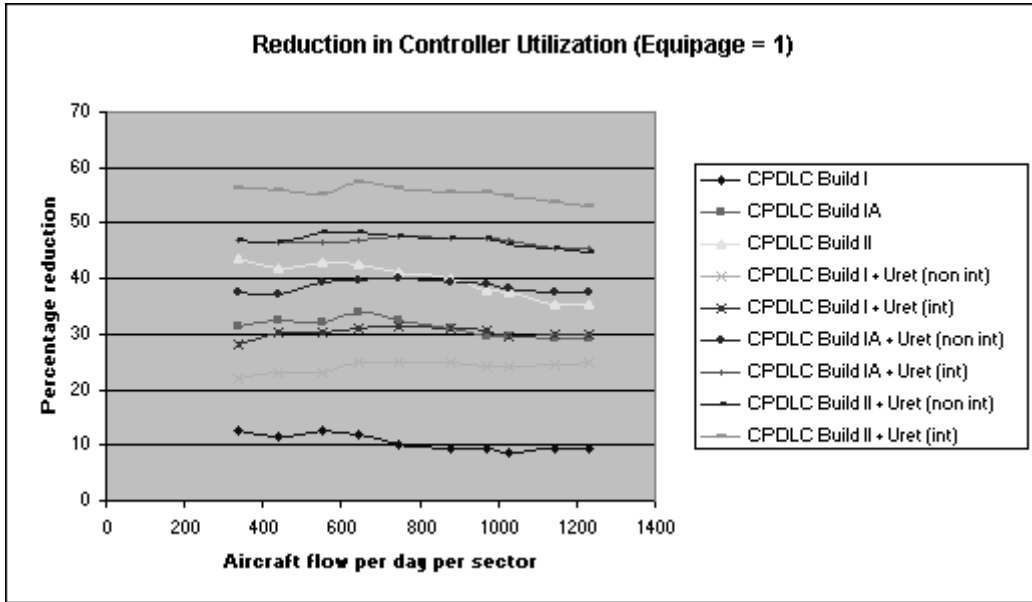


Figure 6.94 Reduction in controller utilization for 100 percent equipage level of aircraft

Figure 6.95 shows the percentage reduction in the controller utilization for aircraft flow per day per sector of 745 for different scenarios. From the figure it can be seen that the percentage reduction increases linearly with increase in equipage level of aircraft meaning that the actual reduction in the time that the controller spends in resolving routine and conflicts tasks increases quadratically with increase in equipage level.

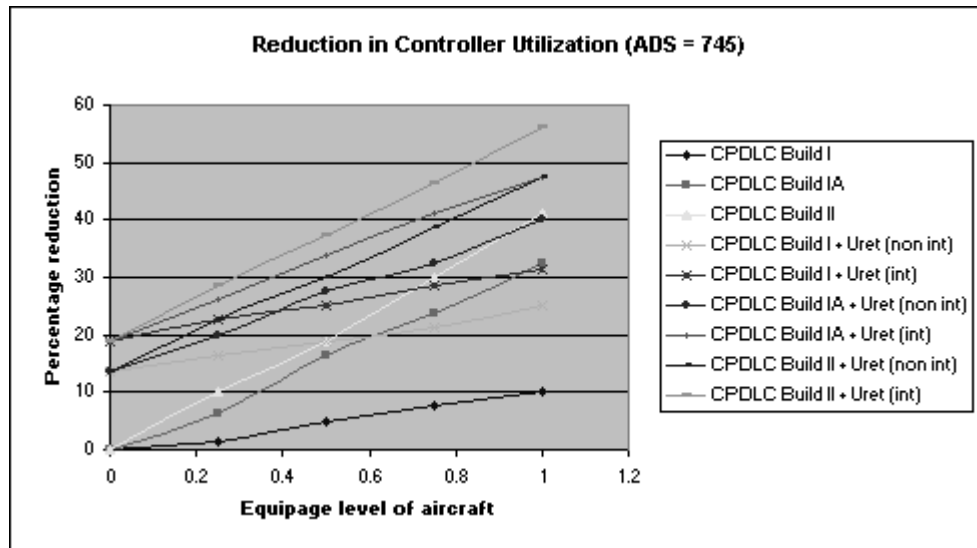


Figure 6.95 Reduction in controller utilization for ADS = 745

Controller Activity Level

Controller Activity Level measures the amount of time per time step (0.1 minute) the enroute controller is busy. It is a non dimensional parameter since its a ratio of amount of time required by the controller to resolve routine and conflict tasks to amount of time available. When the enroute controller activity level becomes equal to or greater than one no further aircraft are admitted into the enroute sector until it becomes less than one again after departure of an aircraft from the sector.

The controller activity level data is divided into four time regions as specified in chapter 5 for different inter-arrival times for injection of aircraft. This is mainly done to capture the actual activity level for peak time periods and non peak time periods rather than display an average value for an entire day.

Figure 6.96 to 6.99 shows the controller activity level for different time regions for different scenarios at 100 percent equipage level of aircraft.

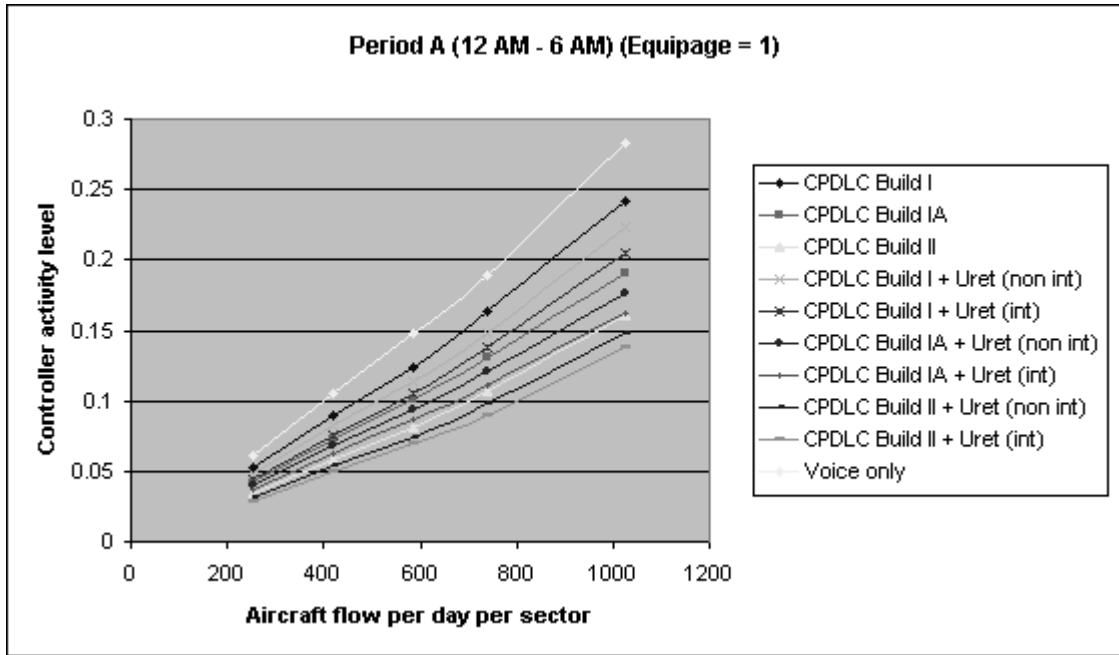


Figure 6.96 Controller activity level for period A for 100 percent equipage level

From figure 6.96, the controller activity level in time period A is fairly low and increases linearly with increase in aircraft flow per day per sector.

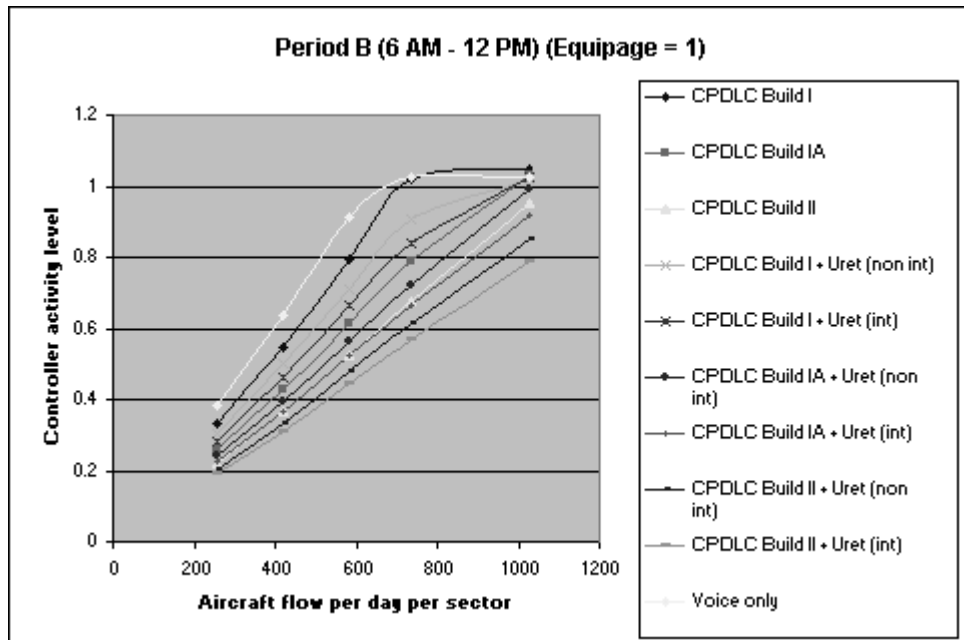


Figure 6.97 Controller activity level for period B for 100 percent equipage level

From figure 6.97, the controller activity level in time period B for alternative A (Voice only) reaches saturation (≥ 1) when the air traffic volume for the entire day is approximately 630 aircraft per day per sector and hence 630 is air traffic volume used to divide the sector time data into congested and uncongested region. Controller activity level increases linearly with increase in aircraft flow per day per sector until it reaches saturation level.

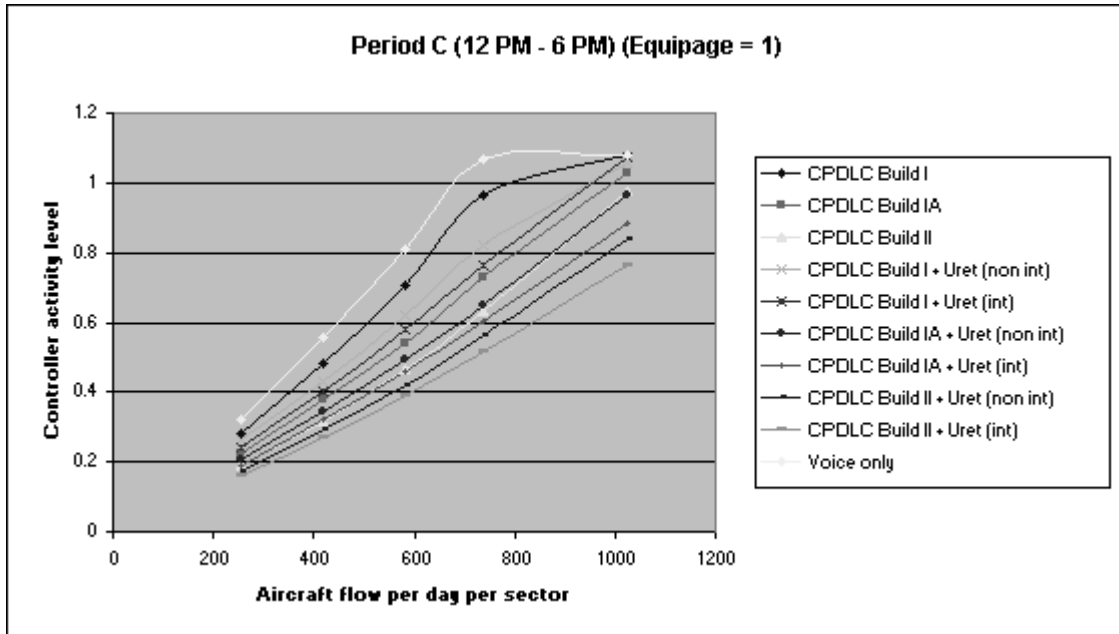


Figure 6.98 Controller activity level for period C for 100 percent equipage level

From figure 6.98, the controller activity level in time period C for alternative A (Voice only) reaches saturation (≥ 1) when the air traffic volume for the entire day is approximately 630 aircraft per day per sector and hence 630 is air traffic volume used to divide the sector time data into congested and uncongested region. Controller activity level increases linearly with increase in aircraft flow per day per sector until it reaches saturation level.

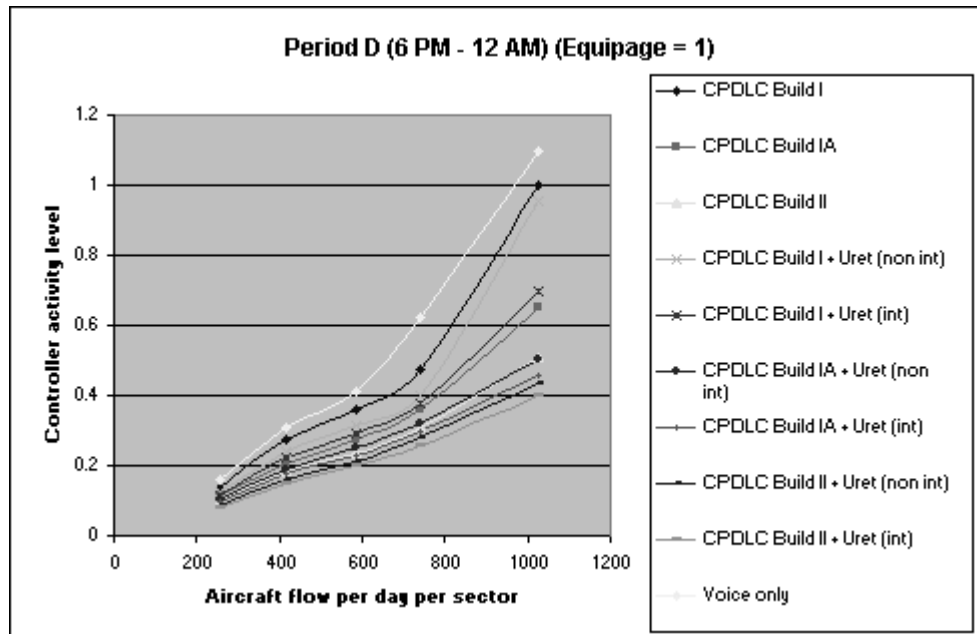


Figure 6.99 Controller activity level for period D for 100 percent equipage level

From figure 6.99, the controller activity level in time period D for alternative A (Voice only) reaches saturation (≥ 1) when the air traffic volume for the entire day is approximately 900 aircraft per day per sector. This is mainly because of the spillback effect of aircraft in the two time periods preceding period D. Controller activity level increases linearly with increase in aircraft flow per day per sector until it reaches saturation level.

Figure 6.100 to 6.103 shows the controller activity level for different scenarios with varying equipage level of aircraft at a aircraft flow per day per sector of 481. As seen from the figures the controller activity level reduces linearly with increase in equipage level of aircraft, this is mainly as more aircraft are equipped with datalink infrastructure onboard, more datalink transactions take place between pilots and controllers thereby reducing the activity level of controllers.

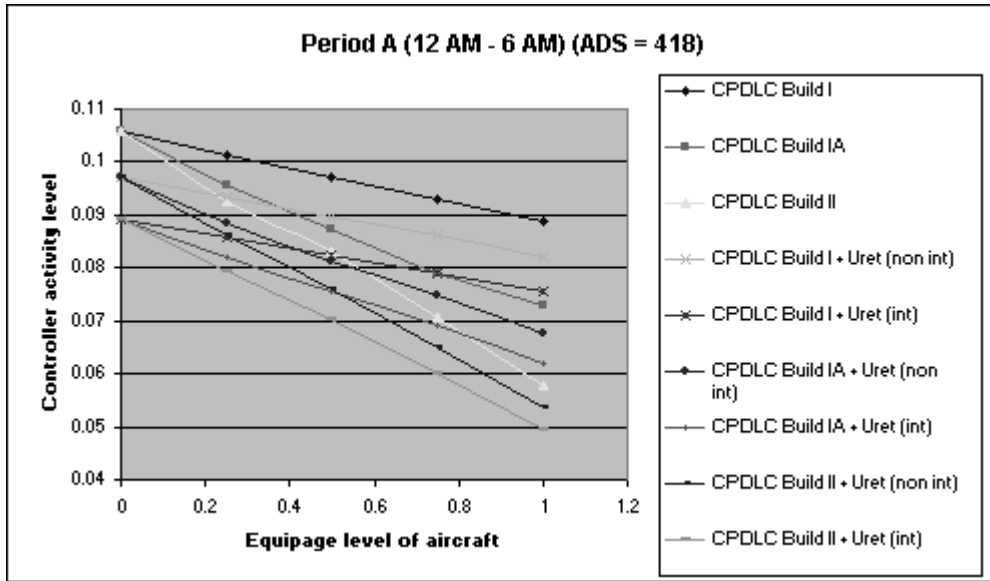


Figure 6.100 Controller activity level for period A for ADS = 418

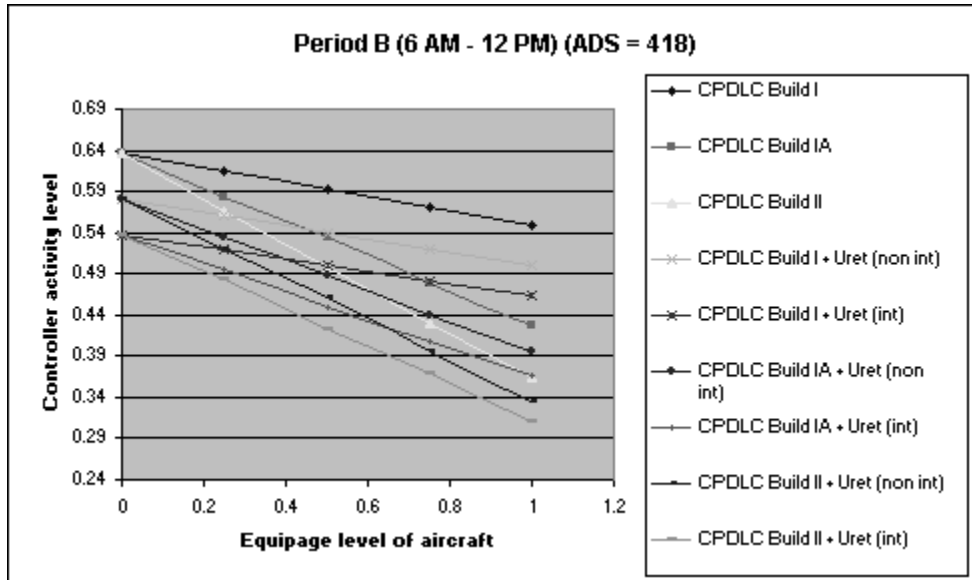


Figure 6.101 Controller activity level for period B for ADS = 418

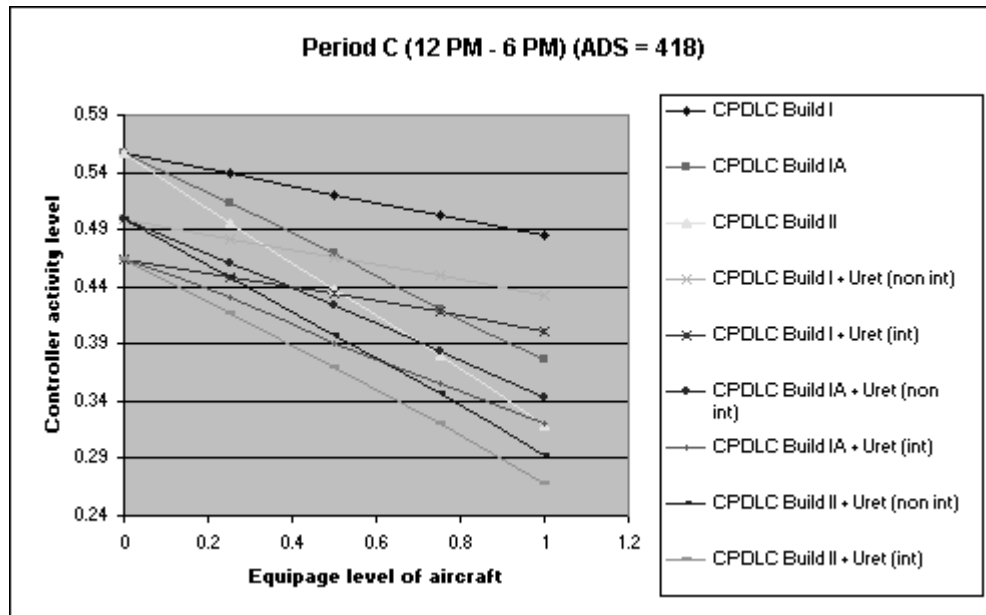


Figure 6.102 Controller activity level for period C for ADS = 418

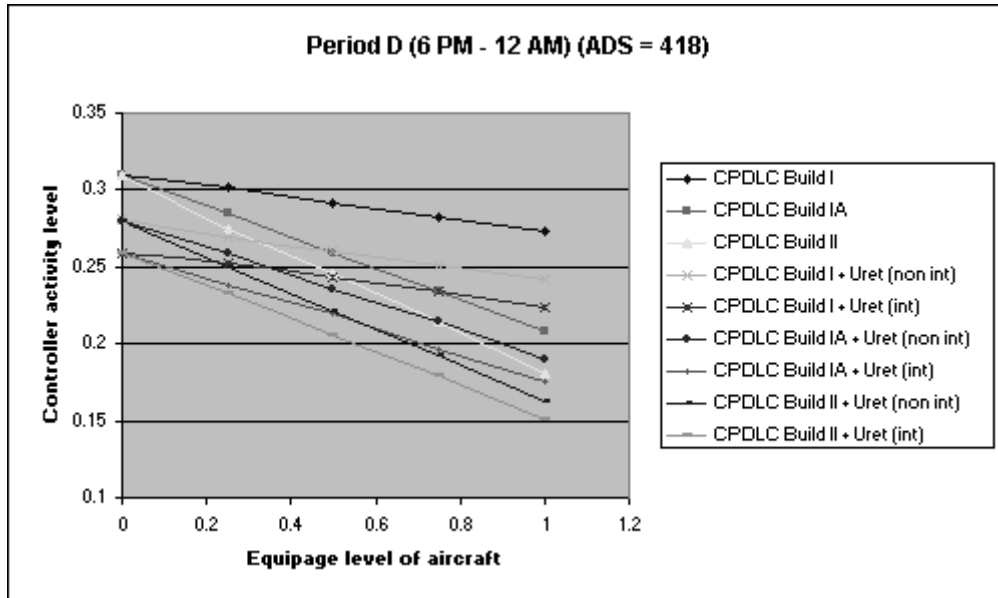


Figure 6.103 Controller activity level for period D for ADS = 418

6.2.3 Communication Channel Utilization

Voice Channel Utilization

Voice channel utilization is a primary measure of the amount of time that the voice channel is used for communications between controllers and pilots. It is a ratio of the total time that the voice communication channel is busy during the entire day to the total amount of time available in the day.

Figure 6.104 shows the actual voice channel utilization for alternative with varying aircraft flow per day per sector. It shows a linear relationship between voice channel utilization and aircraft flow per day per sector.

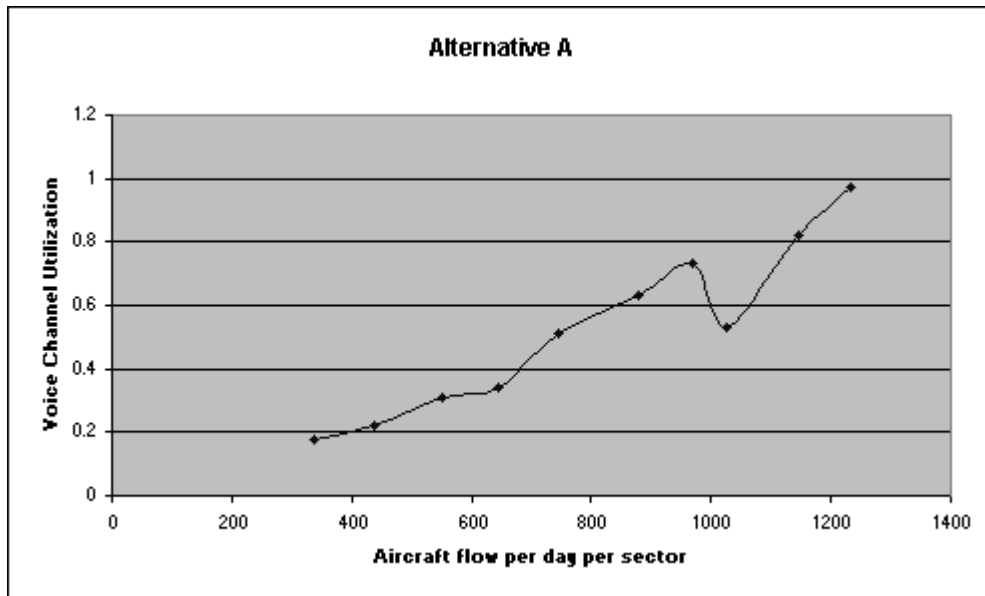


Figure 6.104 Voice channel utilization for alternative A

Figure 6.105 shows the percentage reduction in the voice channel utilization for 100 percent equipage level of aircraft for different scenarios. From the figure it can be seen that the percentage reduction remains fairly constant for varying aircraft flow per day per sector meaning that the actual reduction in the time that the voice channel is used reduces linearly with increase in aircraft flow per day per sector.

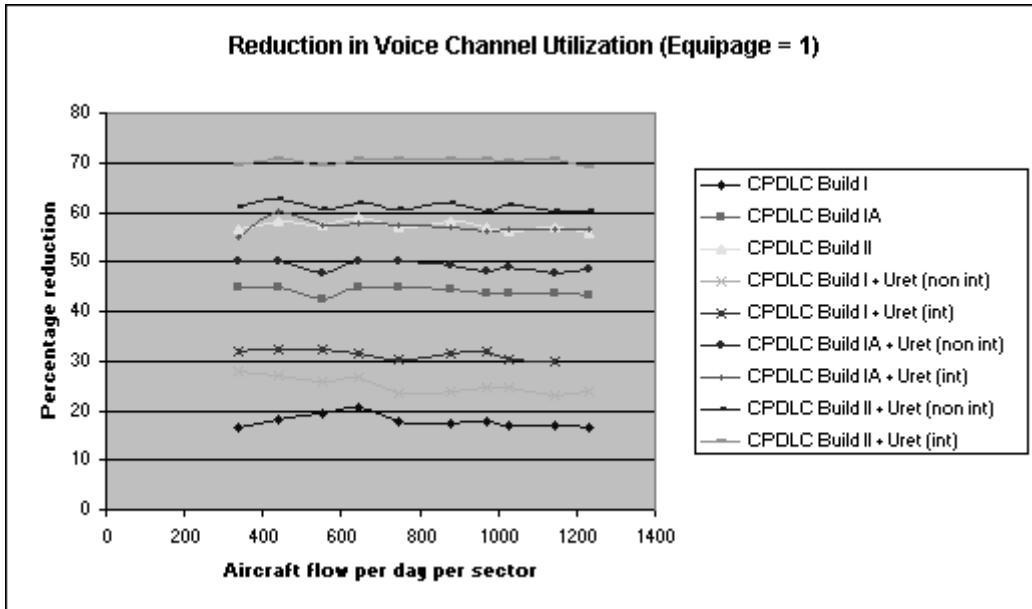


Figure 6.105 Reduction in voice channel utilization for 100 percent equipage level of aircraft

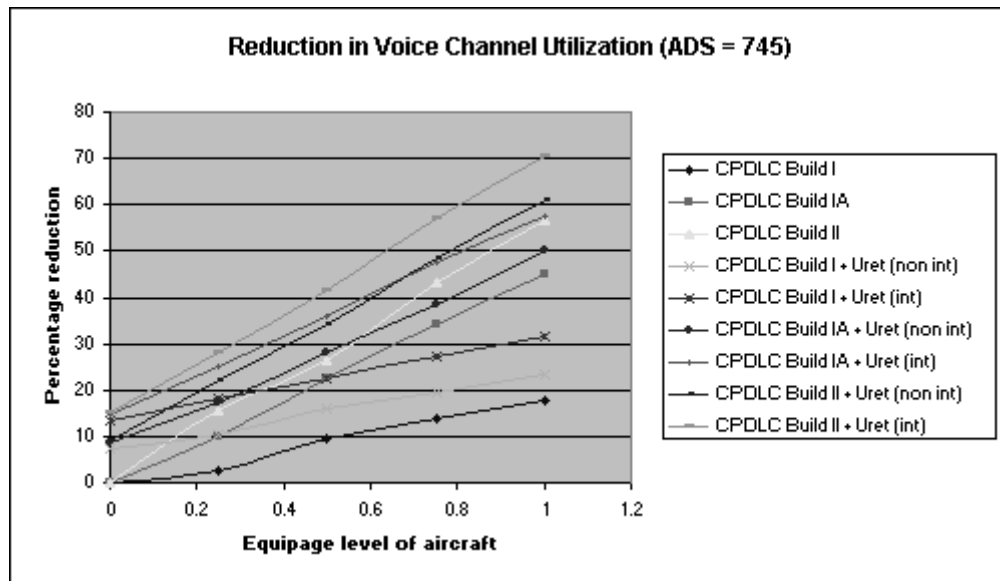


Figure 6.106 Reduction in voice channel utilization for ADS = 745

Macroscopic Model Description

7.1 Outline of the model

The upper level model is the macroscopic annual model and is called the datalink and decision support tools investment model. The macroscopic annual model accepts inputs in the form of response curves from the microscopic daily model and runs over the entire life cycle period. Inputs from the microscopic model are in the form of airspace occupation benefit surfaces as a function of traffic density, equipage level of aircraft and CPDLC Build Status. The life cycle period is considered to be 25 years from the year of implementation of different ATC technologies. The time step of the model is a year. The four major outputs of the model are Airline Benefits, Safety Benefit, Training Cost and Technology Cost. The outputs are coalesced together to determine system wide benefits and costs as applicable to the FAA or airline or both. A number of the parameters have not been quantified since sufficient data is not yet available at the present moment.

The basic structure of the model is that it is divided into four modules each module representing either a kind of benefit or cost to either the FAA or the airline (user). The four modules feed into the main module called the Net Benefits module.

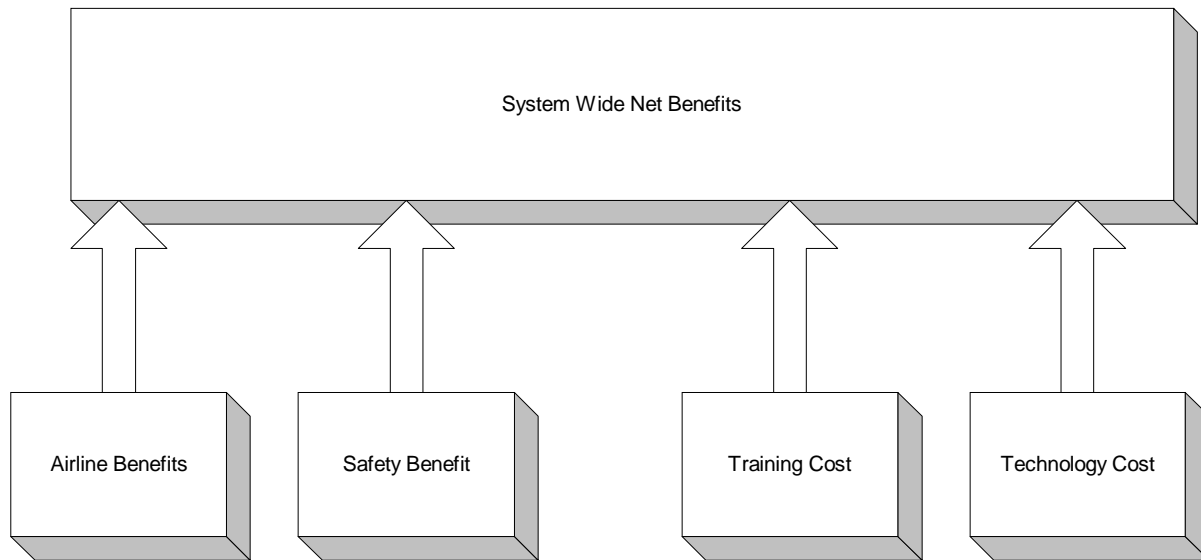


Figure 7.1 Basic structure of the macroscopic annual model

Start Year (Yr_{start})

This variable defines the year that the simulation is supposed to begin. A slider device is assigned to it at the interface layer to change the start year of simulation.

Base Year (Yr_{base})

It is the year at which actual data like traffic volume is obtained and fed into the model and from where data like traffic density are projected forward into the future.

$$Yr_{base} = 2002 \tag{7.1}$$

Traffic Growth (TG)

Traffic Growth is the percentage of flights that is expected to increase over the entire National Airspace System (NAS) as compared to the base year which is 2002. Even though the air traffic growth is estimated to be exponential, the growth is normalized to get a linear increase and a constant percentage every year. Eighty percent of the traffic growth is attributed due to increase in number of aircraft and twenty percent is attributed to a increase in number of flights per aircraft. A slider device is assigned

to it at the interface layer to change its value either before or even during the simulation. A value of 5 percent is used in the simulation.

$$TG = 0.05 \tag{7.2}$$

7.1.1 Simulation Parameters

The model is run over the entire life cycle of 25 years with a time step of 1 year resulting in 25 time steps over the entire life cycle. The model runs from 0 time step to 25 time steps. The run mode for the model can be "Normal," or "Cycle-time." Normal mode was selected since no cycle time metrics have to be generated and collected. There are three methods of integration Euler's, Runge-Kutta second-order, and Runge-Kutta fourth-order methods. Since the model is a continuous one without any discrete objects like Queue and Conveyor variables and Euler's is not as accurate, Runge-Kutta fourth-order was chosen.

From	0 time step
To	25 time step
Time step	1 year
Run mode	Normal
Integration method	Runge Kutta fourth-order

TABLE 7.1 Simulation Parameters of Macroscopic Annual Model

7.1.2 Airline Benefits module

The airline benefits module quantifies the cash in US dollars (\$) saved by airlines due to reduction in travel time of each flight between origin and destination airport. The main input for this module comes from the airspace occupation module of the microscopic daily model. The reduction in the airspace occupation time by an aircraft in the enroute sector as well as tracon airspace is converted to a monetary benefit to the airlines. This benefit is cumulated over the entire life cycle of the model. All the variables in the airline benefit module are described below.

For the purpose of determining the average number of enroute sectors that an aircraft traverses during a typical flight, the flights were categorized into four categories according to their stage length in nautical miles. Stage length is distance between the origin and destination airport of a flight.

	State Length (nautical miles)
Category I	< 750
Category II	750-1500
Category III	1500-2250
Category IV	> 2250

TABLE 7.2 Categorizing flights according to the stage length

Proportion of flights less than 750 nm (P1)

It is the percentage of flights over the entire NAS for the entire year that have a stage length of less than 750 nautical miles.

Proportion of flights bw 750 and 1500 nm (P2)

It is the percentage of flights over the entire NAS for the entire year that have a stage length between 750 and 1500 nautical miles.

Proportion of flights bw 1500 and 2250nm (P3)

It is the percentage of flights over the entire NAS for the entire year that have a stage length between 1500 and 2250 nautical miles.

Proportion of flights greater than 2250 nm (P4)

It is the percentage of flights over the entire NAS for the entire year that have a stage length greater than 2250 nautical miles.

Enroute sectors traversed for P1 (E1)

It is the average number of enroute sectors that an airplane would traverse when the stage length of the flight is less than 750 nautical miles.

Enroute sectors traversed for P2 (E2)

It is the average number of enroute sectors that an airplane would traverse when the stage length of the flight is between 750 and 1500 nautical miles.

Enroute sectors traversed for P3 (E3)

It is the average number of enroute sectors that an airplane would traverse when the stage length of the flight is between 1500 and 2250 nautical miles.

Enroute sectors traversed for P4 (E4)

It is the average number of enroute sectors that an airplane would traverse when the stage length of the flight is greater than 2250 nautical miles.

Weighted Average of enroute sectors traversed (E_w)

It is the average number of enroute sectors that an airplane would traverse. It is determined by taking the weighted average of the number of enroute sectors traversed for each category of stage length.

$$E_w = \sum_{i=1}^4 (P_i \times E_i) \quad (7.3)$$

Equipage rate for CPDLC Build I (E_{BI})

It is the percentage of whole National Airspace System (NAS) that is going to be equipped every year with infrastructure required for implementing CPDLC Build I. It is a rate variable. A slider device is assigned to it at the interface layer to change its value either before or even during the simulation.

Equipage level for CPDLC Build I (El_{BI})

It is percentage of the whole National Airspace System (NAS) of aircraft equipped with infrastructure required for implementing CPDLC Build I. It is a level variable modeled as a reservoir stock

$$El_{BI}(t) = \int_{t1}^t E_{BI} dt \quad (7.4)$$

where t_1 is the year of implementation of CPDLC Build I.

Equipage rate for CPDLC Build IA (E_{BIA})

It is the percentage of whole National Airspace System (NAS) that is going to be equipped every year with additional infrastructure required for implementing CPDLC Build IA. A slider device is assigned to it at the interface layer to change its value either before or even during the simulation.

Equipage level for CPDLC Build IA (El_{BIA})

It is percentage of the whole National Airspace System (NAS) of aircraft equipped with infrastructure required for implementing CPDLC Build IA. It is a level variable modeled as a reservoir stock

$$El_{BIA}(t) = \int_{t_2}^t E_{BIA} dt \quad (7.5)$$

where t_2 is the year of implementation of CPDLC Build IA.

Equipage rate for CPDLC Build II (E_{BII})

It is the percentage of whole National Airspace System (NAS) that is going to be equipped every year with additional infrastructure required for implementing CPDLC Build II. A slider device is assigned to it at the interface layer to change its value either before or even during the simulation.

Equipage level for CPDLC Build I (El_{BII})

It is percentage of the whole National Airspace System (NAS) of aircraft equipped with infrastructure required for implementing CPDLC Build II. It is a level variable modeled as a reservoir stock

$$El_{BII}(t) = \int_{t_3}^t E_{BII} dt \quad (7.6)$$

where t_3 is the year of implementation of CPDLC Build II.

Equipage rate for URET (E_u)

It is the percentage of whole National Airspace System (NAS) that is going to be equipped every year with infrastructure required for implementing URET. A slider device is assigned to it at the interface layer to change its value either before or even during the simulation.

Equipage level for URET (EL_u)

It is percentage of the whole National Airspace System (NAS) of aircraft equipped with infrastructure required for implementing URET. It is a level variable modeled as a reservoir stock

$$EL_u(t) = \int_{t4}^t E_u dt \quad (7.7)$$

where $t4$ is the year of implementation of URET.

Equipage rate for TMA (E_t)

It is the percentage of whole National Airspace System (NAS) that is going to be equipped every year with infrastructure required for implementing TMA. A slider device is assigned to it at the interface layer to change its value either before or even during the simulation.

Equipage level for TMA (EL_t)

It is percentage of the whole National Airspace System (NAS) of aircraft equipped with infrastructure required for implementing TMA. It is a level variable modeled as a reservoir stock

$$EL_t(t) = \int_{t5}^t E_t dt \quad (7.8)$$

where $t5$ is the year of implementation of TMA.

Equipage rate for PFAST (E_p)

It is the percentage of whole National Airspace System (NAS) that is going to be equipped every year

with infrastructure required for implementing PFAST. A slider device is assigned to it at the interface layer to change its value either before or even during the simulation.

Equipage level for PFAST (El_p)

It is percentage of the whole National Airspace System (NAS) of aircraft equipped with infrastructure required for implementing PFAST. It is a level variable modeled as a reservoir stock

$$El_p(t) = \int_{t_6}^t E_p dt \quad (7.9)$$

where t_6 is the year of implementation of PFAST.

No of enroute sectors per flight having CPDLC Build II infrastructure (Ne_{BII})

It is the number of enroute sectors per flight having the necessary infrastructure to carry out datalink message exchange between a controller and pilot from a CPDLC Build II message set. It is product of the Weighted average of enroute sectors and Equipage level for CPDLC Build II.

$$Ne_{BII} = E_w \times El_{BII} \quad (7.10)$$

No of enroute sectors per flight having CPDLC Build IA infrastructure (Ne_{BIA})

It is the number of enroute sectors per flight having the necessary infrastructure to carry out datalink message exchange between a controller and pilot from a CPDLC Build IA message set. It is product of the Weighted average of enroute sectors and difference in Equipage level for CPDLC Build IA and II.

$$Ne_{BII} = E_w \times (El_{BIA} - El_{BII}) \quad (7.11)$$

The proportion of sectors having Build II is subtracted from Build IA to avoid double counting since

Build II is a subset of Build IA.

No of enroute sectors per flight having CPDLC Build I infrastructure (Ne_{BI})

It is the number of enroute sectors per flight having the necessary infrastructure to carry out datalink message exchange between a controller and pilot from a CPDLC Build I message set. It is product of the Weighted average of enroute sectors and difference in Equipage level for CPDLC Build I and IA.

$$Ne_{BI} = E_w \times (El_{BI} - El_{BIA}) \quad (7.12)$$

The proportion of sectors having Build IA is subtracted from Build I to avoid double counting since Build IA is a subset of Build I.

No of enroute sectors per flight having URET infrastructure (Ne_u)

It is the number of enroute sectors per flight having the necessary infrastructure to detect conflicts upto 20 minutes downstream and also have the capability of doing trial planning. It is product of the Weighted average of enroute sectors and Equipage level for URET.

$$Ne_u = E_w \times El_u \quad (7.13)$$

No of sectors in NAS (NS_{NAS})

It is the total number of enroute sectors in NAS. Assuming 40 enroute sectors per ARTCC and 20 ARTCC leads to 800 enroute sectors in NAS.

Base year traffic over NAS ($Demand_{base}$)

It is the number of flights that has taken place over the entire National Airspace System (NAS) during the base year which is 2002.

Year of simulation (Yr_s)

When the model is running over the entire life cycle, year of simulation keeps track of the year being simulated at any time.

$$Yr_s = Yr_{start} + TIME \quad (7.14)$$

Average traffic volume per day (APD)

It is average number of flights taking place over NAS over the entire day for a given year.

$$APD = Demand_{base} \times (1 + TG) \times (Yr_s - Yr_{base}) / 365 \quad (7.15)$$

Proportion of high density sectors (P_{he})

It is the percentage of enroute sectors in NAS that are considered high density. In the model it is assumed to be 33 percent.

Proportion of medium density sectors (P_{me})

It is the percentage of enroute sectors in NAS that are considered medium density. In the model it is assumed to be 33 percent.

Proportion of low density sectors (P_{le})

It is the percentage of enroute sectors in NAS that are considered low density. In the model it is assumed to be 33 percent.

Proportion of traffic into high density sectors (Pt_{he})

It is the percentage of air traffic volume per day that traverses through high density sectors. In the model it is assumed to be 50 percent.

Proportion of traffic into medium density sectors (Pt_{me})

It is the percentage of air traffic volume per day that traverses through medium density sectors. In the model it is assumed to be 33 percent

Proportion of traffic into low density sectors (Pt_{le})

It is the percentage of air traffic volume per day that traverses through low density sectors. In the model it is assumed to be 17 percent.

Traffic density in high density sectors (ATD_{he})

It is the average volume of air traffic per day traversing through an enroute sector classified as high density. The main idea behind dividing the average traffic into three categories of traffic depending upon the traffic density is because an average value across all 3 categories of sector will not capture the true enroute savings especially in the congested region of traffic.

$$ATD_{he} = \frac{APD \times Pt_{he}}{NS_{NAS} \times P_{he}} \quad (7.16)$$

Traffic density in medium density sectors (ATD_{me})

It is the average volume of air traffic per day traversing through an enroute sector classified as medium density.

$$TD_{me} = \frac{APD \times Pt_{me}}{NS_{NAS} \times P_{me}} \quad (7.17)$$

Traffic density in low density sectors (ATD_{le})

It is the average volume of air traffic per day traversing through an enroute sector classified as low density.

$$ATD_{le} = \frac{APD \times Pt_{le}}{NS_{NAS} \times P_{le}} \quad (7.18)$$

Enroute savings per sector (ES)

It is the time saved to traverse an enroute sector by an aircraft for alternative B, C and D as compared to the base alternative A. It depends on the air traffic density and equipage level of aircraft. After running the microscopic model with varying traffic density per day and equipage level of aircraft, 3-D surfaces were generated using non linear regression fits in MATLAB which quantified enroute time savings per sector as a function of equipage level and traffic flow per sector per day. Different surfaces

were generated for each CPDLC Build with and without URET in a integrated and non integrated scenario. The 3-D surfaces for each scenario were divided into two regions, one region uncongested traffic flow denoting all traffic flow upto saturation flow of an enroute sector and second region being the saturated region.

$$ES_{(x, y, z)} = \begin{cases} f_{ucon}(El_a, ATD) & \text{if}(ATD \leq 630) \\ f_{con}(El_a, ATD) & \text{if}(ATD > 630) \end{cases} \quad (7.19)$$

x is the alternative B,C or D.

y is the CPDLC Build whether Build I (BI), IA (BIA) or II (BII) or no build (n).

z is the traffic density category of the enroute sector le, me or he.

All 3-D non linear regression surfaces for all alternatives and for both uncongested and congested region have been described in chapter 6.

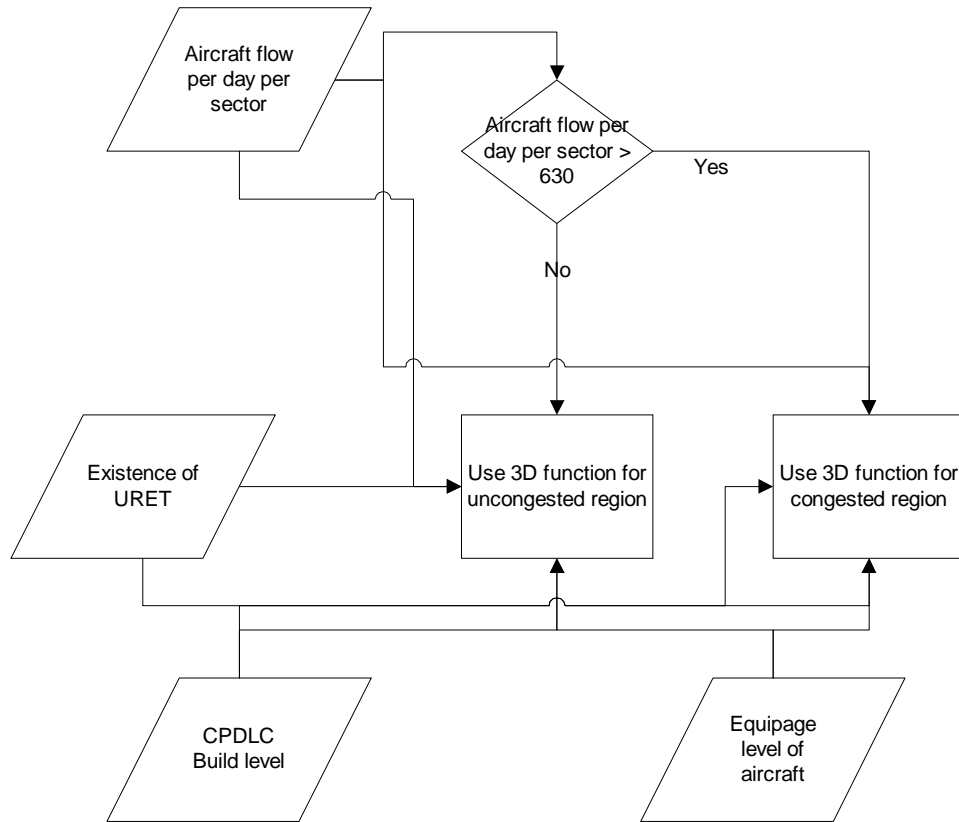


Figure 7.2 Flow chart denoting logic of calculation of enroute savings

Total enroute savings per flight for alternative B (TES)

In a typical flight, some enroute sectors would have the capability to carry out datalink communications in different build stages and some would not. It is the weighted sum of the savings per flight for the enroute part for alternative B.

$$ES_B = \sum_y Ne_y \sum_z (P_z \times ES_{(B, y, z)}) \tag{7.20}$$

Total enroute savings per flight for alternative C (TES)

Some enroute sectors in a flight will have only URET, some will have only some build of CPDLC, some sectors will have both and some enroute sectors might have none. It is the weighted sum of the savings from all enroute sectors per flight for a given alternative for alternative C.

$$\begin{aligned}
 & \sum_y \text{MIN} \left(N_u \times \frac{Ne_y}{Ne_{BI} + Ne_{BIA} + Ne_{BII}}, Ne_y \right) \sum_z (P_z \times ES_{(C, y, z)}) \\
 TES_C = & \sum_y \text{MAX} \left((1 - N_u) \times \frac{Ne_y}{Ne_{BI} + Ne_{BIA} + Ne_{BII}}, 0 \right) \sum_z (P_z \times ES_{(B, y, z)}) + contd^{TMA} \quad (7.21) \\
 & \sum_y \text{MAX}(N_u - Ne_y, 0) \sum_z (P_z \times ES_{(C, n, z)})
 \end{aligned}$$

Total enroute savings per flight for alternative D(TES)

Some enroute sectors in a flight will have only URET, some will have only some build of CPDLC and some sectors will have both. It is the weighted sum of the savings from all enroute sectors per flight for a given alternative for alternative D.

$$\begin{aligned}
 & \sum_y \text{MIN} \left(N_u \times \frac{Ne_y}{Ne_{BI} + Ne_{BIA} + Ne_{BII}}, Ne_y \right) \sum_z (P_z \times ES_{(D, y, z)}) + "" \\
 ES_D = & \sum_y \text{MAX} \left((1 - N_u) \times \frac{Ne_y}{Ne_{BI} + Ne_{BIA} + Ne_{BII}}, 0 \right) \sum_z (P_z \times ES_{(B, y, z)}) + "" \quad (7.22) \\
 & \sum_y \text{MAX}(N_u - Ne_y, 0) \sum_z (P_z \times ES_{(D, n, z)})
 \end{aligned}$$

Arrival savings (ES)

It is the time saved in the arrival segment of the flight for alternative B,C and D as compared to the base

alternative A.

$$AS_{(x, y, z)} = f_{ucon}(El_a, ATD) \quad (7.23)$$

x is the alternative B,C or D.

y is the CPDLC Build whether Build I (BI), IA (BIA) or II (BII) or no build (n).

z is the traffic density category of the airport It (low), mt (medium) or ht (hub).

All 3D functions for all alternatives can be developed using the results from the microscopic model.

Proportion of flights from hub airports (P_{ht})

It is the percentage of all flights in NAS over the entire year that take-off from hub airports.

Proportion of flights from medium airports (P_{mt})

It is the percentage of all flights in NAS over the entire year that take-off from medium size airports.

Proportion of flights from small airports (P_{st})

It is the percentage of all flights in NAS over the entire year that take-off from small size airports.

Total arrival savings per flight (TAS)

It is the weighted sum of the savings per arrival for a given alternative.

$$AS_x = \frac{El_{BII} \times \sum_z (P_z \times AS_{(x, BII, z)}) + (El_{BIA} - El_{II}) \times \sum_z (P_z \times AS_{(x, BIA, z)}) + (El_{BI} - El_{BIA}) \times \sum_z (P_z \times AS_{(x, BI, z)})}{\sum_z (P_z \times AS_{(x, BI, z)})} \quad (7.24)$$

Departure savings (DS)

It is the time saved in the departure segment of the flight for alternative B,C and D as compared to the base alternative A.

Total departure savings per flight (TDS)

It is the weighted sum of the savings per departure for a given alternative.

$$DS_x = \frac{El_{BII} \times \sum_z (P_z \times DS_{(x, BII, z)}) + (El_{BIA} - El_{II}) \times \sum_z (P_z \times DS_{(x, BIA, z)}) + (El_{BI} - El_{BIA}) \times \sum_z (P_z \times DS_{(x, BI, z)})}{\sum_z (P_z \times DS_{(x, BI, z)})} \quad (7.25)$$

Cash Savings per flight (CSF)

It is amount of money saved per flight in US dollars for a given alternative.

$$CSF_x = (TDS_x + TES_x + TAS_x) \times DOC \quad (7.26)$$

where DOC is the direct operating cost per minute.

Direct Operating Cost per minute (DOC)

It is the direct cost of operating an airplane in the airspace per minute in US dollars. Since different classes of aircrafts have different operating costs, an weighted average value was taken as 30\$ per minute.

Interest Rate (R)

It is the rate at which the value of money is expected to decrease every year. It is used for calculating the Net Present Value (NPV) of all costs and benefits. A slider device is assigned to it at the interface layer to change its value either before or even during the simulation.

Airline Operational Benefit rate per year (AOBR)

It is the net present value (NPV) of airline operational benefit per year. The airline operational benefit per year is the product of the Cash saved per flight and the number of flights per year for every year till the end of the life cycle of the model and brought back to the present value.

$$AOBR_x = \frac{Demand_{base} \times (1 + TG \times (Yr + TIME)) \times CSF_x}{(1 + R)^{(Yr + TIME)}} \quad (7.27)$$

Airline Operational Benefit (AOB)

It is the net present value of total airline operational benefits. It is the integral of Airline Operational benefit rate per year.

$$AOB_x = \int_0^t AOB(t) dt \quad (7.28)$$

7.1.3 Safety Benefit Module

An operational error is defined as a violation of minimum spacing requirements between two aircraft. Most enroute operational errors are caused primarily due to two reasons, first is communication errors between controller and pilot and second is lack of situational awareness of conflicts and air traffic for a controller. 23 percent of all operational errors are caused due to communication mistakes and 65 percent of all operational errors are caused due to lack of situational awareness. The implementation of datalink and decision support tools is expected to result in reduction of operational errors mainly due to reduction in communication errors and gain in situational awareness. Since datalink is used as a communication channel, all messages transacted via the datalink channel would be free from errors like communication mistakes and repeats. The use of URET in the enroute sector increases the situational awareness of conflicts since URET detects conflicts upto 20 minutes into the future.

Error rate (Er)

It is number of operational errors that take place per 100000 flight operations. From 1989 to 1998, the error rate has been a constant 1.2 [Celio, 2000].

Operational Errors in Alternative A (OE_A)

It is number of operational errors that would take place in a given year for alternative A (voice only)

scenario.

$$OE_A(t) = Demand_{base} \times (1 + TG \times (Yr + TIME)) \times Er / 100000 \quad (7.29)$$

Proportion of operation errors caused by communication errors (P_{oc})

It is percentage of all operational errors caused every year due to communication errors like mistakes and repeats between a controller and pilot. In 1988, the FAA noted that 23 percent of all operational errors were caused by communication errors.

$$P_{oc} = 0.23 \quad (7.30)$$

Proportion of errors caused due to lack of situational awareness (P_{os})

It is the percentage of all operational errors caused every year due to lack of awareness of the controller about conflicts and aircraft in an enroute sector. From data (Conflict data from TAAM analysis), it is 65 percent or 0.65.

$$P_{os} = 0.65 \quad (7.31)$$

Year of implementation of CPDLC Build I ($t1$)

It is the year that infrastructure required for allowing the datalink message exchange for message set for CPDLC Build I is implemented. A knob is provided at the interface layer to change its value before starting the simulation.

Year of implementation of CPDLC Build IA ($t2$)

It is the year that infrastructure required for allowing the datalink message exchange for message set for CPDLC Build IA is implemented. A knob is provided at the interface layer to change its value before the simulation.

Year of implementation of CPDLC Build II ($t3$)

It is the year that infrastructure required for allowing the datalink message exchange for message set

for CPDLC Build II is implemented. A knob is provided at the interface layer to change its value before the simulation.

CPDLC Build Switches

The CPDLC Build Switches are used for the same purpose as in microscopic model, only they are activated differently. In the microscopic model they were manual activated by a flip of a switch. In the macroscopic annual model, they are automatically activated when the year of simulation becomes equal to or greater than the year of implementation.

$$CSI = IF(Yr_s \geq t1)THEN(1)ELSE(0) \tag{7.32}$$

$$CSIA = IF(Yr_s \geq t2)THEN(1)ELSE(0) \tag{7.33}$$

$$CSII = IF(Yr_s \geq t3)THEN(1)ELSE(0) \tag{7.34}$$

Reduction in Operational Errors (ROE)

It is reduction in operational errors in alternatives B, C and D as compared to the base alternative A. In alternative B, which is a datalink scenario, reduction in operational error takes place due to reduction in communication mistakes. FAA noted in 1988 that 23 percent of all operational errors were caused due to communication mistakes. The amount of reduction will depend upon equipage level of each build and the proportion of messages transacted via the datalink channel in each build.

$$ROE_B = \frac{OE_A \times P_{oc} \times (El_{BII} \times DP + (El_{BIA} - El_{BII}) \times (PcdI + APcdIA) \times (El_{BI} - El_{BIA}) \times "")}{PcdI} \tag{7.35}$$

In alternatives C and D, a further reduction of operational errors will take place due to better conflict detection capability by URET and due to trial planning procedure in URET which allows a controller to check for any downstream conflicts that could place for a given advisory. 65 percent of all opera-

tional errors are caused to lack of situational awareness on part of the controller. The amount of reduction will depend upon the proportion of conflicts resolved by trial planning (PTP) and the traffic density. For alternatives C and D, it will be the summation of the reduction of errors due to reduction in communication errors and reduction in errors due to gain in situational awareness.

$$ROE_x = ROE_B + OE_A \times P_{os} \times El_u \times (PTP_x + P_r \times (1 - PTP_x)) \quad (7.36)$$

where x is either alternative C or D,

P_r is the proportion of reduction,

El_u is the Equipage level for URET.

Proportion of reduction (P_r)

It is the percentage of reduction of operational errors for a given air traffic density. It is assumed that as traffic density increases the reduction in errors due to gain in situational awareness will reduce as compared to the reduction at lower traffic densities.

Cost per Operational Error (COE)

It is cost borne by the FAA for each operational error. Usually when an operational error occurs the controller responsible for the error is sent for retraining the cost of which is borne by the FAA. Operational error is also a potential situation for a collision between two aircraft but only a very small percentage of operational errors would actually end up in collisions which would be a huge cost to the FAA. The cost per operational error takes in account both these costs.

Safety Benefit per year (SBR)

It is the net present value of the safety benefit incurred every year till the end of the life cycle.

$$SBR_x = \frac{ROE_x \times COE}{(1 + R)^{(Yr + TIME)}} \quad (7.37)$$

where x is alternative B, C or D.

Safety Benefit (SB)

It is the cumulative value of benefits occurring every year till the end of the life cycle of the model.

$$SB_x = SBR_x(t - dt) + \int SBR_x dt \quad (7.38)$$

7.1.4 Training Cost module

This module quantifies the cost borne by the FAA and the airlines to train controllers and pilots in the usage of new technologies like datalink and decision support tools. Controllers have to be trained in the use of datalink messaging and usage of decision support tools like URET, TMA and PFAST before these technologies can be implemented and these costs are borne by the FAA. Pilots have to be trained in the use of datalink messaging before aircraft can be fitted with datalink infrastructure and these costs are borne by the airlines or user.

Datalink Controllers (DC)

It is the total number of controllers that have to be trained in the usage of datalink messaging. There are 17000 air traffic controller's in 476 towers. Mostly the R-side controller needs to be trained in datalink and some of the D-side controllers's hence applying a reduction factor of 0.8 gives 13600 controller's.

$$DC = 13600 \quad (7.39)$$

URET Controllers (UC)

It is the total number of enroute controllers that have to be trained in the usage of the conflict probe tool, URET. There are approximately 40 sectors per ARTCC and a total of 20 ARTCC's and assuming three shifts per day gives 4800 enroute controllers. Only the D-side controller needs to be trained in URET hence number of controller's to be trained in URET is 2400.

$$UC = 2400 \quad (7.40)$$

PFAST Controllers (TC)

It is the total number of traffic management coordinators that have to be trained in the usage of traffic management advisor (TMA) tool. Since there are 20 ARTCC's and assuming 1 traffic management coordinator per ARTCC and three shifts per day gives a total of 60 TMA controllers.

$$TC = 60 \quad (7.41)$$

PFAST Controllers (PC)

It is the total number of terminal area controllers that have to be trained in the usage of the PFAST. There are around 470 commercial airports all of which are not actively used. Assuming a reduction factor of 0.9 gives a total of 423 airports. Assuming five controllers per airport would use PFAST gives a total of 2115 controllers.

$$PC = 2115 \quad (7.42)$$

Initial No of pilots to be trained (INP)

It is the number of pilots that have to be trained in datalink messaging for the base year. There are 62000 pilots at 42 airlines in US and Canada. Assuming 90 percent of those are in US only gives 55800 pilots.

$$INP = 55800 \quad (7.43)$$

Datalink Controller training Cost (DTC)

It is the cost of training a controller in the usage of datalink messaging. Assuming a typical 1 month training program would entail costs for the equipment usage as well as remuneration of the controller. Assuming 4000\$ remuneration for the controller and another 10,000\$ cost to the FAA for the training itself gives a total of 14,000 \$.

$$DTC = 14000 \quad (7.44)$$

URET Controllers training cost (UTC)

It is the cost of training enroute controllers in the usage of the conflict probe tool, URET. It is as-

sumed same as for datalink.

$$UTC = 14000 \quad (7.45)$$

TMA Controllers training cost (TTC)

It is the cost of training a traffic management coordinators in the usage of traffic management advisor (TMA) tool. It is assumed same as for datalink.

$$TTC = 14000 \quad (7.46)$$

PFAST Controllers training cost (PFTC)

It is the cost of training a terminal area controllers in the usage of the PFAST. It is assumed same as for datalink.

$$PFTC = 14000 \quad (7.47)$$

Datalink training rate (DTR)

It is the number of controllers trained per year in datalink. It depends on the equipage rate of datalink since it would be uneconomical to train more controllers than available datalink equipped ATC infrastructure. It is equal to the Equipage rate for CPDLC Build I.

$$DTR = Eq_{BI} \quad (7.48)$$

No of controllers to be trained in datalink (ND)

It is the number of controllers that are remaining to be trained in datalink at the start of each year. The initial value is the number of datalink controllers (DC).

$$ND(t) = ND(t - dt) - \int (DTR(t)) dt \quad (7.49)$$

Datalink training cost rate (DTCR)

It is the cost per year for training no of controllers in datalink required to be trained per year. If the datalink training rate is less than the number of datalink controllers to be trained, then it is the cost for training the datalink training rate otherwise it is the cost for training the remaining number of pilots.

$$DTCR(t) = \begin{matrix} IF(ND(t) \geq DTR(t)) THEN(DTR(t) \times DTC) \\ ELSE(DTC \times ND(t)) \end{matrix} \quad (7.50)$$

Total Cost for training controllers in datalink (TDTC)

It is the cumulative cost for training controller's in datalink message exchange throughout the life cycle period.

$$TDTC(t) = TDTC(t-dt) + \int(DTCR(t))dt \quad (7.51)$$

URET training rate (UTR)

It is the number of controllers trained per year in URET. It depends on the equipage rate of URET since it would be uneconomical to train more controllers than available URET equipped ATC infrastructure. It is equal to the Equipage rate for CPDLC Build I.

$$UTR = Eq_u \quad (7.52)$$

No of controllers to be trained in URET (NU)

It is the number of controllers that are remaining to be trained in URET at the start of each year. The initial value is the number of URET controllers (UC).

$$NU(t) = NU(t-dt) - \int(UTR(t))dt \quad (7.53)$$

URET training cost rate (UTCR)

It is the cost per year for training no of controllers in URET required to be trained per year. If the URET training rate is less than the number of URET controllers to be trained, then it is the cost for training the URET training rate otherwise it is the cost for training the remaining number of controller's.

$$UTCR(t) = \begin{array}{l} IF(NU(t) \geq UTR(t))THEN(UTR(t) \times UTC) \\ ELSE(UTC \times NU(t)) \end{array} \quad (7.54)$$

Total Cost for training controllers in URET (TUTC)

It is the cumulative cost for training controller's in URET for all years.

$$TUTC(t) = TUTC(t - dt) + \int(UTCR(t))dt \quad (7.55)$$

TMA training rate (TTR)

It is the number of traffic management coordinator trained per year in TMA. It depends on the equipage rate of TMA since it would be uneconomical to train more traffic management coordinator's than available TMA equipped ATC infrastructure. It is equal to the Equipage rate for TMA.

$$TTR = Eq_t \quad (7.56)$$

No of controllers to be trained in TMA (NT)

It is the number of traffic management coordinator that are remaining to be trained in TMA at the start of each year. The initial value is the number of traffic management coordinator's (TC).

$$NT(t) = NT(t - dt) - \int(TTR(t))dt \quad (7.57)$$

TMA training cost rate (TTCR)

It is the cost per year for training no of traffic management coordinator's in TMA required to be trained

per year. If the TMA training rate is less than the number of TMA traffic coordinator's to be trained, then it is the cost for training the TMA training rate otherwise it is the cost for training the remaining number of traffic coordinator's.

$$TTCR(t) = \begin{cases} IF(NT(t) \geq TTR(t)) THEN (TTR(t) \times TTC) \\ ELSE (TTC \times NT(t)) \end{cases} \quad (7.58)$$

Total Cost for training controllers in TMA (TTTC)

It is the cumulative cost for training traffic coordinator's in TMA for all years.

$$TTTC(t) = TTTC(t - dt) + \int (TTCR(t)) dt \quad (7.59)$$

PFAST training rate (PFTR)

It is the number of terminal airspace controller's trained per year in PFAST. It depends on the equipage rate of PFAST since it would be uneconomical to train more controller's than available PFAST equipped ATC infrastructure. It is equal to the Equipage rate for PFAST.

$$PFTR = Eq_p \quad (7.60)$$

No of controllers to be trained in PFAST (NPF)

It is the number of terminal airspace controller's that are remaining to be trained in PFAST at the start of each year. The initial value is the number of PFAST controllers (PC).

$$NPF(t) = NPF(t - dt) - \int (PFTR(t)) dt \quad (7.61)$$

PFAST training cost rate (PFTCR)

It is the cost per year for training number of terminal airspace controller's required to be trained per year in PFAST. If the PFAST training rate is less than the number of PFAST controller's to be trained,

then it is the cost for training the PFAST training rate otherwise it is the cost for training the remaining number of PFAST controller's.

$$PFTCR(t) = \begin{matrix} IF(NPF(t) \geq PFTR(t)) THEN (PFTR(t) \times PFTC) \\ ELSE (PFTC \times NPF(t)) \end{matrix} \quad (7.62)$$

Total Cost for training controllers in PFAST (TPFTC)

It is the cumulative cost for training traffic coordinator's in TMA for all years.

$$TPFTC(t) = TPFTC(t - dt) + \int (PFTCR(t)) dt \quad (7.63)$$

Pilot training cost (PTC)

It is the cost of training a pilot in the usage of datalink messaging. Assuming a 2 week training program would entail operational cost for aircraft usage as well as remuneration of the pilot. Assuming 4000\$ remuneration for the pilot for the 2 week period and another 20,000\$ cost to the airline for the training itself gives a total of 24,000 \$.

$$PTC = 24000 \quad (7.64)$$

Percentage of pilot increase (P_p)

It is the percentage increase in the number of pilots per percent increase in the air traffic. Since there is a increase in air traffic hence there will be a increase in the number of pilots as well. The pilot growth rate should be proportional to traffic growth rate. It is assumed to be 20 percent or 0.2 in the model.

$$P_p = 0.2 \quad (7.65)$$

Pilots training rate (PTR)

It is the number of pilots trained per year. Firstly it will depend on the equipage level of aircraft since it would be uneconomical to train more pilots than available datalink equipped aircraft. It also depends on the percentage of pilot increase and the traffic growth.

$$PTR = El_a \times INP \times (1 + P_p \times TG \times Yr) \quad (7.66)$$

Pilot Growth Rate (PGR)

It is the number of pilots that is expected to increase every year due to increase in the air traffic.

$$PGR = INP \times (1 + P_p \times TG \times Yr) \times P_p \times TG \quad (7.67)$$

No of pilots to be trained (NP)

It is the number of pilots that are remaining to be trained at the start of each year. Since there is a increase in air traffic hence there will be a increase in the number of pilots as well. The pilot growth rate will be the proportional to the traffic growth rate. It is integral difference of the pilot growth rate and no of pilots trained per year.

$$NP(t) = NP(t - dt) + \int (PGR(t) - PTR(t))dt \quad (7.68)$$

Pilot training cost rate (PTCR)

It is the cost per year for training no of pilots required to be trained per year. If the pilot training rate is less than the number of pilots to be trained, then it is the cost for training the pilot training rate otherwise it is the cost for training the remaining number of pilots.

$$PTCR(t) = \begin{matrix} IF(PGR(t) + NP(t) \geq PTR(t))THEN(PTR(t) \times PTC) \\ ELSE(PTC \times (PGR(t) + NP(t))) \end{matrix} \quad (7.69)$$

Total Cost for training pilots (TPTC)

It is the cumulative cost for training pilots in datalink message exchange for all years.

$$TPTC(t) = TPTC(t - dt) + \int (PTCR(t))dt \quad (7.70)$$

FAA Training Cost Rate (FAATCR)

It is the net present value of the cumulative of all training costs borne by the FAA for training control-

ler's in datalink, URET and PFAST and for training traffic management coordinator's in TMA.

$$FAATCR(t) = \frac{(DTCR(t) + UTCR(t) + TTCR(t) + PFTCR(t))}{(1 + R)^{(Yr + TIME)}} \quad (7.71)$$

Airline Training Cost Rate (ATCR)

It is the net present value of the cumulative of all training costs borne by the airline or user per year for training pilot's in datalink.

$$ATCR(t) = \frac{PTCR(t)}{(1 + R)^{(Yr + TIME)}} \quad (7.72)$$

Training Cost (TC)

It is the net present value of the cumulative of all training costs borne by the airline and the FAA until the end of the life cycle period.

$$TC(t) = TC(t - dt) + \int (ATCR(t) + FAATCR(t)) dt \quad (7.73)$$

7.1.5 Technology cost module

This module quantifies the all the cost associated with the development, implementation and maintenance of datalink and decision support tools. The cost for implementing datalink, URET, TMA and PFAST infrastructure on the ground is borne by the FAA. The cost for implementing datalink infrastructure on aircraft is borne by the user or airlines.

The cost for implementing datalink, URET, TMA and PFAST on the ground includes development costs including software and hardware costs, costs associated with physical implementation and recurring maintenance cost. The cost for implementing datalink infrastructure on aircraft includes cost for buying the technology followed by the physical implementation of the technology on the aircraft.

Year of implementation of URET ($t4$)

It is the year that infrastructure required for deploying URET is implemented.

Year of implementation of TMA ($t5$)

It is the year that infrastructure required for deploying TMA is implemented.

Year of implementation of PFAST ($t6$)

It is the year that infrastructure required for deploying PFAST is implemented.

Decision Support Tools Switches

The Decision Support Tools Switches are automatically activated when the year of simulation becomes equal or greater than the year of implementation. They are meant to kick in the costs and benefits of implementation of decision support tools from the year of implementation.

$$US = IF(Yr_s \geq t4)THEN(1)ELSE(0) \quad (7.74)$$

$$TMAS = IF(Yr_s \geq t5)THEN(1)ELSE(0) \quad (7.75)$$

$$PS = IF(Yr_s \geq t6)THEN(1)ELSE(0) \quad (7.76)$$

Initial cost of datalink (ICD)

It is the initial cost of development of the datalink technology including the technology for all three Builds. It includes both the hardware and software cost. This cost is borne by the FAA and is approximately 420 Million \$. A slider is provided at the interface layer to change its value before the simulation.

$$ICD = 420 \times 10^6 \quad (7.77)$$

Initial cost of URET (ICU)

It is the initial cost of development of the user request evaluation tool. It includes both the hardware and software cost. This cost is approximately between 195-208 Million \$ and is borne by the FAA. A slider is provided at the interface layer to change its value before the simulation.

$$ICU = 200 \times 10^6 \quad (7.78)$$

Initial cost of TMA (ICT)

It is the initial cost of development of the traffic management advisor tool. It includes both the hardware and software cost. This cost is borne by the FAA. The CTAS host of tools cost approximately 224 Million \$. Assigning half of that value to TMA and the other half to PFAST. A slider is provided at the interface layer to change its value before the simulation.

$$ICT = 112 \times 10^6 \quad (7.79)$$

Initial cost of PFAST (ICP)

It is the initial cost of development of the passive final approach spacing tool. It includes both the hardware and software cost. This cost is borne by the FAA. The CTAS host of tools cost approximately 224 Million \$. Assigning half of that value to TMA and the other half to PFAST. A slider is provided at the interface layer to change its value before the simulation.

$$ICP = 112 \times 10^6 \quad (7.80)$$

Percentage equipped per year with CPDLC Build I (PE_{BI})

It is the percentage of entire NAS equipped with datalink infrastructure on the ground per year for the implementation of CPDLC Build I technology. It is equal to the equipage rate for CPDLC Build I.

$$PE_{BI} = Eq_{BI} \quad (7.81)$$

Percentage of NAS to be equipped with CPDLC Build I (P_{BI})

It is the percentage of NAS remaining to be equipped with datalink infrastructure for the implementation of CPDLC Build I technology. The initial value at the year of implementation is 100 percent or 1.

$$P_{BI}(t) = P_{BI}(t - dt) - \int (PE_{BI})dt \quad (7.82)$$

Cost per percent equipage of CPDLC Build I (CE_{BI})

It is cost borne by the FAA for equipping each percent of NAS with datalink infrastructure on the ground for implementing CPDLC Build I. CPDLC is expected to cost 645 Million \$ for implementation at 15 ARTCC's. Hence for 20 ARTCC's or 100 percent equipage level it will cost 860 Million \$. After distributing this cost equally into the three builds. Hence the cost per percent equipage is equal to 2.86 Million \$.

$$CE_{BI} = 2.86 \times 10^6 \quad (7.83)$$

Equipage cost rate for CPDLC Build I (C_{BI})

It is cost borne by the FAA for implementing the infrastructure for CPDLC Build I technology according to the percentage equipage rate per year or percentage to be equipped whichever is smaller.

$$C_{BI}(t) = IF(P_{BI}(t) \geq PE_{BI}) THEN (PE_{BI} \times CE_{BI}) ELSE (P_{BI}(t) \times CE_{BI}) \quad (7.84)$$

Percentage equipped per year with CPDLC Build IA (PE_{BIA})

It is the percentage of entire NAS equipped with datalink infrastructure on the ground per year for the implementation of CPDLC Build IA technology. It is equal to the equipage rate for CPDLC Build IA.

$$PE_{BIA} = Eq_{BIA} \quad (7.85)$$

Percentage of NAS to be equipped with CPDLC Build IA (P_{BIA})

It is the percentage of NAS remaining to be equipped with datalink infrastructure for the implementation of CPDLC Build IA technology. The initial value at the year of implementation is 100 percent or 1.

$$P_{BIA}(t) = P_{BIA}(t-dt) - \int (PE_{BIA})dt \quad (7.86)$$

Cost per percent equipage of CPDLC Build IA (CE_{BIA})

It is cost borne by the FAA for equipping each percent of NAS with datalink infrastructure on the ground for implementing CPDLC Build IA. It is same as for Build I.

$$CE_{BIA} = 2.86 \times 10^6 \quad (7.87)$$

Equipage cost rate for CPDLC Build IA (C_{BIA})

It is cost borne by the FAA for implementing the infrastructure for CPDLC Build IA technology according to the percentage equipage rate per year or percentage to be equipped whichever is smaller.

$$C_{BIA}(t) = IF(P_{BIA}(t) \geq PE_{BIA}) THEN (PE_{BIA} \times CE_{BIA}) ELSE (P_{BIA}(t) \times CE_{BIA}) \quad (7.88)$$

Percentage equipped per year with CPDLC Build II (PE_{BII})

It is the percentage of entire NAS equipped with datalink infrastructure on the ground per year for the implementation of CPDLC Build II technology. It is equal to the equipage rate for CPDLC Build IA.

$$PE_{BII} = Eq_{BII} \quad (7.89)$$

Percentage of NAS to be equipped with CPDLC Build II (P_{BII})

It is the percentage of NAS remaining to be equipped with datalink infrastructure for the implementation of CPDLC Build II technology. The initial value at the year of implementation is 100 percent or 1.

$$P_{BII}(t) = P_{BII}(t-dt) - \int (PE_{BII})dt \quad (7.90)$$

Cost per percent equipage of CPDLC Build II (CE_{BII})

It is cost borne by the FAA for equipping each percent of NAS with datalink infrastructure on the ground for implementing CPDLC Build II. It is same as for Build I.

$$CE_{BII} = 2.86 \times 10^6 \quad (7.91)$$

Equipage cost rate for CPDLC Build II (C_{BII})

It is cost borne by the FAA for implementing the infrastructure for CPDLC Build II technology according to the percentage equipage rate per year or percentage to be equipped whichever is smaller.

$$C_{BII}(t) = IF(P_{BII}(t) \geq PE_{BII}) THEN (PE_{BII} \times CE_{BII}) ELSE (P_{BII}(t) \times CE_{BII}) \quad (7.92)$$

Percentage equipped per year with URET (PE_u)

It is the percentage of entire NAS equipped with datalink infrastructure on the ground per year for the implementation of URET technology. It is equal to the equipage rate for URET.

$$PE_u = Eq_u \quad (7.93)$$

Percentage of NAS to be equipped with URET (P_u)

It is the percentage of NAS remaining to be equipped with infrastructure for the implementation of URET technology. The initial value at the year of implementation is 100 percent or 1.

$$P_u(t) = P_u(t-dt) - \int (PE_u) dt \quad (7.94)$$

Cost per percent equipage of URET (CE_u)

It is cost borne by the FAA for equipping each percent of NAS with infrastructure on the ground for implementing URET. It is assumed to be same as that for TMA or PFAST.

$$CE_u = 4 \times 10^6 \quad (7.95)$$

Equipage cost rate for URET (C_u)

It is cost borne by the FAA for implementing the infrastructure for URET technology according to the percentage equipage rate per year or percentage to be equipped whichever is smaller.

$$C_u(t) = IF(P_u(t) \geq PE_u) THEN (PE_u \times CE_u) ELSE (P_u(t) \times CE_u) \quad (7.96)$$

Percentage equipped per year with TMA (PE_t)

It is the percentage of entire NAS equipped with datalink infrastructure on the ground per year for the implementation of TMA technology. It is equal to the equipage rate for TMA.

$$PE_t = Eq_t \quad (7.97)$$

Percentage of NAS to be equipped with TMA (P_t)

It is the percentage of NAS remaining to be equipped with infrastructure for the implementation of TMA technology. The initial value at the year of implementation is 100 percent or 1.

$$P_t(t) = P_t(t - dt) - \int (PE_t) dt \quad (7.98)$$

Cost per percent equipage of TMA (CE_t)

It is cost borne by the FAA for equipping each percent of NAS with infrastructure on the ground for implementing TMA. The implementation of CTAS in 22 Major airports and 15 ARTCC's is expected to cost 600 Million \$. Hence for 20 ARTCC's or 100 percent equipage level the cost will be 800 Million \$. After distributing the cost equally for TMA and PFAST, the cost per percent equipage is 4 Million \$.

$$CE_t = 4 \times 10^6 \quad (7.99)$$

Equipage cost rate for TMA (C_t)

It is cost borne by the FAA for implementing the infrastructure for TMA technology according to the percentage equipage rate per year or percentage to be equipped whichever is smaller.

$$C_t(t) = IF(P_t(t) \geq PE_t) THEN(PE_t \times CE_t) ELSE(P_t(t) \times CE_t) \quad (7.100)$$

Percentage equipped per year with PFAST (PE_p)

It is the percentage of entire NAS equipped with infrastructure on the ground per year for the implementation of PFAST technology. It is equal to the equipage rate for PFAST.

$$PE_p = Eq_p \quad (7.101)$$

Percentage of NAS to be equipped with PFAST (P_p)

It is the percentage of NAS remaining to be equipped with infrastructure for the implementation of PFAST technology. The initial value at the year of implementation is 100 percent or 1.

$$P_p(t) = P_p(t - dt) - \int (PE_p) dt \quad (7.102)$$

Cost per percent equipage of PFAST (CE_p)

It is cost borne by the FAA for equipping each percent of NAS with infrastructure on the ground for implementing PFAST. It is assumed same as that for TMA.

$$CE_p = 4 \times 10^6 \quad (7.103)$$

Equipage cost rate for PFAST (C_p)

It is cost borne by the FAA for implementing the infrastructure for PFAST technology according to the percentage equipage rate per year or percentage to be equipped whichever is smaller.

$$C_p(t) = IF(P_p(t) \geq PE_p) THEN(PE_p \times CE_p) ELSE(P_p(t) \times CE_p) \quad (7.104)$$

Initial No of aircraft (INA)

It is the number of aircraft that have to be equipped with datalink infrastructure for the base year. In the year 2000, there were 5194 commercial aircraft flying over NAS. 80 percent of the traffic growth is attributed to an increase in number of aircraft and 20 percent is attributed to a increase in number of flights per aircraft. For the year 2015, 8943 commercial aircraft are expected to be flying over NAS [C/AFT, 1999]. This approximates to about an increase in 250 aircraft every year.

$$INA = 5194 + (5194 \times P_{acft} \times TG \times (Yr_{base} - 2000)) \quad (7.105)$$

Percentage of aircraft increase (P_{acft})

It is the percentage increase in the number of aircraft per percent increase in the air traffic. Since there is a increase in air traffic hence there will be a increase in the number of aircraft as well. Since 80 percent of the traffic growth is attributed to an increase in number of aircraft hence it is equal to 0.8.

$$P_{acft} = 0.8 \quad (7.106)$$

Aircraft Growth Rate (AGR)

It is the number of aircraft that is expected to increase every year due to increase in the air traffic.

$$AGR(t) = INA \times (1 + P_{acft} \times TG \times Yr) \times P_{acft} \times TG \quad (7.107)$$

Retiring Rate for aircraft (RR_{acft})

It is the number of aircraft that are retired every year from commercial or personal service. It is assumed to be 100 aircraft per year.

Number of aircraft equipped per year (NE_{acft})

It is the number of aircraft equipped with datalink infrastructure per year for allowing 2-way datalink message exchange. It is proportional to the equipage rate for aircraft.

$$NE_a = INA \times Eq_a \times (1 + P_{acft} \times TG \times Yr) \quad (7.108)$$

Number of aircraft to be equipped with datalink (Nt_{acft})

It is the number of aircraft remaining to be equipped with datalink infrastructure. The initial value at the year of implementation is $INA \cdot (1 + TG \cdot P_{acft} \cdot Yr)$.

$$Nt_{acft}(t) = Nt_{acft}(t-dt) - \int (RR_{acft} + NE_{acft}(t) - AGR(t)) dt \quad (7.109)$$

Infrastructure cost per aircraft (C_{acft})

It is the cost borne by the airline for fitting each aircraft with datalink infrastructure to carry out 2-way datalink message exchange. This cost is expected to vary between 80,000 to 150,000 \$ per aircraft.

$$C_{acft} = 150000 \quad (7.110)$$

No of aircraft equipped with datalink (N_{acft})

It is the total number of aircraft in NAS that are in commercial or personal service and are fitted with datalink.

$$N_{acft}(t) = N_{acft}(t-dt) + \int (NE_{acft}(t)) dt \quad (7.111)$$

Maintenance cost per aircraft (C_{ma})

It is the cost of maintaining the datalink infrastructure per aircraft. This cost includes all repairs and scheduled and unscheduled maintenance required on board each aircraft.

Airline Technology cost rate ($Tech_{airline}$)

It is the net present value of the cost borne by the airline or user for fitting aircraft with datalink infrastructure and maintaining the infrastructure to carry out 2-way datalink message exchange according to the equipage rate per year or number to be equipped whichever is smaller.

$$\begin{aligned}
 Tech_{airline}(t) = & \quad IF(Nt_{acft}(t) + AGR(t) \geq NE_{acft} + RR_{acft}) \\
 & \quad THEN \left(\frac{NE_{acft} \times C_{acft} + C_{ma} \times N_{acft} + MCost_{ATC}}{(1 + R)^{(Yr + TIME)}} \right) \\
 & \quad ELSE \left(\frac{C_{acft} \times (Nt_{acft} + AGR(t) - RR_{acft}) + N_{acft} \times C_{ma} + MCost_{ATC}}{(1 + R)^{(Yr + TIME)}} \right)
 \end{aligned} \tag{7.112}$$

Recurring Maintenance cost per percent equipage (C_{me})

It is the cost of maintaining the infrastructure for datalink, URET, TMA and PFAST per percentage of NAS per year. This cost includes all repairs and scheduled and unscheduled maintenance required on the ATC infrastructure on the ground.

Recurring Maintenance cost (C_m)

It is the cost of maintaining the infrastructure for datalink, URET, TMA and PFAST per year. This cost includes all repairs and scheduled and unscheduled maintenance required on the ATC infrastructure on the ground.

$$C_m(t) = \begin{cases} (300 - P_{BI}(t) + P_{BIA}(t) + P_{BII}(t)) \times C_{me} & \text{Alternative B} \\ (600 - P_{BI} + P_{BIA} + P_{BII} + P_u + P_t + P_f) \times C_{me} & \text{Alternative C} \end{cases} \tag{7.113}$$

Additional recurring maintenance cost per percent due to integration (ACP_m)

This is additional maintenance cost due to integration of URET with datalink per percent equipage level of URET in NAS.

Additional recurring maintenance cost due to integration (AC_m)

This is the additional cost due to integration of URET with datalink. It depends on the equipage level of URET.

$$AC_m(t) = (100 - P_u(t)) \times ACP_m \tag{7.114}$$

AOC Benefit ($Benefit_{AOC}$)

Airline Communication Addressing and Reporting System (ACARS) is the current system used for AOC. More frequencies have been added to deal with the increased message traffic, but the time is fast approaching when spectrum capacity will be exceeded. ACARS is a shared-access system based on a non-discriminatory system of frequencies. There are limited numbers of VHF frequencies available and any expansion is doomed to be short-lived and expensive. Many areas of the US are already experiencing congestion on en route frequencies at the same time as other industries are looking at petitioning for available spectrum. VDL Mode 2 network has been proposed by ARINC to carry out AOC operations.

VDL Mode 2 is a binary-oriented system, as opposed to character-oriented for POA, thus the number of bits required to transmit messages is reduced. The model assigns a cost savings benefit due to this message length reduction of VDL Mode 2 AOC messages. The low-end estimate of this assumes at least a 2:1 improvement due to the bit-oriented format, while a maximum of 6:1 improvement is estimated at the high end because large amounts of data are transferred by ACARS subsystems.

The benefit due to VDL Mode 2 depends upon the number of AOC messages per flight (NM_{AOC}), number of flights per aircraft (NF_{acft}), number of equipped aircraft (N_{acft}), reduction of kilobits per message (Red_{kb}) and cost per kilobit of message ($Cost_{kb}$).

$$Benefit_{AOC} = \frac{N_{acft} \times NF_{acft} \times NM_{AOC} \times Red_{kb} \times Cost_{kb}}{(1 + R)^{(Yr + TIME)}} \quad (7.115)$$

Number of AOC messages per flight (NM_{AOC})

It is the number of AOC messages transacted per flight.

Reduction of kbits per message (Red_{kb})

It is the reduction of kbits per message when transitioning from ACARs to VDL Mode 2. The number of kilobits per message in VDL Mode 2 is one - third the number of kilobits in ACARs. So the reduction is two-thirds of number of kilobits per message in VDL Mode 2.

$$Red_{kb} = \frac{2 \times NVDL_{kb}}{3} \quad (7.116)$$

Cost per kbit of message

It is the cost per kilobit of message sent via VDL Mode 2 network. It depends upon the total number of kilobits of message sent per year as shown in table 7.3.

No of million kilobits annually	Average cost per ATC kilobit (\$)
Upto 1	0.18
1 to 4	0.14
4 to 8	0.1
8 to 15	0.06

TABLE 7.3 Cost per kbit of message [C/AFT, 1999]

$$Cost_{kb} = \begin{cases} 0.18 & \text{if}(T_{kb} \leq 10^6) \\ 0.14 & \text{if}(10^6 < T_{kb} \leq 4 \times 10^6) \\ 0.1 & \text{if}(4 \times 10^6 < T_{kb} \leq 8 \times 10^6) \\ 0.06 & \text{if}(T_{kb} > 8 \times 10^6) \end{cases} \quad (7.117)$$

Total number of kbts per year (T_{kb})

It is total number of kbts transacted via the datalink channel for exchanging ATC messages. It is product of the number of datalink equipped aircraft, number of flights per aircraft, number of ATC messages per flight, number of kbts per message and datalink proportion of messages.

$$T_{kb} = N_{acft} \times NF_{acft} \times NMD_{ATC} \times NVDL_{kb} \times DP \quad (7.118)$$

where NMD_{ATC} is the number of ATC messages per equipped flight.

$NVDL_{kb}$ is the number of kilobits per ATC message.

DP is the data link proportion of messages.

ATC message cost ($MCost_{ATC}$)

It is uncertain at this time whether the FAA or airlines will be responsible for paying the ATC message costs. There has even been some discussion that the FAA would pay for uplinks and airlines pay for downlinks. The model takes this uncertainty into account by calculating the annual ATC message costs, then applying a multiplying factor, where 0 assumes that the FAA pays all costs, 0.5 that airlines and FAA split costs, and 1 that airlines pay all message costs. The annual message costs are calculated using the following formula:

$$MCost_{ATC} = T_{kb} \times Cost_{kb} \times P_x \tag{7.119}$$

P_x is the proportion of ATC message costs distributed to airline ($x = \text{airline}$) or FAA ($x = \text{FAA}$). P_x is assumed 0.5 for airline and 0.5 for FAA.

Table 5.14 shows the values of NMD_{ATC} and $NVDL_{kb}$.

	10 percentile	50 percentile	90 percentile
No of ATC messages per flight	200	229	260
No of kilobits per message	4	5.6	7.5

TABLE 7.4 ATC VDL Mode 2 parameters [FAA JRC Charts]

FAA Technology Cost per year ($Tech_{faa}$)

It is the net present value of the cost borne by the FAA for equipping NAS with infrastructure required for implementing datalink, URET, TMA and PFAST. Equation below denotes the FAA technology

costs for alternatives B, C and D.

$$Tech_{faa}(t) = \begin{cases} (C_{BI}(t) + C_{BIA}(t) + C_{BII}(t) + C_m(t) + MCost_{ATC}) / (1 + R)^{(Yr + TIME)} \\ \frac{((C_{BI}(t)) + C_{BIA}(t) + C_{BII}(t) + C_u(t) + C_t(t) + C_p(t) + C_m(t) + MCost_{ATC})}{(1 + R)^{(Yr + TIME)}} & (7.120) \\ \frac{(C_{BI}(t) + C_{BIA}(t) + C_{BII}(t) + C_u(t) + C_t(t) + C_p(t) + C_m(t) + AC_m(t) + MCost_{ATC})}{(1 + R)^{(Yr + TIME)}} \end{cases}$$

7.1.6 Net Benefits module

The net benefits module aggregates all benefits and costs for all four alternatives from the other four modules into a system wide cost and benefit. It also classifies all costs and benefit into net benefits as applicable to the FAA and airlines.

Net Benefits of Airline (NB_{airline})

It is an aggregation of all benefits applicable to the airline like Airline Operational Benefits and AOC Benefits and all costs like pilot training cost and technology cost to airline.

$$NB_{airline}(t) = NB_{airline}(t - dt) + \int (AOBR(t) + Benefit_{AOC}(t) - ATCR(t) - Tech_{airline}(t)) dt \quad (7.121)$$

Net Benefits of FAA (NB_{faa})

It is an aggregation of all benefits applicable to the FAA like Safety Benefit and all costs like training cost and technology cost to FAA.

$$NB_{faa}(t) = NB_{faa}(t - dt) + \int (SBR(t) - FAATCR(t) - Tech_{faa}(t)) dt \quad (7.122)$$

System wide net benefits (NB_{system-wide})

It is an aggregation of all net benefits as applicable to airline and the FAA.

$$NB_{system-wide}(t) = NB_{system-wide}(t - dt) + \int (NB_{faa}(t) + NB_{airline}(t)) dt \quad (7.123)$$

7.1.7 Interface layer of macroscopic annual model

As stated earlier, STELLA has three levels, the top level is called the interface or Graphic User Interface (GUI) layer. The middle level is the model building layer while as the bottom level is the equation layer. A number of things can be done at the interface level like the model can be run, the simulation parameters can be changed, input values of variables can be specified and results can be displayed in table or graphical format. Since the main model is comprised of five modules a navigation menu is created at the interface layer so as to able to navigate to any module with ease. Figure 7.3 shows the schematic representation of the interface layer of the datalink and decision support tools investment model.

There are six screens or windows at the interface layer, five screens for the five modules and a sixth screen for description of the model. There is also a navigation menu window from where one can navigate to any one of the five output screens or model description screen. The six screens are Net Benefits, Airline Operational Benefits, Safety Benefit, Technology Cost, Training Cost and Model Description window.

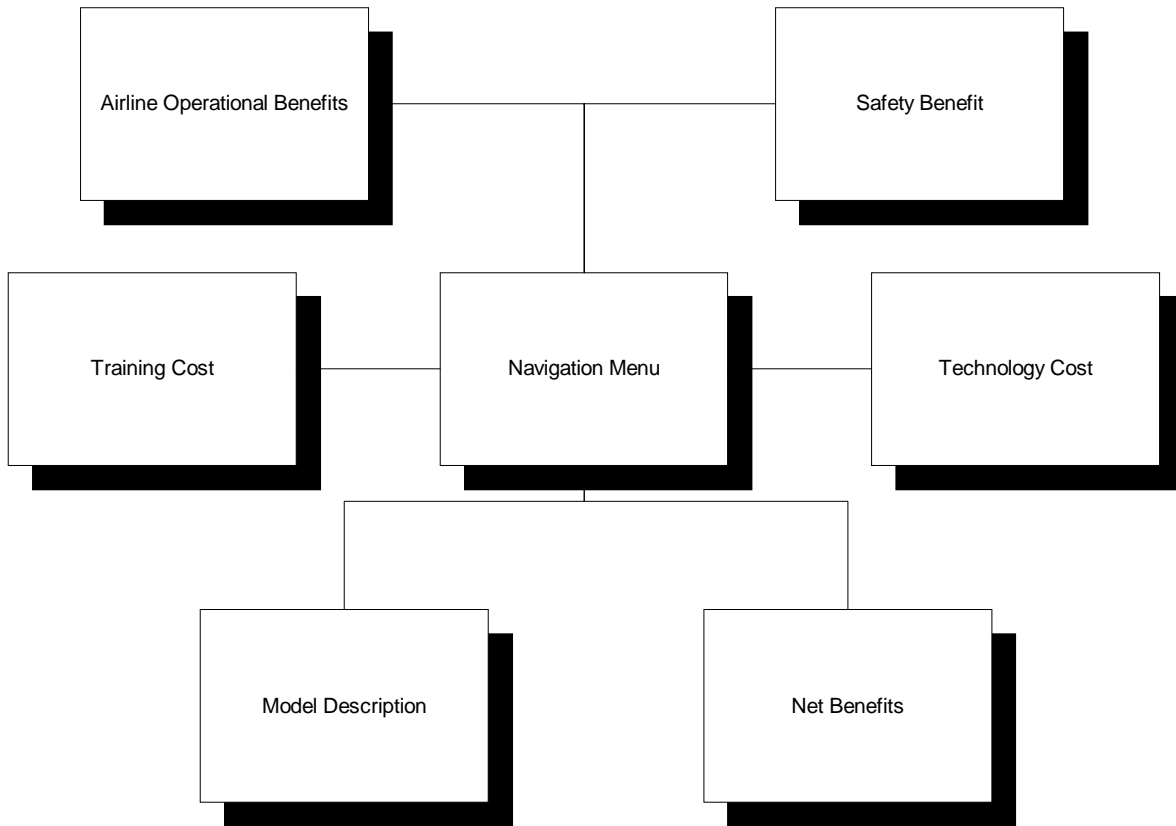


Figure 7.3 Schematic Outline of the Interface layer

When the model is opened, the navigation menu at the interface layer is the first screen from where any of the output windows can be accessed. The navigation menu is the common link between any of the windows. For example, if you would want to go from the Technology Cost window to the Airline Operational Benefits window, first you would go to the Navigation Menu and from there to the Airline Operational Benefits window. Figure 7.4 shows a snapshot of the navigation menu window.

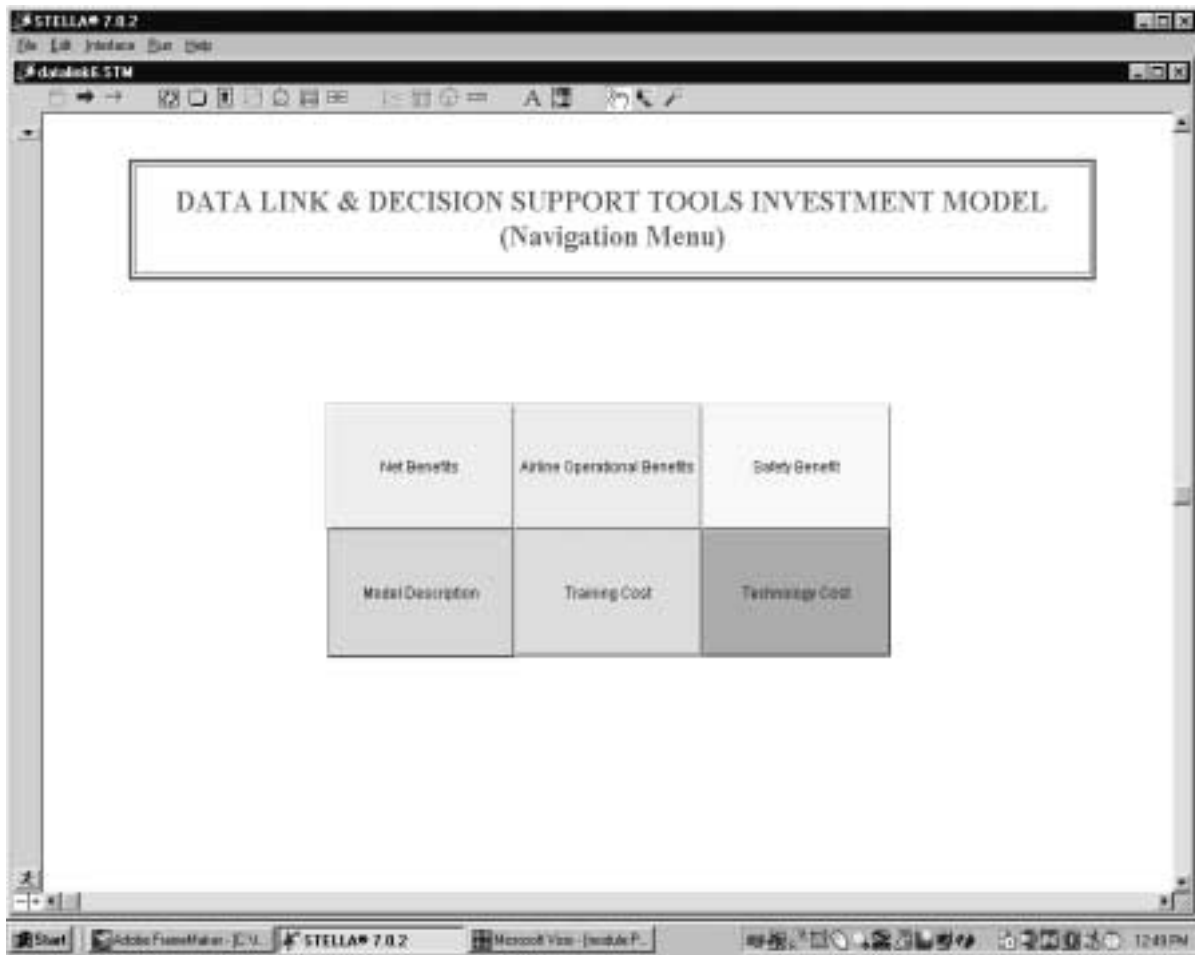


Figure 7.4 Snapshot of the navigation menu

The Airline Operational Benefits screen displays the amount in US dollars saved by the airlines due to reduced airspace occupation times in the enroute and terminal airspace. A slider is provided to change the value of the direct operating cost (DOC) per minute.

8.1 Final Review

Finally to conclude a modeling framework is outlined in this thesis to do a benefit/cost analysis of implementation of CPDLC and DSTs like URET, PFAST and TMA. This methodology of using two models, lower model for capturing various metrics on a microscopic level and transferring it to a higher life cycle model, can be extended to evaluate the costs and benefits of implementing any new technology in the future.

Analysis using the model indicates a threshold at 630 aircraft per day per sector separating the uncongested and congested regions. There are large differences in the sector traversal times for aircraft traffic densities greater than 630 due to the saturation of controller workload for alternative A as compared to traversal times at traffic densities less than saturation level. Hence to accurately represent the variation of the functional form of the benefits as a function of traffic density and equipage level, the output data was segregated into congested and uncongested region. From the airspace benefit surfaces it seems that the major benefit of implementing CPDLC and various DSTs arises when the controller workload for the base alternative becomes saturated.

8.2 Scope for further research

In this thesis, only the enroute module of DATSIM was run and the results were documented. The terminal airspace still needs to be run and the results documented. From the results the airspace benefit surfaces for terminal airspace needs to be developed and embedded into the higher life cycle model.

After embedding the benefit surfaces for both enroute and terminal airspace into the annual model, the annual life cycle model needs to be run to evaluate various implementation scenarios so as to determine break even point in the investment among other benefit/cost criteria for the optimum implementation schedule.

Some of these DSTs are not yet fully implemented and only a prototype is being used in certain ARTCCs and hub airports. Hence some of the relationships in the model are assumed since they cannot be quantified at this point of time. These relationships need to be more accurately quantified if and when accurate and reliable data is available.

Final goal of the life cycle annual model is to be used by the FAA and airlines to evaluate various strategies for implementing these new technologies.

Bibliography

-
- [1] Beins, D.R., "Data Link Communications, Acronyms and Message Content: An Operational Perspective", (SAE Tech. Paper 951981), Warrendale, PA: SAE International, 1995
 - [2] Billings, C. E. and Cheaney E. S. "Information Transfer Problems In The Aviation System" (NASA Tech. Paper 1875) Moffet Field, CA: NASA Ames Research Center, 1978.
 - [3] Blassic, E. J. and Kerns, K. "Controller Evaluation Of Terminal Data Link Services: Study I" (Mitre Tech. Report MTR 90W215), McLean, VA: The Mitre Corporation, 1990.
 - [4] Bruce, D.S., "An Explanatory Model for Influences of Air Traffic Control Task Parameters on Controller Work Pressure", 1993.
 - [5] Burski, M.J., and Celio, J. "Restriction Relaxation Experiments enabled by URET: A Strategy Planning Tool", June 2000.
 - [6] Celio, J., Walker, M. and McFarland, A. "User Request Evaluation Tool Benefits during Free Flight Phase 1", July 2000.
 - [7] CNS/ATM Focussed Team (CAFT), "European Data Link Investment Analysis", 2000.
 - [8] CNS/ATM Focussed Team (CAFT), "Data Link Investment Analysis", 1999.
 - [9] Corwin, W.H. and McCauley, H.W. "Considerations for Retrofit of Data Link", (SAE Tech. Paper 901886), Warrendale, PA: SAE International, 1990
 - [10] Darby, Evan et al, "Controller Evaluation of CPDLC Services implemented on Display System Replacement (DSR) Workstation, Study 1-- Initial Assessment of Services transitioned from PVD and Design Development of Additional Services", (DOT/FAA/CT-TN 99/11), 1999.
 - [11] Darby, Evan R. "Controller Evaluation of CPDLC Services implemented on Display System Replacement (DSR) Workstation, Study 1-- Assessment of Build I and IA Human Computer Interfaces, Training and Procedures", (DOT/FAA/CT-TN 00/02), 2000
 - [12] Darby, Evan R., "CPDLC Build I: Phase 1 - Air Traffic Operational Effectiveness Test", (DOT/FAA/CT-TN 01/10) 2001.

-
- [13] Davis, T.J., Isaacson, D.R., Robinson, J.E. III, Den Braven, W., Lee, K.K. and Sanford, B., "Operational Test Results of Final Spacing Approach Tool" In: Proceedings of the IFAC 8th Symposium on Transportation Systems, Chania, Greece, June 16-18, 1997.
- [14] Farley, T. C., Foster J.D, Hoang T., Lee K.K., "A Time-Based Approach to Metering Arrival Traffic to Philadelphia", AIAA-2001-5241, First AIAA Aircraft Technology, Integration, and Operations Forum, Los Angeles, California, October 16-18, 2001.
- [15] Federal Aviation Administration, "Test Plan For Assessing User Benefits Of Two-Way Data Link ATC Communications" (Report No. DOT/FAA/CT-ACD32094/3), Washington, DC.
- [16] Federal Aviation Administration Data Link Benefits Study Team, "Benefits of Controller-Pilot Data Link ATC Communications in Terminal Airspace", FAA Report FAA/CT-96-3, September 1996.
- [17] Federal Aviation Administration Data Link Benefits Study Team, "User Benefits of Two-Way Data Link ATC Communications: Aircraft Delay and Flight Efficiency in Congested En Route Airspace", FAA Report FAA/CT-95-4, February 1995.
- [18] Federal Aviation Administration, "Initial Requirements Document for Controller Pilot Data Link Communications (CPDLC) Service", Final Report, June 22, 1998.
- [19] Ferra, Steven E. and Darby, Evan R., Rehmann, A.J. and Reynolds, M.C, "CPDPC Build I: Air Ground Integration Study Test Report", December 2000)
- [20] Flathers, G. W. "Development Of An Air-Ground Data Exchange Concept: Flight Deck Perspective", (NASA Contractor Rep. No. 4074), Hampton, VA: NASA Langley Research Center, 1987.
- [21] Forrester, J.W. Industrial Dynamics, The MIT Press, Cambridge, MA. 1971.
- [22] Garcia, J. "MAESTRO - A metering and spacing tool". In Proceedings of the American Control Conference, San Diego, California, pp. 501-507, 1990.
- [23] Gervais, Edward A., "New Generation Aircraft-Airport Compatibility", Proceedings of the 23rd. ASCE International Air Transportation Conference, Arlington, Virginia, June 22-24, 1994.
- [24] Groce, J. L. and Boucek, G. P. "Air Transport Crew Tasking In An ATC Data Link Environment", (SAE Tech. Paper 871764), Warrendale, PA: SAE International, 1987.
- [25] Hahn, E. C. and Hansman Jr. R. J. "Experimental Studies On The Effects Of Automation On Pilot Situational Awareness In The Data Link ATC Environment", (SAE Tech. Paper 922022), Warrendale, PA: SAE International, 1992.
- [26] Hinton, D. A. and Lohr, G. A. "Simulator Investigation Of Digital Data Link ATC Communications In. Single-Pilot Operations (NASA Tech. Paper 2837), Hampton, VA: NASA Langley Research Center, 1988.
- [27] Hoang, T., and Swenson, H. "The Challenges of Field Testing the Traffic Management Advisor (TMA) in an operational Air Traffic Control Facility", August 1997.
- [28] Human Factors Task Force, "Human Factors Requirements For Data Link", (RTCA Paper No. 754-92/SC- 169-194), Washington, DC: RTCA, 1992.
- [29] Kerns, K. "Data link communications between controllers and pilots: "A review and synthesis of the simulation literature", The International Journal of Aviation Psychology I(3), pp. 181-204, 1991.
- [30] Knox, C. E. and Scanlon, C. H. "Flight Tests With A Data Link Used For Air Traffic Control Information Exchange", (NASA Tech. Paper 3135). Hampton, VA: NASA Langley Research Center, 1991.
- [31] Lee, K. K., Quinn C.M, Hoang T., and Sanford B.D., "Human Factors Report: TMA Operational Evaluations 1996 & 1998", February 2000.
- [32] Lee, K.K., and Sandford, B.D. "Human Factors Assessment: The Passive Final Approach Spacing Tool Operational Evaluation", NASA Technical Memorandum 208750, Ames Research Center, Moffet Field, California, 1998.
- [33] Lozito, S. A., McGann, S. A. and Corker, K. "Data link air traffic control and flight deck environments: Experiments

-
- in flight crew performance”, In R. E. Jensen and D. Neumeister (Eds.), Proceedings of the 7th International Symposium on Aviation Psychology (pp 1009-1015). Columbus, OH: The Ohio State University, 1993
- [34] Mackintosh, M., Lozito, S., McGann, A. and Logsdon, E., “Designing Procedures for Controller-Pilot Data Link Communication: Effects of Textual Data Link on Information Transfer”, (SAE Tech. Paper 1999-01-5507), Warrendale, PA: SAE International, 1999.
- [35] Martin, D.A and Wilet, F.M. “Development and Application of a Terminal Spacing System”, FAA Rept. NA-68-25, 1968.
- [36] Massimini Patricia A., “Insertion of CPDLC into the National Airspace System: Is it more efficient”, September 2000.
- [37] Mattox, Jr. A.S. “Pilot-Controller Communication - A Line Pilot’s Perspective”, (SAE Tech. Paper 902354), Warrendale, PA: SAE International, 1990
- [38] McGann, A., Lozito, S. and Corker, K. “Cockpit Data Link Displays: An Evaluation of Textual Formats”, (SAE Tech. Paper 922025), Warrendale, PA: SAE International, 1992
- [39] McKinlay, R.A., “Data Link comes of age”, 1996
- [40] Midkiff, A. H. and Hansman Jr. R. J. “Identification of important “Party Line” information elements and implications for situational awareness in the data link environment.”, Air Traffic Control Quarterly, 1 (1), pp 5-30, 1993.
- [41] Mueller, K. Tyson and Robinson, E. John. “Final Approach Spacing Tool: Velocity Accuracy Performance Analysis”, AIAA, 1998.
- [42] Murphy, M.E. “Data Link: A Conceptual Flight Deck System and Related Issues”, (SAE Tech. Paper 922002), Warrendale, PA: SAE International, 1992
- [43] National Aeronautics and Space Administration (NASA), CTAS Program Web Site, <http://ctas.nasa.gov>, 1999.
- [44] Nelson, M.A., “Data Link Implementation: A Global Perspective from an Aircraft Manufacturer”, 1996.
- [45] Rehman, A. J., & Mogford, R. H., “Airborne data link study report” (Draft Tech. Report). Washington, DC: U.S. Department of Transportation, Federal Aviation Administration, 1994.
- [46] Rehmann, A., “Human Factors Recommendations for Airborne Controller-Pilot Data Link Communications (CPDLC) Systems: A Synthesis of Research Results and Literature”, Federal Aviation Administration Report FAA/CT-TN97/6, June 1997.
- [47] Reynolds, M.C. “A Prospectus of pilot factors in data link at the Federal Aviation Administration Technical Center”, (SAE Tech. Paper 901884), Warrendale, PA: SAE International, 1990
- [48] Riley, V. “Human Factors Issues of Data Link: Application of a Systems Analysis”, (SAE Tech. Paper 922021), Warrendale, PA: SAE International, 1992
- [49] Rodgers, M., Embt, D. and Colligan, W., “A Multi-Center NASSIM Analysis of the Effects of Data Link Equipage Rates on voice Communications”, Federal Aviation Administration and CSSI, Inc., Draft 1.1 February, 1997.
- [50] RTCA, Inc., “Human Engineering Guidance for Data Link Systems”, RTCA Document DO-238, April 2, 1997.
- [51] RTCA, Inc., “Minimum Operational Performance Standards (MOPS) for Aeronautical Telecommunication Network (ATN) Avionics”, RTCA Document DO-240, July 29, 1997.
- [52] RTCA, Inc., “Minimum Operational Performance Standards for Traffic Information Service (TIS) Data Link Communications”, RTCA Document DO-239, April 2, 1997.
- [53] RTCA, Inc., “Operational Concepts and Data Elements Required to Improve Air Traffic Management (ATM)-Aeronautical Operational Control (AOC) Ground-Ground Information Exchange to Facilitate Collaborative Decision Making”, RTCA Document DO-241, October 6, 1997.
- [54] Ryan, P.R. “Airline Data Link Automation Progress and Issues”, (SAE Tech. Paper 901957), Warrendale, PA: SAE International, 1990
-

-
- [55] Ryan, P.R., "Airline Perspective on Data Link", (SAE Tech. Paper 922001), Warrendale, PA: SAE International, 1992
- [56] Shingledecker, C.A., "Controller Evaluations of ATC Data Link Services", (SAE Tech. Paper 922027), Warrendale, PA: SAE International, 1992
- [57] Shingledecker, C.A. and Talotta, N.J., "Controller Workload in the development of Data Link Air Traffic Control Services", 1993
- [58] Shingledecker, C. A. and Darby Jr. E. R. "Effects of data link ATC communications on controller teamwork and sector productivity", *Air Traffic Control Quarterly*, 3(2), pp 65-94, 1995.
- [59] Skinner, G.R., "An Inventory of Cost Benefit Studies in the Field of ATC Data Communications", Eurocontrol, Revision 2.1, November 19, 1996.
- [60] Swenson, H. N., Hoang T., Engelland S., Vincent D., Sanders T., Sanford B., and Heere K., "Design and Operational Evaluation of the Traffic Management Advisor at the Fort Worth Air Route Traffic Control Center", 1st USA/Europe Air Traffic Management R&D Seminar, Saclay, France, June, 1997
- [61] Talotta, N. J., Shingledecker, C., Zurinskas, T., Kerns, K., Marek, H., Vancampen, W. and Rosenberg, B., "Controller evaluation of initial data link air traffic control services: Mini-study 1, Volume I", (Report No. DOT/FAA/CT-89/25, I). Washington, DC: U.S. Department of Transportation, Federal Aviation data link Administration, 1988.
- [62] Talotta, N. J., Shingledecker, C., Zurinskas, T., Kerns, K. and Marek, H., "Controller evaluation of initial data link air traffic control services: Mini-study 2, Volume I" (Report No. DOT/FAA/CT-89/14, I). Washington, DC: U.S. Department of Transportation, Federal Aviation Administration, 1989.
- [63] Talotta, N. J., "Controller Evaluation If Initial Data Link Terminal Air Traffic Control Services: Mini-Study 3, Volume I" (Report No. DOT/FAA/CT-92/18,I), Washington, DC: US Department of Transportation, Federal Aviation Administration, 1992.
- [64] Talotta, N. J., "Operational Evaluation Of Initial Data Link En Route Services, Volume I" (Report No. DOT/FAA/CT-90/1,I), Washington, DC: US Department of Transportation, Federal Aviation Administration, 1990.
- [65] Talotta, N.J. "Data Link System Development at the FAA Technical Center", (SAE Tech. Paper 922026), Warrendale, PA: SAE International, 1992
- [66] Van Gent, R. N., Bohnen, H. G. and Jorna, P. G., "Flight Simulator Evaluation Of Baseline Crew Performance With Three Data Link Interfaces (Draft Tech. Report)", Washington, DC: US Department of Transportation, Federal Aviation Administration, 1994.
- [67] Volckers, U. "Arrival Planning and Sequencing with COMPAS-OP at the Frankfurt ATC Center". In Proceedings of the American Control Conference, San Diego, California, pp. 496-501, 1990.
- [68] Waller, M. C., "Flight Deck Benefits Of Integrated Data Link Communication (NASA Tech. Paper 3219)", Hampton, VA: NASA Langley Research Center, 1989.
- [69] Waller, M. C., & Lohr, G. W., "A piloted simulation of data link ATC message exchange (NASA Tech. Paper 2859)". Hampton, VA: NASA Langley Research Center, 1989.

APPENDIX A Microscopic Model Input Equations

Enroute sector (Datalink + Voice + DSTs (int))

Aircraft_in_enroute_sector_in_integrated[Density](t) =

Aircraft_in_enroute_sector_in_integrated[Density](t - dt) + (QDR_in_integrated[Density] -
Rate_out_in_integrated[Density]) * dt

INIT Aircraft_in_enroute_sector_in_integrated[Density] = 0

INFLOWS:

QDR_in_integrated[Density] = IF(Controller_Activity_in_integrated[Density] >= 1)

THEN(0)

ELSE(IF(AQ_outside_sector_for_integrated[Density] = 0)

THEN(0)

ELSE(1))

OUTFLOWS:

Rate_out_in_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Transit_time_in_integrated[Density]

AQ_outside_sector_for_integrated[Density](t) = AQ_outside_sector_for_integrated[Density](t - dt)
+ (Rate_in_integrated[Density] - QDR_in_integrated[Density]) * dt

INIT AQ_outside_sector_for_integrated[Density] = 0

INFLOWS:

Rate_in_integrated[Density] = Acft_Injector[Density]

OUTFLOWS:

QDR_in_integrated[Density] = IF(Controller_Activity_in_integrated[Density] >= 1)

```

THEN(0)
ELSE(IF(AQ_outside_sector_for_integrated[Density] = 0)
THEN(0)
ELSE(1))
Routine_communication_in_integrated[Density](t) = Routine_communication_in_integrated[Den-
sity](t - dt) + (routine_comm_rate_in_integrated[Density]) * dt
INIT Routine_communication_in_integrated[Density] = 0
INFLOWS:
routine_comm_rate_in_integrated[Density] = acft_rate_in_integrated[Den-
sity]*(No_of_routine_comm_per_aircraft_in_integrated +
Extra_voice_comm_in_enroute_in_integrated)
Total_acft_exited_in_integrated[Density](t) = Total_acft_exited_in_integrated[Density](t - dt) +
(exit_rate_in_integrated[Density]) * dt
INIT Total_acft_exited_in_integrated[Density] = 0
INFLOWS:
exit_rate_in_integrated[Density] = Rate_out_in_integrated[Density]
Total_acft_integrated_in_enroute[Density](t) = Total_acft_integrated_in_enroute[Density](t - dt) +
(acft_rate_in_integrated[Density]) * dt
INIT Total_acft_integrated_in_enroute[Density] = 0
INFLOWS:
acft_rate_in_integrated[Density] = QDR_in_integrated[Density]
Total_conflicts_in_integrated[Density](t) = Total_conflicts_in_integrated[Density](t - dt) +
(Conflict_rate_in_integrated[Density]) * dt
INIT Total_conflicts_in_integrated[Density] = 0
INFLOWS:
Conflict_rate_in_integrated[Density] = No_of_conflicts_per_acft_integrated[Density]
Total_conflict_by_datalink_in_integrated[Density](t) =
Total_conflict_by_datalink_in_integrated[Density](t - dt) +
(conflict_rate_by_datalink_in_integrated[Density]) * dt
INIT Total_conflict_by_datalink_in_integrated[Density] = 0
INFLOWS:
conflict_rate_by_datalink_in_integrated[Density] = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts) THEN(No_of_conflicts_per_acft_integrated[Den-
sity]*Percentage_of_conflicts_allocated_to_datalink)
ELSE(0)
Total_conflict_by_voice_in_integrated[Density](t) = Total_conflict_by_voice_in_integrated[Den-
sity](t - dt) + (conflict_rate_by_voice_in_integrated[Density]) * dt
INIT Total_conflict_by_voice_in_integrated[Density] = 0
INFLOWS:

```

$\text{conflict_rate_by_voice_in_integrated}[\text{Density}] = \text{IF}(\text{RANDOM}(0,1) \leq \text{Equipage_level_for_aircrafts}) \text{ THEN}(\text{No_of_conflicts_per_acft_integrated}[\text{Density}] * (1 - \text{Percentage_of_conflicts_allocated_to_datalink}))$
 $\text{ELSE}(\text{No_of_conflicts_per_acft_integrated}[\text{Density}])$
 $\text{Total_conflict_time_by_datalink_in_integrated}[\text{Density}](t) = \text{Total_conflict_time_by_datalink_in_integrated}[\text{Density}](t - dt) + (\text{Conflict_time_rate_by_datalink_in_integrated}[\text{Density}]) * dt$
 $\text{INIT Total_conflict_time_by_datalink_in_integrated}[\text{Density}] = 0$
INFLOWS:
 $\text{Conflict_time_rate_by_datalink_in_integrated}[\text{Density}] = \text{IF}(\text{RANDOM}(0,1) \leq \text{Equipage_level_for_aircrafts})$
 $\text{THEN}(\text{No_of_conflicts_per_acft_integrated}[\text{Density}] * \text{Percentage_of_conflicts_allocated_to_datalink} * (\text{Average_time_per_conflict_by_datalink_non_trial_planning} + \text{Proportion_of_conflicts_resolved_by_trial_planning_integrated} * (\text{Average_time_per_conflict_by_datalink_with_trial_planning_int}[\text{Density}] - \text{Average_time_per_conflict_by_datalink_non_trial_planning})))$
 $\text{ELSE}(0)$
 $\text{Total_conflict_time_by_voice_in_integrated}[\text{Density}](t) = \text{Total_conflict_time_by_voice_in_integrated}[\text{Density}](t - dt) + (\text{Conflict_time_rate_by_voice_in_integrated}[\text{Density}]) * dt$
 $\text{INIT Total_conflict_time_by_voice_in_integrated}[\text{Density}] = 0$
INFLOWS:
 $\text{Conflict_time_rate_by_voice_in_integrated}[\text{Density}] = \text{IF}(\text{RANDOM}(0,1) \leq \text{Equipage_level_for_aircrafts}) \text{ THEN}(\text{No_of_conflicts_per_acft_integrated}[\text{Density}] * (1 - \text{Percentage_of_conflicts_allocated_to_datalink}) * (\text{Average_time_per_conflict_by_voice_non_trial_planning} + \text{Proportion_of_conflicts_resolved_by_trial_planning_integrated} * (\text{Average_Time_per_conflict_by_voice_with_trial_planning}[\text{Density}] - \text{Average_time_per_conflict_by_voice_non_trial_planning})))$
 $\text{ELSE}(\text{No_of_conflicts_per_acft_integrated}[\text{Density}] * (\text{Average_time_per_conflict_by_voice_non_trial_planning} + \text{Proportion_of_conflicts_resolved_by_trial_planning_integrated} * (\text{Average_Time_per_conflict_by_voice_with_trial_planning}[\text{Density}] - \text{Average_time_per_conflict_by_voice_non_trial_planning})))$
 $\text{Total_routine_datalink_comm_in_integrated}[\text{Density}](t) = \text{Total_routine_datalink_comm_in_integrated}[\text{Density}](t - dt) + (\text{routine_datalink_comm_rate_in_integrated}[\text{Density}]) * dt$
 $\text{INIT Total_routine_datalink_comm_in_integrated}[\text{Density}] = 0$
INFLOWS:
 $\text{routine_datalink_comm_rate_in_integrated}[\text{Density}] = \text{IF}(\text{RANDOM}(0,1) \leq \text{Equipage_level_for_aircrafts})$

```

THEN(QDR_in_integrated[Density]*No_of_routine_communication_per__aircraft_in_enroute_sector*Datalink_Proportion_of_msgs)
ELSE(0)
Total_routine_datalink_occupation_time_in_integrated[Density](t) =
Total_routine_datalink_occupation_time_in_integrated[Density](t - dt) +
(routine_datalink_occupation_rate_in_integrated[Density]) * dt
INIT Total_routine_datalink_occupation_time_in_integrated[Density] = 0
INFLOWS:
routine_datalink_occupation_rate_in_integrated[Density] =
routine_datalink_comm_rate_in_integrated[Density]*Average_time_per_routine_communication_via_datalink
acft_rate_integrated[Density] = Total_acft_integrated_in_enroute[Density]*10*60*24/TIME
Adjusted_no_of_conflicts_per_acft_in_integrated[Density] =
Expected_no_of_conflicts_per_acft_in_integrated[Density]*Reduction_factor_of_conflicts_due_to_uret_conflict_detection_int[Density]*(1 +
Proportionate_increase_in_conflict_rate_in_integrated)*Reduction_factor_due_to_trial_planning_in_integrated
Average_time_per_conflict_by_datalink_with_trial_planning_int[Density] =
Conflict_Perception_Time_with_uret +
Conflict_Resolution_Finding_Time_with_trial_planning[Density] +
Datalink_Resolution_Time_integrated
Conflict_per_acft_MS_10_int[Density] = .00106*acft_rate_integrated[Density]
Conflict_per_acft_MS_2_int[Density] = .000167*acft_rate_integrated[Density]
Conflict_per_acft_MS_3_int[Density] = .000266*acft_rate_integrated[Density]
Conflict_per_acft_MS_5_int[Density] = .0000004*acft_rate_integrated[Density]*acft_rate_integrated[Density] + .0003*acft_rate_integrated[Density]
Conflict_per_acft_MS_75_int[Density] = .000733*acft_rate_integrated[Density]
Controller_Activity_in_integrated[Density] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
THEN(Aircraft_in_enroute_sector_in_integrated[Density]*((No_of_routine_comm_per_aircraft_in_integrated*(Average_time_per_routine_communication_via_voice +
Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink -
Average_time_per_routine_communication_via_voice))) +
(Extra_voice_comm_in_enroute_in_integrated*Average_time_per_routine_communication_via_voice) +
(Adjusted_no_of_conflicts_per_acft_in_integrated[Density]/
1.5*(Percentage_of_conflicts_allocated_to_datalink*(Average_time_per_conflict_by_datalink_non_trial_planning +
Proportion_of_conflicts_resolved_by_trial_planning_integrated*(Average_time_per_conflict_by_da

```

talink_with_trial_planning_int[Density] -
Average_time_per_conflict_by_datalink_non_trial_planning)) +
(1 -
Percentage_of_conflicts_allocated_to_datalink)*(Average_time_per_conflict_by_voice_non_trial_planning + Proportion_of_conflicts_resolved_by_trial_planning_integrated*
(Average_Time_per_conflict_by_voice_with_trial_planning[Density] -
Average_time_per_conflict_by_voice_non_trial_planning))))/Transit_time_in_integrated[Density])
ELSE(Aircraft_in_enroute_sector_in_integrated[Density]*(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_per_aircraft_in_integrated +
Extra_voice_comm_in_enroute_in_integrated) +
Adjusted_no_of_conflicts_per_acft_in_integrated[Density]/
1.5*(Average_time_per_conflict_by_voice_non_trial_planning +
Proportion_of_conflicts_resolved_by_trial_planning_integrated*
(Average_Time_per_conflict_by_voice_with_trial_planning[Density] -
Average_time_per_conflict_by_voice_non_trial_planning))))/Transit_time_in_integrated[Density])
Corrected_Percentage_of_aircraft_in_conflict_in_integrated[Density] =
No_of_aircraft_in_conflict_in_integrated[Density]/(Aircraft_in_enroute_sector_in_integrated[Density] + 1)
Datalink_Resolution_Time_integrated = 1/6
DCU_in_integrated[Density] = (Total_routine_datalink_comm_in_integrated[Density] +
Total_conflict_by_datalink_in_integrated[Density])*lag_time_in_datalink_in_enroute/14400
Diversion_time_per_conflict_in_datalink_with_trial_planning_int[Density] =
Diversion_time_per_conflict_in_voice_non_uret +
Average_time_per_conflict_by_datalink_with_trial_planning_int[Density] -
Average_time_per_conflict_by_voice_non_uret + lag_time_in_datalink_in_enroute -
lag_time_in_voice_in_enroute + Average_time_for_reading_and_uploading_message -
Typing_message_time
Enroute_controller_utilization_in_integrated[Density] =
(Total_conflict_time_by_datalink_in_integrated[Density] +
Total_conflict_time_by_voice_in_integrated[Density] +
Total_routine_datalink_occupation_time_in_integrated[Density] +
Total_time_spent_in_RVC_in_integrated[Density])/14400
Excess_VCU_in_integrated[Density] = MAX(VCU_in_integrated[Density] - 1,0)
Expected_no_of_conflicts_per_acft_in_integrated[Density] = IF(Minimum_Separation <= 2)
THEN(Conflict_per_acft_MS_2_int[Density]*Minimum_Separation/2)
ELSE(IF(Minimum_Separation <= 3) AND (Minimum_Separation > 2)
THEN((Conflict_per_acft_MS_3_int[Density] - Conflict_per_acft_MS_2_int[Density])*(Minimum_Separation - 2) + Conflict_per_acft_MS_2_int[Density])
ELSE(IF(Minimum_Separation <= 5) AND (Minimum_Separation > 3)

```

THEN((Conflict_per_acft_MS_5_int[Density] - Conflict_per_acft_MS_3_int[Density])*(Minimum_Separation - 3)/2 + Conflict_per_acft_MS_3_int[Density])
ELSE(IF(Minimum_Separation <= 7.5) AND (Minimum_Separation > 5)
THEN((Conflict_per_acft_MS_75_int[Density] - Conflict_per_acft_MS_5_int[Density])*(Minimum_Separation - 5)/2.5 + Conflict_per_acft_MS_5_int[Density])
ELSE(IF(Minimum_Separation <= 10) AND (Minimum_Separation > 7.5)
THEN((Conflict_per_acft_MS_10_int[Density] - Conflict_per_acft_MS_75_int[Density])*(Minimum_Separation - 7.5)/2.5 + Conflict_per_acft_MS_75_int[Density])
ELSE(0))))))
Extra_voice_comm_in_enroute_in_integrated = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts) THEN(No_of_routine_comm_per_aircraft_in_integrated
*Percentage_extra_comm_per_comm*(1 - Datalink_Proportion_of_msgs))
ELSE(No_of_routine_comm_per_aircraft_in_integrated*Percentage_extra_comm_per_comm)
Mean_ST_in_integrated[Density] = CTMEAN(Rate_out_in_integrated[Density])
No_of_aircraft_in_conflict_in_integrated[Density] =
Aircraft_in_enroute_sector_in_integrated[Density]*Percentage_of_aircraft_in_conflict_in_integrated[Density]*Reduction_factor_of_conflicts_due_to_uret_conflict_detection_int[Density]*(1 +
Proportionate_increase_in_conflict_rate_in_integrated)*(1 -
Proportion_of_conflicts_resolved_by_trial_planning_integrated/2)
No_of_conflicts_per_acft_integrated[Density] = IF(QDR_in_integrated[Density] > 0)
THEN(Adjusted_no_of_conflicts_per_acft_in_integrated[Density])
ELSE(0)
No_of_restrictions_relaxed_in_integrated =
Percentage_of_restrictions_relaxed_in_integrated*Total_no_of_routing_restrictions
No_of_routine_comm_per_aircraft_in_integrated =
No_of_routine_communication_per__aircraft_in_enroute_sector -
No_of_restrictions_relaxed_in_integrated
No_of_routine_diversions_per_sector_in_integrated = No_of_routine_diversions_per_sector -
No_of_restrictions_relaxed_in_integrated
Percentage_of_restrictions_relaxed_in_integrated = .4
Pilot_Utilization_in_integrated[Density] =
Proportion_of_msgs_to_be_fed_into_the_FMS*(Average_time_for_hearing_and_uploading_the_message*(Total_conflict_by_voice_in_integrated[Density] + RVC_in_integrated[Density]) +
Average_time_for_reading_and_uploading_message*(Total_routine_datalink_comm_in_integrated[Density] + Total_conflict_by_datalink_in_integrated[Density]))/(Transit_time_in_integrated[Density]*(Total_acft_integrated_in_enroute[Density] + .001))
Proportionate_increase_in_conflict_rate_in_integrated =
Percentage_of_restrictions_relaxed_in_integrated
Proportion_of_conflicts_resolved_by_trial_planning_integrated = .8

```

Reduction_factor_due_to_trial_planning_in_integrated = 1 -
 (.3*Proportion_of_conflicts_resolved_by_trial_planning_integrated)
 Reduction_factor_of_conflicts_due_to_uret_conflict_detection_int[Density] =
 IF(acft_rate_integrated[Density] <= 200)
 THEN(1 - .0014*acft_rate_integrated[Density])
 ELSE(.71)
 RVC_in_integrated[Density] = Routine_communication_in_integrated[Density] -
 Total_routine_datalink_comm_in_integrated[Density]
 sector_time_difference_in_integrated[Density] = Mean_ST_in_voice[Density] -
 Mean_ST_in_integrated[Density]
 Sector_Time_in_integrated[Density] = CYCLETIME(Rate_out_in_integrated[Density])
 Total_Excess_voice_channel_time_in_integrated[Density] = Excess_VCU_in_integrated[Density]*(TIME + 1)
 Total_time_spent_in_RVC_in_integrated[Density] =
 Average_time_per_routine_communication_via_voice*RVC_in_integrated[Density]
 Total_time_spent_in_trial_planning_in_integrated[Density] =
 Total_conflicts_in_integrated[Density]*Proportion_of_conflicts_resolved_by_trial_planning_integrated*Time_taken_per_trial_planning
 Transit_time_in_integrated[Density] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Free_Flow_enroute_transit_time +
 (No_of_routine_diversions_per_sector_in_integrated*(Diversion_time_per_routine_comm_in_voice
 + Datalink_Proportion_of_msgs*(Diversion_time_per_routine_comm_in_datalink_in_enroute -
 Diversion_time_per_routine_comm_in_voice))) +
 (Extra_voice_comm_in_enroute_in_integrated*Average_time_per_routine_communication_via_voice)
 +
 (Adjusted_no_of_conflicts_per_acft_in_integrated[Density]*(Percentage_of_conflicts_allocated_to_datalink*(Diversion_time_per_conflict_in_datalink_non_trial_planning +
 Proportion_of_conflicts_resolved_by_trial_planning_integrated*(Diversion_time_per_conflict_in_datalink_with_trial_planning_int[Density] -
 Diversion_time_per_conflict_in_datalink_non_trial_planning))) +
 (1 -
 Percentage_of_conflicts_allocated_to_datalink)*(Diversion_time_per_conflict_in_voice_non_trial_planning + Proportion_of_conflicts_resolved_by_trial_planning_integrated*
 (Diversion_time_per_conflict_in_voice_with_trial_planning[Density] -
 Diversion_time_per_conflict_in_voice_non_trial_planning))))))
 ELSE(Free_Flow_enroute_transit_time +
 (No_of_routine_diversions_per_sector_in_integrated*Diversion_time_per_routine_comm_in_voice
 +
 Extra_voice_comm_in_enroute_in_integrated*Average_time_per_routine_communication_via_voice

e) + Adjusted_no_of_conflicts_per_acft_in_integrated[Density]*(Diversion_time_per_conflict_in_voice_non_trial_planning + Proportion_of_conflicts_resolved_by_trial_planning_integrated*(Diversion_time_per_conflict_in_voice_with_trial_planning[Density] - Diversion_time_per_conflict_in_voice_non_trial_planning)))
VCU_in_integrated[Density] = (RVC_in_integrated[Density] + Total_conflict_by_voice_in_integrated[Density])*lag_time_in_voice_in_enroute/14400
Percentage_of_aircraft_in_conflict_in_integrated[Density] = GRAPH(Aircraft_in_enroute_sector_in_integrated[Density])
(0.00, 0.00), (3.00, 0.00), (6.00, 0.05), (9.00, 0.08), (12.0, 0.15), (15.0, 0.25), (18.0, 0.36), (21.0, 0.4), (24.0, 0.43), (27.0, 0.45), (30.0, 0.49)

Enroute Sector (Datalink + Voice + DSTs (non))

Aircraft_in_enroute_sector_in_non_integrated[Density](t) = Aircraft_in_enroute_sector_in_non_integrated[Density](t - dt) + (QDR_in_non_integrated[Density] - Rate_out_in_non_integrated[Density]) * dt

INIT Aircraft_in_enroute_sector_in_non_integrated[Density] = 0

INFLOWS:

QDR_in_non_integrated[Density] = IF(Controller_Activity_in_non_integrated[Density] >= 1) THEN(0)

ELSE(IF(AQ_outside_enroute_sector_for_non_integrated[Density] = 0)

THEN(0)

ELSE(1))

OUTFLOWS:

Rate_out_in_non_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Transit_time_in__non_integrated[Density]

AQ_outside_enroute_sector_for_non_integrated[Density](t) =

AQ_outside_enroute_sector_for_non_integrated[Density](t - dt) + (Rate_in_non_integrated[Density] - QDR_in_non_integrated[Density]) * dt

INIT AQ_outside_enroute_sector_for_non_integrated[Density] = 0

INFLOWS:

Rate_in_non_integrated[Density] = Acft_Injector[Density]

OUTFLOWS:

QDR_in_non_integrated[Density] = IF(Controller_Activity_in_non_integrated[Density] >= 1) THEN(0)

ELSE(IF(AQ_outside_enroute_sector_for_non_integrated[Density] = 0)

THEN(0)

ELSE(1))

$Routine_communication_in_non_integrated[Density](t) =$
 $Routine_communication_in_non_integrated[Density](t - dt) +$
 $(routine_comm_rate_in_non_integrated[Density]) * dt$
 INIT $Routine_communication_in_non_integrated[Density] = 0$
 INFLOWS:
 $routine_comm_rate_in_non_integrated[Density] = QDR_in_non_integrated[Density] * (No_of_routine_comm_per_aircraft_in_non_integrated +$
 $Extra_voice_comm_in_enroute_in_non_integrated)$
 $Total_acft_exited_in_non_integrated[Density](t) = Total_acft_exited_in_non_integrated[Density](t -$
 $dt) + (exit_rate_in_non_integrated[Density]) * dt$
 INIT $Total_acft_exited_in_non_integrated[Density] = 0$
 INFLOWS:
 $exit_rate_in_non_integrated[Density] = Rate_out_in_non_integrated[Density]$
 $Total_acft_in_non_integrated_in_enroute[Density](t) =$
 $Total_acft_in_non_integrated_in_enroute[Density](t - dt) + (rate_non_integrated[Density]) * dt$
 INIT $Total_acft_in_non_integrated_in_enroute[Density] = 0$
 INFLOWS:
 $rate_non_integrated[Density] = QDR_in_non_integrated[Density]$
 $Total_conflicts_by_datalink_in_non_integrated[Density](t) =$
 $Total_conflicts_by_datalink_in_non_integrated[Density](t - dt) +$
 $(conflict_rate_by_datalink_in_non_integrated[Density]) * dt$
 INIT $Total_conflicts_by_datalink_in_non_integrated[Density] = 0$
 INFLOWS:
 $conflict_rate_by_datalink_in_non_integrated[Density] = IF(RANDOM(0,1) <=$
 $Equipage_level_for_aircrafts) THEN(No_of_conflicts_per_acft_in_non_integrated[Density] * Percentage_of_conflicts_allocated_to_datalink)$
 ELSE(0)
 $Total_conflicts_by_voice_in_non_integrated[Density](t) =$
 $Total_conflicts_by_voice_in_non_integrated[Density](t - dt) +$
 $(conflict_rate_by_voice_in_non_integrated[Density]) * dt$
 INIT $Total_conflicts_by_voice_in_non_integrated[Density] = 0$
 INFLOWS:
 $conflict_rate_by_voice_in_non_integrated[Density] = IF(RANDOM(0,1) <=$
 $Equipage_level_for_aircrafts) THEN(No_of_conflicts_per_acft_in_non_integrated[Density] * (1 -$
 $Percentage_of_conflicts_allocated_to_datalink))$
 ELSE($No_of_conflicts_per_acft_in_non_integrated[Density]$)
 $Total_conflict_time_by_datalink_in_non_integrated[Density](t) =$
 $Total_conflict_time_by_datalink_in_non_integrated[Density](t - dt) +$
 $(Conflict_time_rate_by_datalink_in_non_integrated[Density]) * dt$

```

INIT Total_conflict_time_by_datalink_in_non_integrated[Density] = 0
INFLOWS:
Conflict_time_rate_by_datalink_in_non_integrated[Density] = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts)
THEN(No_of_conflicts_per_acft_in_non_integrated[Density]*Percentage_of_conflicts_allocated_to
_datalink*(Average_time_per_conflict_by_datalink_non_trial_planning +
Proportion_of_conflicts_resolved_by_trial_planning_non_integrated*(Average_Time_per_conflict_
by_datalink_with_trial_planning_non[Density] -
Average_time_per_conflict_by_datalink_non_trial_planning)))
ELSE(0)
Total_conflict_time_by_voice_in_non_integrated[Density](t) =
Total_conflict_time_by_voice_in_non_integrated[Density](t - dt) +
(Conflict_time_rate_by_voice_in_non_integrated[Density]) * dt
INIT Total_conflict_time_by_voice_in_non_integrated[Density] = 0
INFLOWS:
Conflict_time_rate_by_voice_in_non_integrated[Density] = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts) THEN(No_of_conflicts_per_acft_in_non_integrated[Density]*(1 -
Percentage_of_conflicts_allocated_to_datalink)*(Average_time_per_conflict_by_voice_non_trial_pl
anning + Proportion_of_conflicts_resolved_by_trial_planning_non_integrated*
(Average_Time_per_conflict_by_voice_with_trial_planning[Density] -
Average_time_per_conflict_by_voice_non_trial_planning)))
ELSE(No_of_conflicts_per_acft_in_non_integrated[Density]*(Average_time_per_conflict_by_voice_non_trial_planning +
Proportion_of_conflicts_resolved_by_trial_planning_non_integrated*(Average_Time_per_conflict_
by_voice_with_trial_planning[Density] -
Average_time_per_conflict_by_voice_non_trial_planning)))
Total_no_of_conflicts_in_non_integrated[Density](t) =
Total_no_of_conflicts_in_non_integrated[Density](t - dt) + (conflict_rate_in_non_integrated[Density]) * dt
INIT Total_no_of_conflicts_in_non_integrated[Density] = 0
INFLOWS:
conflict_rate_in_non_integrated[Density] = No_of_conflicts_per_acft_in_non_integrated[Density]
Total_Routine_datalink_comm_in_non_integrated[Density](t) =
Total_Routine_datalink_comm_in_non_integrated[Density](t - dt) +
(Routine_datalink_comm_rate_in_non_integrated[Density]) * dt
INIT Total_Routine_datalink_comm_in_non_integrated[Density] = 0
INFLOWS:
Routine_datalink_comm_rate_in_non_integrated[Density] = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts) THEN(QDR_in_non_integrated[Density]

```

density]*No_of_routine_comm_per_aircraft_in_non_integrated*Datalink_Proportion_of_msgs)

ELSE(0)

Total_routine_datalink_occupation_time_in_non_integrated[Density](t) =

Total_routine_datalink_occupation_time_in_non_integrated[Density](t - dt) +

(routine_datalink_occupation_rate_in_non_integrated[Density]) * dt

INIT Total_routine_datalink_occupation_time_in_non_integrated[Density] = 0

INFLOWS:

routine_datalink_occupation_rate_in_non_integrated[Density] =

Routine_datalink_comm_rate_in_non_integrated[Den-

sity]*Average_time_per_routine_communication_via_datalink

acft_rate_non_integrated[Density] = Total_acft_in_non_integrated_in_enroute[Density]*10*60*24/

TIME

Actual_Enroute_utilization_in_non_integrated[Density] =

Enroute_controller_utilization_in_non_integrated[Density] +

((Excess_conflict_time_in_non_integrated[Density] +

Excess_Routine_time_in_non_integrated[Density])/(TIME + 1))

Actual_total_no_of_datalink_communications_in_non_integrated[Density] =

Actual_total_no_of_datalink_conflict_comm_in_non_integrated[Density] +

Actual_total_no_of_routine_datalink_comm_in_non_integrated[Density]

Actual_total_no_of_datalink_conflict_comm_in_non_integrated[Density] =

(Total_conflict_time_by_datalink_in_non_integrated[Density] +

Excess_conflict_time_in_non_integrated[Density])/

Average_time_per_conflict_by_datalink_non_uret

Actual_total_no_of_routine_datalink_comm_in_non_integrated[Density] =

Extra_Number_of_routine_Voice_msg_in_non_transferred_to_datalink[Density] +

Total_Routine_datalink_comm_in_non_integrated[Density]

Actual_total_no_of_routine_voice_comm_in_non_integrated[Density] =

Routine_communication_in_non_integrated[Density] -

Actual_total_no_of_routine_datalink_comm_in_non_integrated[Density]

Actual_total_no_of_voice_communications_in_non_integrated[Density] =

Actual_total_no_of_routine_voice_comm_in_non_integrated[Density] +

Actual_total_no_of_voice_conflict_comm_in_non_integrated[Density]

Actual_total_no_of_voice_conflict_comm_in_non_integrated[Density] =

Total_no_of_conflicts_in_non_integrated[Density] -

Actual_total_no_of_datalink_conflict_comm_in_non_integrated[Density]

Adjusted_no_of_conflicts_per_acft_in_non_integrated[Density] =

Expected_no_of_conflicts_per_acft_in_non_integrated[Density]*Reduction_factor_of_conflicts_

due_to_uret_conflict_detection_non[Density]*(1 +

Proportionate_increase_in_conflict_rate_in_non_integrated)*Reduction_factor_due_to_trial_plannin

g_non

Average_time_per_conflict_by_datalink_non_trial_planning = Conflict_Perception_Time_with_uret
+ Conflict_Resolution_Finding_Time_non_trial_planning +

Datalink_Resolution_Time_non_integrated

Average_Time_per_conflict_by_datalink_with_trial_planning_non[Density] =

Conflict_Perception_Time_with_uret +

Conflict_Resolution_Finding_Time_with_trial_planning[Density] +

Datalink_Resolution_Time_non_integrated

Average_time_per_conflict_by_voice_non_trial_planning = Conflict_Perception_Time_with_uret +

Conflict_Resolution_Finding_Time_non_trial_planning + Voice_Resolution_Time

Average_Time_per_conflict_by_voice_with_trial_planning[Density] =

Conflict_Perception_Time_with_uret +

Conflict_Resolution_Finding_Time_with_trial_planning[Density] + Voice_Resolution_Time

Conflict_Perception_Time_with_uret = 6/6

Conflict_per_acft_MS_10_non[Density] = .00106*acft_rate_non_integrated[Density]

Conflict_per_acft_MS_2_non[Density] = .000167*acft_rate_non_integrated[Density]

Conflict_per_acft_MS_3_non[Density] = .000266*acft_rate_non_integrated[Density]

Conflict_per_acft_MS_5_non[Density] = .0000004*acft_rate_non_integrated[Density] + .0003*acft_rate_non_integrated[Density]

Conflict_Resolution_Finding_Time_with_trial_planning[Density] =

No_of_trial_plans_done_per_conflict[Density]*Time_taken_per_trial_planning

Controller_Activity_in_non_integrated[Density] = IF(RANDOM(0,1) <=

Equipage_level_for_aircrafts)

THEN(Aircraft_in_enroute_sector_in_non_integrated[Density]*((No_of_routine_comm_per_aircraft_in_non_integrated*(Average_time_per_routine_communication_via_voice +

Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink - Average_time_per_routine_communication_via_voice)))) +

(Extra_voice_comm_in_enroute_in_non_integrated*Average_time_per_routine_communication_via_voice) +

(Adjusted_no_of_conflicts_per_acft_in_non_integrated[Density]/

1.5*(Percentage_of_conflicts_allocated_to_datalink*(Average_time_per_conflict_by_datalink_non_trial_planning +

Proportion_of_conflicts_resolved_by_trial_planning_non_integrated*(Average_Time_per_conflict_by_datalink_with_trial_planning_non[Density] -

Average_time_per_conflict_by_datalink_non_trial_planning)) +

(1 -

Percentage_of_conflicts_allocated_to_datalink)*(Average_time_per_conflict_by_voice_non_trial_planning + Proportion_of_conflicts_resolved_by_trial_planning_non_integrated*

(Average_Time_per_conflict_by_voice_with_trial_planning[Density] -

Average_time_per_conflict_by_voice_non_trial_planning))))))/
 Transit_time_in__non_integrated[Density])
 ELSE(Aircraft_in_enroute_sector_in_non_integrated[Density]*(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_per_aircraft_in_non_integrated +
 Extra_voice_comm_in_enroute_in_non_integrated) +
 Adjusted_no_of_conflicts_per_acft_in_non_integrated[Density]/
 1.5*(Average_time_per_conflict_by_voice_non_trial_planning +
 Proportion_of_conflicts_resolved_by_trial_planning_non_integrated*
 (Average_Time_per_conflict_by_voice_with_trial_planning[Density] -
 Average_time_per_conflict_by_voice_non_trial_planning)))/Transit_time_in__non_integrated[Density])
 DCU_in_non_integrated[Density] = (Total_Routine_datalink_comm_in_non_integrated[Density] +
 Total_conflicts_by_datalink_in_non_integrated[Density])*lag_time_in_datalink_in_enroute/14400
 Enroute_controller_utilization_in_non_integrated[Density] =
 (Total_conflict_time_by_datalink_in_non_integrated[Density] +
 Total_conflict_time_by_voice_in_non_integrated[Density] +
 Total_routine_datalink_occupation_time_in_non_integrated[Density] +
 Total_time_spent_in_RVC_in_non_integrated[Density])/14400
 Excess_conflict_time_in_non_integrated[Density] = IF(CPDLC_Build_IA_Switch=1)
 THEN((Total_Excess_Voice_channel_time_in_non_integrated[Density]/2) -
 (Total_Excess_Voice_channel_time_in_non_integrated[Density]*Average_time_per_conflict_by_datalink_non_uret*CPDLC_Build_IA_Switch/(2*Average_time_per_conflict_by_voice_non_uret)))
 ELSE(0)
 Excess_Routine_time_in_non_integrated[Density] = IF(CPDLC_Build_IA_Switch = 1)
 THEN((Total_Excess_Voice_channel_time_in_non_integrated[Density]/2) -
 (Total_Excess_Voice_channel_time_in_non_integrated[Density]*Average_time_per_routine_communication_via_datalink/
 (Average_time_per_routine_communication_via_voice*2)))
 ELSE(Total_Excess_Voice_channel_time_in_non_integrated[Density] -
 (Total_Excess_Voice_channel_time_in_non_integrated[Density]*Average_time_per_routine_communication_via_datalink/
 (Average_time_per_routine_communication_via_voice)))
 Excess_VCU_in_non_integrated[Density] = MAX(VCU_in_non_integrated[Density] - 1,0)
 Expected_no_of_conflicts__per_acft__in_non_integrated[Density] = IF(Minimum_Separation <= 2)
 THEN(Conflict_per_acft_MS_2_non[Density]*Minimum_Separation/2)
 ELSE(IF(Minimum_Separation <= 3) AND (Minimum_Separation > 2)
 THEN((Conflict_per_acft_MS_3_non[Density] - Conflict_per_acft_MS_2_non[Density])*(Minimum_Separation - 2) + Conflict_per_acft_MS_2_non[Density])
 ELSE(IF(Minimum_Separation <= 5) AND (Minimum_Separation > 3)

THEN((Conflict_per_acft_MS_5_non[Density] - Conflict_per_acft_MS_3_non[Density])*(Minimum_Separation - 3)/2 + Conflict_per_acft_MS_3_non[Density])
 ELSE(IF(Minimum_Separation <= 7.5) AND (Minimum_Separation > 5)
 THEN((Conflict_per_acft_MS_75_non[Density] - Conflict_per_acft_MS_5_non[Density])*(Minimum_Separation - 5)/2.5 + Conflict_per_acft_MS_5_non[Density])
 ELSE(IF(Minimum_Separation <= 10) AND (Minimum_Separation > 7.5)
 THEN((Conflict_per_acft_MS_10_non[Density] - Conflict_per_acft_MS_75_non[Density])*(Minimum_Separation - 7.5)/2.5 + Conflict_per_acft_MS_75_non[Density])
 ELSE(0))))))
 Extra_Number_of_routine_Voice_msg_in_non__transferred_to_datalink[Density] =
 IF(CPDLC_Build_IA_Switch = 1)
 THEN(Total_Excess_Voice_channel_time_in_non_integrated[Density]/
 (Average_time_per_routine_communication_via_voice*2))
 ELSE(Total_Excess_Voice_channel_time_in_non_integrated[Density]/
 Average_time_per_routine_communication_via_voice)
 Extra_voice_comm_in_enroute_in_non_integrated = IF(RANDOM(0,1) <=
 Equipage_level_for_aircrafts) THEN(No_of_routine_comm_per_aircraft_in_non_integrated
 Percentage_extra_comm_per_comm(1 - Datalink_Proportion_of_msgs))
 ELSE(No_of_routine_comm_per_aircraft_in_non_integrated*Percentage_extra_comm_per_comm)
 Mean_ST_in_non_integrated[Density] = CTMEAN(Rate_out_in_non_integrated[Density])
 No_of_conflicts_per_acft_in_non_integrated[Density] = IF(QDR_in_non_integrated[Density] > 0)
 THEN(Adjusted_no_of_conflicts_per_acft_in_non_integrated[Density])
 ELSE(0)
 No_of_routine_comm_per_aircraft_in_non_integrated =
 No_of_routine_communication_per__aircraft_in_enroute_sector -
 No_of_routing_restrictions_relaxed_in_non_integrated
 No_of_routine_diversions_per_sector_in_non_integrated = No_of_routine_diversions_per_sector -
 No_of_routing_restrictions_relaxed_in_non_integrated
 No_of_routing_restrictions_relaxed_in_non_integrated =
 Percentage_of_restrictions_relaxed_in_non_integrated*Total_no_of_routing_restrictions
 No_of_trial_plans_done_per_conflict[Density] = MIN(1,No_of_trial_plans_per_aircraft/
 (Adjusted_no_of_conflicts_per_acft_in_non_integrated[Density] + .0001))
 No_of_trial_plans_per_aircraft = .2104
 Percentage_of_acft_in_conflict_in_non = 1
 Percentage_of_restrictions_relaxed_in_non_integrated = .2
 Pilot_Utilization_in_non_integrated[Density] =
 Proportion_of_msgs_to_be_fed_into_the_FMS*(Average_time_for_hearing_and_uploading_the_message*(Total_conflicts_by_voice_in_non_integrated[Density] + RVC_in_non_integrated[Density]) +
 Average_time_for_reading_and_uploading_message*(Total_Routine_datalink_comm_in_non_integr

ated[Density] + Total_conflicts_by_datalink_in_non_integrated[Density]))/
 (Transit_time_in__non_integrated[Density]*(Total_acft_in_non_integrated_in_enroute[Density] +
 .001))
 Proportionate_increase_in_conflict_rate_in_non_integrated =
 Percentage_of_restrictions_relaxed_in_non_integrated
 Proportion_of_conflicts_resolved_by_trial_planning_non_integrated = .6
 Reduction_factor_due_to_trial_planning_non = 1 -
 (.3*Proportion_of_conflicts_resolved_by_trial_planning_non_integrated)
 Reduction_factor_of_conflicts_due_to_uret_conflict_detection_non[Density] =
 IF(acft_rate_non_integrated[Density] <= 200)
 THEN(1 - .0014*acft_rate_non_integrated[Density])
 ELSE(.71)
 RVC_in_non_integrated[Density] = Routine_communication_in_non_integrated[Density] -
 Total_Routine_datalink_comm_in_non_integrated[Density]
 sector_time_difference_in_non_integrated[Density] = Mean_ST_in_voice[Density] -
 Mean_ST_in_non_integrated[Density]
 Sector_time_in_non_integrated[Density] = CYCLETIME(Rate_out_in_non_integrated[Density])
 Time_saved_per_routing_restriction_relaxation = .5
 Time_taken_per_trial_planning = 12/6
 Total_Excess_Voice_channel_time_in_non_integrated[Density] =
 Excess_VCU_in_non_integrated[Density]*(TIME + 1)
 Total_no_of_routing_restrictions = 1.75
 Total_time_spent_in_RVC_in_non_integrated[Density] =
 Average_time_per_routine_communication_via_voice*RVC_in_non_integrated[Density]
 Transit_time_in__non_integrated[Density] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Free_Flow_enroute_transit_time +
 (No_of_routine_diversions_per_sector_in_non_integrated*(Diversion_time_per_routine_comm_in_
 voice + Datalink_Proportion_of_msgs*(Diversion_time_per_routine_comm_in_datalink_in_enroute
 - Diversion_time_per_routine_comm_in_voice))) +
 (Extra_voice_comm_in_enroute_in_non_integrated*Average_time_per_routine_communication_via
 _voice) +
 (Adjusted_no_of_conflicts_per_acft_in_non_integrated[Density]*(Percentage_of_conflicts_allocate
 d_to_datalink*(Diversion_time_per_conflict_in_datalink_non_trial_planning +
 Proportion_of_conflicts_resolved_by_trial_planning_non_integrated*(Diversion_time_per_conflict_
 in_datalink_with_trial_planning_non[Density] -
 Diversion_time_per_conflict_in_datalink_non_trial_planning)) +
 (1 -
 Percentage_of_conflicts_allocated_to_datalink)*(Diversion_time_per_conflict_in_voice_non_trial_
 planning + Proportion_of_conflicts_resolved_by_trial_planning_non_integrated*

(Diversion_time_per_conflict_in_voice_with_trial_planning[Density] -
 Diversion_time_per_conflict_in_voice_non_trial_planning))))))
 ELSE(Free_Flow_enroute_transit_time +
 (No_of_routine_diversions_per_sector_in_non_integrated*Diversion_time_per_routine_comm_in_v
 oice +
 Extra_voice_comm_in_enroute_in_non_integrated*Average_time_per_routine_communication_via
 _voice) + Adjusted_no_of_conflicts_per_acft_in_non_integrated[Den-
 sity]*(Diversion_time_per_conflict_in_voice_non_trial_planning +
 Proportion_of_conflicts_resolved_by_trial_planning_non_integrated*
 (Diversion_time_per_conflict_in_voice_with_trial_planning[Density] -
 Diversion_time_per_conflict_in_voice_non_trial_planning)))
 VCU_in_non_integrated[Density] = (RVC_in_non_integrated[Density] +
 Total_conflicts_by_voice_in_non_integrated[Density])*lag_time_in_voice_in_enroute/14400

Enroute Sector (Datalink + Voice)

Aircraft_in_enroute_sector_in_datalink[Density](t) = Aircraft_in_enroute_sector_in_datalink[Den-
 sity](t - dt) + (QDR_in_datalink[Density] - Rate_out_in_datalink[Density]) * dt

INIT Aircraft_in_enroute_sector_in_datalink[Density] = 0

INFLOWS:

QDR_in_datalink[Density] = IF(Controller_Activity_in_datalink[Density] >= 1)

THEN(0)

ELSE(IF(AQ_outside_enroute_sector_for_datalink[Density] = 0)

THEN(0)

ELSE(1))

OUTFLOWS:

Rate_out_in_datalink[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Transit_time_in_datalink[Density]

AQ_outside_enroute_sector_for_datalink[Density](t) =

AQ_outside_enroute_sector_for_datalink[Density](t - dt) + (Rate_in_datalink_[Density] -
 QDR_in_datalink[Density]) * dt

INIT AQ_outside_enroute_sector_for_datalink[Density] = 0

INFLOWS:

Rate_in_datalink_[Density] = Acft_Injector[Density]

OUTFLOWS:

QDR_in_datalink[Density] = IF(Controller_Activity_in_datalink[Density] >= 1)

THEN(0)

ELSE(IF(AQ_outside_enroute_sector_for_datalink[Density] = 0)

THEN(0)

ELSE(1))

Total_acft_exited_in_datalink[Density](t) = Total_acft_exited_in_datalink[Density](t - dt) +
(exit_rate__in_datalink[Density]) * dt

INIT Total_acft_exited_in_datalink[Density] = 0

INFLOWS:

exit_rate__in_datalink[Density] = Rate_out_in_datalink[Density]

Total_acft_in_datalink_in_enroute[Density](t) = Total_acft_in_datalink_in_enroute[Density](t - dt) +
(aircraft_in_rate_in_datalink[Density]) * dt

INIT Total_acft_in_datalink_in_enroute[Density] = 0

INFLOWS:

aircraft_in_rate_in_datalink[Density] = QDR_in_datalink[Density]

Total_conflicts_by_datalink_in_datalink[Density](t) = Total_conflicts_by_datalink_in_datalink[Density](t - dt) + (conflict_rate_by_datalink_in_datalink[Density]) * dt

INIT Total_conflicts_by_datalink_in_datalink[Density] = 0

INFLOWS:

conflict_rate_by_datalink_in_datalink[Density] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts) THEN(No_of_conflicts_per_acft_in_datalink[Density]*Percentage_of_conflicts_allocated_to_datalink)

ELSE(0)

Total_conflicts_by_voice_in_datalink[Density](t) = Total_conflicts_by_voice_in_datalink[Density](t - dt) + (conflict_rate_by_voice_in_datalink[Density]) * dt

INIT Total_conflicts_by_voice_in_datalink[Density] = 0

INFLOWS:

conflict_rate_by_voice_in_datalink[Density] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts) THEN(No_of_conflicts_per_acft_in_datalink[Density]*(1 - Percentage_of_conflicts_allocated_to_datalink))

ELSE(No_of_conflicts_per_acft_in_datalink[Density])

Total_conflict_time_by_datalink_in_datalink[Density](t) = Total_conflict_time_by_datalink_in_datalink[Density](t - dt) + (Coflict_time_rate_by_datalink_in_datalink[Density]) * dt

INIT Total_conflict_time_by_datalink_in_datalink[Density] = 0

INFLOWS:

Coflict_time_rate_by_datalink_in_datalink[Density] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)

THEN(No_of_conflicts_per_acft_in_datalink[Density]*Average_time_per_conflict_by_datalink_n_uret*Percentage_of_conflicts_allocated_to_datalink)

ELSE(0)

Total_conflict_time_by_voice_in_datalink[Density](t) =

Total_conflict_time_by_voice_in_datalink[Density](t - dt) +

```

(Conflict_time_rate_by_voice_in_datalink[Density]) * dt
INIT Total_conflict_time_by_voice_in_datalink[Density] = 0
INFLOWS:
Conflict_time_rate_by_voice_in_datalink[Density] = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts)
THEN(Average_time_per_conflict_by_voice_non_uret*No_of_conflicts_per_acft_in_datalink[Density]*(1 - Percentage_of_conflicts_allocated_to_datalink))
ELSE (Average_time_per_conflict_by_voice_non_uret*No_of_conflicts_per_acft_in_datalink[Density])
Total_No_of_conflicts_in_datalink[Density](t) = Total_No_of_conflicts_in_datalink[Density](t - dt)
+ (conflict_rate_in_datalink[Density]) * dt
INIT Total_No_of_conflicts_in_datalink[Density] = 0
INFLOWS:
conflict_rate_in_datalink[Density] = No_of_conflicts_per_acft_in_datalink[Density]
Total_No_of_routine_communications_in_datalink[Density](t) =
Total_No_of_routine_communications_in_datalink[Density](t - dt) +
(Routine_communication_rate_in_datalink[Density]) * dt
INIT Total_No_of_routine_communications_in_datalink[Density] = 0
INFLOWS:
Routine_communication_rate_in_datalink[Density] = QDR_in_datalink[Density]*(No_of_routine_communication_per__aircraft_in_enroute_sector +
Extra_voice_comm_in_enroute_in_datalink)
Total_no_of_routine_datalink_communications_in_datalink[Density](t) =
Total_no_of_routine_datalink_communications_in_datalink[Density](t - dt) +
(routine_datalink_comm_rate_in_datalink[Density]) * dt
INIT Total_no_of_routine_datalink_communications_in_datalink[Density] = 0
INFLOWS:
routine_datalink_comm_rate_in_datalink[Density] = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts)
THEN(QDR_in_datalink[Density]*No_of_routine_communication_per__aircraft_in_enroute_sector*Datalink_Proportion_of_messages)
ELSE(0)
Total_time_spent_in_routine_datalink_comm_in_datalink[Density](t) =
Total_time_spent_in_routine_datalink_comm_in_datalink[Density](t - dt) +
(routine_datalink_occupation_rate_in_datalink[Density]) * dt
INIT Total_time_spent_in_routine_datalink_comm_in_datalink[Density] = 0
INFLOWS:
routine_datalink_occupation_rate_in_datalink[Density] =

```

$$\text{routine_datalink_comm_rate_in_datalink}[\text{Density}] * \text{Average_time_per_routine_communication_via_datalink}$$

$$\text{acft_rate_in_datalink}[\text{Density}] = \text{Total_acft_in_datalink_in_enroute}[\text{Density}] * 10 * 60 * 24 / \text{TIME}$$

$$\text{Actual_Enroute_Controller_Utilization_in_datalink}[\text{Density}] =$$

$$\text{Enroute_Controller_Utilization_in_datalink}[\text{Density}] - ((\text{Excess_Conflict_time_in_datalink}[\text{Density}] + \text{Excess_Routine_time_in_datalink}[\text{Density}]) / (\text{TIME} + 1))$$

$$\text{Actual_Percentage_of_msg_allocated_to_datalink}[\text{Density}] =$$

$$\text{Actual_Total_No_of_routine_datalink_communications_in_datalink}[\text{Density}] /$$

$$(\text{MAX}(\text{Total_No_of_routine_communications_in_datalink}[\text{Density}], 1) * (\text{CPDLC_Build_I_Switch} * \text{Message_set_ratio_for_Build_I} +$$

$$\text{Additional_Message_ratio_set_for_Build_IA} * \text{CPDLC_Build_IA_Switch} +$$

$$\text{CPDLC_Build_II_Switch} * \text{Additional_Message_ratio_set_for_Build_II}))$$

$$\text{Actual_Total_No_of_datalink_communications_in_datalink}[\text{Density}] =$$

$$\text{Actual_Total_No_of_datalink_conflict_communications}[\text{Density}] +$$

$$\text{Actual_Total_No_of_routine_datalink_communications_in_datalink}[\text{Density}]$$

$$\text{Actual_Total_No_of_datalink_conflict_communications}[\text{Density}] =$$

$$(\text{Total_conflict_time_by_datalink_in_datalink}[\text{Density}] + \text{Excess_Conflict_time_in_datalink}[\text{Density}]) / \text{Average_time_per_conflict_by_datalink_non_uret}$$

$$\text{Actual_Total_No_of_routine_datalink_communications_in_datalink}[\text{Density}] =$$

$$\text{Total_no_of_routine_datalink_communications_in_datalink}[\text{Density}] +$$

$$\text{Extra_no_of_routine_voice_msg_in_datalink_transferred_to_datalink}[\text{Density}]$$

$$\text{Actual_Total_No_of_routine_voice_communications_in_datalink}[\text{Density}] =$$

$$\text{Total_No_of_routine_communications_in_datalink}[\text{Density}] -$$

$$\text{Actual_Total_No_of_routine_datalink_communications_in_datalink}[\text{Density}]$$

$$\text{Actual_Total_No_of_voice_communications_in_datalink}[\text{Density}] =$$

$$\text{Actual_Total_No_of_routine_voice_communications_in_datalink}[\text{Density}] +$$

$$\text{Actual_Total_No_of_voice_conflict_communications}[\text{Density}]$$

$$\text{Actual_Total_No_of_voice_conflict_communications}[\text{Density}] =$$

$$\text{Total_No_of_conflicts_in_datalink}[\text{Density}] -$$

$$\text{Actual_Total_No_of_datalink_conflict_communications}[\text{Density}]$$

$$\text{Additional_Message_ratio_set_for_Build_IA} = \text{Additional_Message_set_for_Build_IA} /$$

$$(\text{Additional_Message_set_for_Build_IA} + \text{Message_set_for_Build_I} +$$

$$\text{Additional_Message_set_for_Build_II})$$

$$\text{Additional_Message_ratio_set_for_Build_II} = \text{Additional_Message_set_for_Build_II} /$$

$$(\text{Message_set_for_Build_I} + \text{Additional_Message_set_for_Build_IA} +$$

$$\text{Additional_Message_set_for_Build_II})$$

$$\text{Additional_Message_set_for_Build_IA} = 5$$

$$\text{Additional_Message_set_for_Build_II} = 3$$

$$\text{Addn_Proportion_of_comm_by_datalink_for_Build_IA} =$$

Additional_Message_ratio_set_for_Build_IA*Percentage_of_msg_allocated_to_datalink
 Addn_Proportion_of_comm_by_datalink_for_Build_II =
 Additional_Message_ratio_set_for_Build_II*Percentage_of_msg_allocated_to_datalink
 Average_time_for_reading_and_uploading_message = 14/6
 Average_time_per_conflict_by_datalink_non_uret = Conflict_Perception_Time_in_non_uret_case +
 Conflict_Resolution_Finding_Time_non_trial_planning +
 Datalink_Resolution_Time_non_integrated
 Average_time_per_routine_communication_via_datalink = 4/6
 Conflict_Perception_Time_in_non_uret_case = 24/6
 Conflict_per_acft_MS_10_datalink[Density] = .00106*acft_rate_in_datalink[Density]
 Conflict_per_acft_MS_2_datalink[Density] = .000167*acft_rate_in_datalink[Density]
 Conflict_per_acft_MS_3_datalink[Density] = .000266*acft_rate_in_datalink[Density]
 Conflict_per_acft_MS_5_datalink[Density] = .0000004*acft_rate_in_datalink[Density]*
 acft_rate_in_datalink[Density]+ .0003*acft_rate_in_datalink[Density]
 Conflict_per_acft_MS_75_datalink[Density] = .000733*acft_rate_in_datalink[Density]
 Conflict_Resolution_Finding_Time_non_trial_planning = 4
 Controller_Activity_in_datalink[Density] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Aircraft_in_enroute_sector_in_datalink[Density]*((No_of_routine_communication_per__air
 craft_in_enroute_sector*(Average_time_per_routine_communication_via_voice +
 Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink -
 Average_time_per_routine_communication_via_voice))) +
 (Extra_voice_comm_in_enroute_in_datalink*Average_time_per_routine_communication_via_voice
) + (Expected_no_of_conflicts_per_acft_in_datalink[Density]/
 1.5*(Average_time_per_conflict_by_voice_non_uret +
 Percentage_of_conflicts_allocated_to_datalink*(Average_time_per_conflict_by_datalink_non_uret -
 Average_time_per_conflict_by_voice_non_uret)))/Transit_time_in_datalink[Density])
 ELSE(Aircraft_in_enroute_sector_in_datalink[Density]*(Average_time_per_routine_communicatio
 n_via_voice*(No_of_routine_communication_per__aircraft_in_enroute_sector
 +Extra_voice_comm_in_enroute_in_datalink) +
 (Average_time_per_conflict_by_voice_non_uret*Expected_no_of_conflicts_per_acft_in_datalink[D
 ensity]/1.5))/Transit_time_in_datalink[Density])
 CPDLC_Build_IA_Switch = 1
 CPDLC_Build_II_Switch = 1
 CPDLC_Build_I_Switch = 1
 Datalink_Resolution_Time_non_integrated =
 Average_time_per_routine_communication_via_datalink
 DCU_in_datalink_in_enroute[Density] =
 (Total_no_of_routine_datalink_communications_in_datalink[Density] +
 Total_conflicts_by_datalink_in_datalink[Density])*lag_time_in_datalink_in_enroute/14400

Diversion_time_per_conflict_in_datalink_non_trial_planning =
 Diversion_time_per_conflict_in_voice_non_uret +
 Average_time_per_conflict_by_datalink_non_trial_planning -
 Average_time_per_conflict_by_voice_non_uret + lag_time_in_datalink_in_enroute -
 lag_time_in_voice_in_enroute + Average_time_for_reading_and_uploading_message -
 Typing_message_time
 Diversion_time_per_conflict_in_datalink_non_uret =
 Diversion_time_per_conflict_in_voice_non_uret +
 (Average_time_per_conflict_by_datalink_non_uret -
 Average_time_per_conflict_by_voice_non_uret) + lag_time_in_datalink_in_enroute -
 lag_time_in_voice_in_enroute + Average_time_for_reading_and_uploading_message -
 Typing_message_time
 Diversion_time_per_conflict_in_datalink_with_trial_planning_non[Density] =
 Diversion_time_per_conflict_in_voice_non_uret +
 Average_Time_per_conflict_by_datalink_with_trial_planning_non[Density] -
 Average_time_per_conflict_by_voice_non_uret + lag_time_in_datalink_in_enroute -
 lag_time_in_voice_in_enroute + Average_time_for_reading_and_uploading_message -
 Typing_message_time
 Diversion_time_per_conflict_in_voice_non_trial_planning =
 Diversion_time_per_conflict_in_voice_non_uret +
 Average_time_per_conflict_by_voice_non_trial_planning -
 Average_time_per_conflict_by_voice_non_uret
 Diversion_time_per_conflict_in_voice_with_trial_planning[Density] =
 Diversion_time_per_conflict_in_voice_non_uret +
 Average_Time_per_conflict_by_voice_with_trial_planning[Density] -
 Average_time_per_conflict_by_voice_non_uret
 Diversion_time_per_routine_comm_in_datalink_in_enroute =
 Diversion_time_per_routine_comm_in_voice +
 (Average_time_per_routine_communication_via_datalink -
 Average_time_per_routine_communication_via_voice) + lag_time_in_datalink_in_enroute -
 lag_time_in_voice_in_enroute + Average_time_for_reading_and_uploading_message -
 Typing_message_time
 Diversion_time_per_routine_comm_in_datalink_in_terminal_airspace =
 Diversion_time_per_routine_comm_in_voice +
 (Average_time_per_routine_communication_via_datalink -
 Average_time_per_routine_communication_via_voice) +
 lag_time_in_datalink_in_terminal_airspace - lag_time_in_voice_in_terminal_airspace +
 Average_time_for_reading_and_uploading_message - Typing_message_time
 Enroute_Controller_Utilization_in_datalink[Density] =

(Total_conflict_time_by_datalink_in_datalink[Density] +
 Total_conflict_time_by_voice_in_datalink[Density] +
 Total_time_spent_in_routine_datalink_comm_in_datalink[Density] +
 Total_time_spent_in_RVC_in_datalink_only[Density])/14400
 Equipage_level_for_aircrafts = .75
 Equipage_rate_for_aircrafts = .2
 Excess_Conflict_time_in_datalink[Density] = IF(CPDLC_Build_IA_Switch=1)
 THEN((Total_Excess_Voice_Channel_time_in_datalink[Density]/2) -
 (Total_Excess_Voice_Channel_time_in_datalink[Den-
 sity]*Average_time_per_conflict_by_datalink_non_uret*CPDLC_Build_IA_Switch/
 (2*Average_time_per_conflict_by_voice_non_uret)))
 ELSE(0)
 Excess_Routine_time_in_datalink[Density] = IF(CPDLC_Build_IA_Switch = 1)
 THEN((Total_Excess_Voice_Channel_time_in_datalink[Density]/2) -
 (Total_Excess_Voice_Channel_time_in_datalink[Den-
 sity]*Average_time_per_routine_communication_via_datalink/
 (Average_time_per_routine_communication_via_voice*2)))
 ELSE(Total_Excess_Voice_Channel_time_in_datalink[Density] -
 (Total_Excess_Voice_Channel_time_in_datalink[Den-
 sity]*Average_time_per_routine_communication_via_datalink/
 (Average_time_per_routine_communication_via_voice)))
 Excess_VCU_in_datalink_in_enroute[Density] = MAX(VCU_in_datalink_in_enroute[Density] -
 1,0)
 Expected_no_of_conflicts_per_acft_in_datalink[Density] = IF(Minimum_Separation <= 2)
 THEN(Conflict_per_acft_MS_2_datalink[Density]*Minimum_Separation/2)
 ELSE(IF(Minimum_Separation <= 3) AND (Minimum_Separation > 2)
 THEN((Conflict_per_acft_MS_3_datalink[Density] - Conflict_per_acft_MS_2_datalink[Den-
 sity])*(Minimum_Separation - 2) + Conflict_per_acft_MS_2_datalink[Density])
 ELSE(IF(Minimum_Separation <= 5) AND (Minimum_Separation > 3)
 THEN((Conflict_per_acft_MS_5_datalink[Density] - Conflict_per_acft_MS_3_datalink[Den-
 sity])*(Minimum_Separation - 3)/2 + Conflict_per_acft_MS_3_datalink[Density])
 ELSE(IF(Minimum_Separation <= 7.5) AND (Minimum_Separation > 5)
 THEN((Conflict_per_acft_MS_75_datalink[Density] - Conflict_per_acft_MS_5_datalink[Den-
 sity])*(Minimum_Separation - 5)/2.5 + Conflict_per_acft_MS_5_datalink[Density])
 ELSE(IF(Minimum_Separation <= 10) AND (Minimum_Separation > 7.5)
 THEN((Conflict_per_acft_MS_10_datalink[Density] - Conflict_per_acft_MS_75_datalink[Den-
 sity])*(Minimum_Separation - 7.5)/2.5 + Conflict_per_acft_MS_75_datalink[Density])
 ELSE(0))))))
 Extra_no_of_routine_voice_msg_in_datalink_transferred_to_datalink[Density] =

```

IF(CPDLC_Build_IA_Switch = 1)
THEN(Total_Excess_Voice_Channel_time_in_datalink[Density]/
(Average_time_per_routine_communication_via_voice*2))
ELSE(Total_Excess_Voice_Channel_time_in_datalink[Density]/
Average_time_per_routine_communication_via_voice)
Extra_voice_comm_in_enroute_in_datalink = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
THEN(Extra_voice_comm_in_enroute_in_voice*(1 - Datalink_Proportion_of_msgs))
ELSE(Extra_voice_comm_in_enroute_in_voice)
lag_time_in_datalink_in_enroute = 10/6
lag_time_in_voice_in_enroute = RANDOM(1,2)
Mean_ST_in_datalink[Density] = CTMEAN(Rate_out_in_datalink[Density])
Message_set_for_Build_I = 4
Message_set_ratio_for_Build_I = Message_set_for_Build_I/(Message_set_for_Build_I +
Additional_Message_set_for_Build_II + Additional_Message_set_for_Build_IA)
No_of_conflicts_per_acft_in_datalink[Density] = IF(QDR_in_datalink[Density] > 0)
THEN(Expected_no_of_conflicts_per_acft_in_datalink[Density])
ELSE(0)
Percentage_of_conflicts_allocated_to_datalink = IF(CPDLC_Build_IA_Switch = 0)
THEN(0)
ELSE(Percentage_of_msg_allocated_to_datalink)
Percentage_of_msg_allocated_to_datalink = .58
Pilot_Utilization_in_datalink[Density] =
Proportion_of_msgs_to_be_fed_into_the_FMS*(Average_time_for_hearing_and_uploading_the_message*(Total_conflicts_by_voice_in_datalink[Density] +
Routine_Voice_Messages_in_data_link_only[Density]) +
Average_time_for_reading_and_uploading_message*(Total_no_of_routine_datalink_communications_in_datalink[Density] + Total_conflicts_by_datalink_in_datalink[Density]))/
(Transit_time_in_datalink[Density]*(Total_acft_in_datalink_in_enroute[Density]+ .001))
Proportion_of_comm_by_datalink_for_Build_I =
Message_set_ratio_for_Build_I*Percentage_of_msg_allocated_to_datalink
Routine_Voice_Messages_in_data_link_only[Density] =
Total_No_of_routine_communications_in_datalink[Density] -
Total_no_of_routine_datalink_communications_in_datalink[Density]
sector_time_difference_in_datalink[Density] = Mean_ST_in_voice[Density] -
Mean_ST_in_datalink[Density]
Sector_time_in_datalink[Density] = CYCLETIME(Rate_out_in_datalink[Density])
Total_Excess_Voice_Channel_time_in_datalink[Density] =
Excess_VCU_in_datalink_in_enroute[Density]*(TIME + 1)
Total_time_spent_in_RVC_in_datalink_only[Density] =

```

Routine_Voice_Messages_in_data_link_only[Density]*Average_time_per_routine_communication_via_voice
 Transit_time_in_datalink[Density] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Free_Flow_enroute_transit_time +
 (No_of_routine_diversions_per_sector*(Diversion_time_per_routine_comm_in_voice +
 Datalink_Proportion_of_msgs*(Diversion_time_per_routine_comm_in_datalink_in_enroute -
 Diversion_time_per_routine_comm_in_voice))) +
 (Extra_voice_comm_in_enroute_in_datalink*Average_time_per_routine_communication_via_voice
) + (Expected_no_of_conflicts_per_acft_in_datalink[Density]*(Diversion_time_per_conflict_in_voice_non_uret +
 Percentage_of_conflicts_allocated_to_datalink*(Diversion_time_per_conflict_in_datalink_non_uret
 - Diversion_time_per_conflict_in_voice_non_uret))))
 ELSE(Free_Flow_enroute_transit_time +
 (No_of_routine_diversions_per_sector*Diversion_time_per_routine_comm_in_voice) +
 (Extra_voice_comm_in_enroute_in_datalink*Average_time_per_routine_communication_via_voice
) + (Expected_no_of_conflicts_per_acft_in_datalink[Density]*Diversion_time_per_conflict_in_voice_non_uret))
 Typing_message_time = 24/6
 VCU_in_datalink_in_enroute[Density] = (Routine_Voice_Messages_in_data_link_only[Density] +
 Total_conflicts_by_voice_in_datalink[Density])*lag_time_in_voice_in_enroute/14400
 Voice_Resolution_Time = Average_time_per_routine_communication_via_voice

Enroute sector (Voice Only)

Aircraft_in_enroute_sector_in_voice[Density](t) = Aircraft_in_enroute_sector_in_voice[Density](t -
 dt) + (QDR_in_voice[Density] - Rate_out_enroute_sector[Density]) * dt
 INIT Aircraft_in_enroute_sector_in_voice[Density] = 0

INFLOWS:

QDR_in_voice[Density] = IF(Controller_Activity_in_voice[Density] >= 1)

THEN(0)

ELSE(IF(AQ_outside__enroute_sector_in_voice[Density] = 0)

THEN(0)

ELSE(1))

OUTFLOWS:

Rate_out_enroute_sector[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Transit_time_in_voice[Density]

AQ_outside__enroute_sector_in_voice[Density](t) = AQ_outside__enroute_sector_in_voice[Density](t -
 dt) + (Rate_in_enroute_sector[Density] - QDR_in_voice[Density]) * dt

INIT AQ_outside__enroute_sector_in_voice[Density] = 0

INFLOWS:

Rate_in_enroute_sector[Density] = Acft_Injector[Density]

OUTFLOWS:

QDR_in_voice[Density] = IF(Controller_Activity_in_voice[Density] >= 1)

THEN(0)

ELSE(IF(AQ_outside__enroute_sector_in_voice[Density] = 0)

THEN(0)

ELSE(1))

Time_since_last_generation[Density](t) = Time_since_last_generation[Density](t - dt) +

(rate_in[Density] - rate_out[Density]) * dt

INIT Time_since_last_generation[Density] = 0

INFLOWS:

rate_in[Density] = IF(Acft_Injector[Density] = 0)

THEN(DT)

ELSE(0)

OUTFLOWS:

rate_out[Density] = IF(Acft_Injector[Density] = 1)

THEN(Time_since_last_generation[Density])

ELSE(0)

Total_acft_exited_in_voice[Density](t) = Total_acft_exited_in_voice[Density](t - dt) +

(exit_rate_in_voice[Density]) * dt

INIT Total_acft_exited_in_voice[Density] = 0

INFLOWS:

exit_rate_in_voice[Density] = Rate_out_enroute_sector[Density]

Total_acft_in_enroute_airspace_in_voice[Density](t) =

Total_acft_in_enroute_airspace_in_voice[Density](t - dt) + (demand_rate[Density]) * dt

INIT Total_acft_in_enroute_airspace_in_voice[Density] = 0

INFLOWS:

demand_rate[Density] = QDR_in_voice[Density]

Total_conflict_time_in_enroute[Density](t) = Total_conflict_time_in_enroute[Density](t - dt) +

(Conflict_time_rate_in_voice[Density]) * dt

INIT Total_conflict_time_in_enroute[Density] = 0

INFLOWS:

Conflict_time_rate_in_voice[Density] = conflict_rate_in__enroute_in_voice[Density]*Average_time_per_conflict_by_voice_non_uret

Total_No_of_comm_in_voice[Density](t) = Total_No_of_comm_in_voice[Density](t - dt) +

(comm_rate_in_voice[Density]) * dt

INIT Total_No_of_comm_in_voice[Density] = 0

INFLOWS:

comm_rate_in_voice[Density] = QDR_in_voice[Density]*(routine_voice_comm_rate[Density] +
Expected_no_of_conflicts_per_acft_in_voice[Density])

Total_no_of_conflict_in_enroute_in_voice[Density](t) =
Total_no_of_conflict_in_enroute_in_voice[Density](t - dt) +
(conflict_rate_in__enroute_in_voice[Density]) * dt

INIT Total_no_of_conflict_in_enroute_in_voice[Density] = 0

INFLOWS:

conflict_rate_in__enroute_in_voice[Density] = QDR_in_voice[Density]*Expected_no_of_conflicts_per_acft_in_voice[Density]

Total_no_of_routine_voice_comm[Density](t) = Total_no_of_routine_voice_comm[Density](t - dt)
+ (routine_voice_comm_rate[Density]) * dt

INIT Total_no_of_routine_voice_comm[Density] = 0

INFLOWS:

routine_voice_comm_rate[Density] = QDR_in_voice[Density]*(No_of_routine_communication_per__aircraft_in_enroute_sector +
Extra_voice_comm_in_enroute_in_voice)

Total_time_high_density_sector[Density](t) = Total_time_high_density_sector[Density](t - dt) +
(high_density_rate[Density]) * dt

INIT Total_time_high_density_sector[Density] = 0

INFLOWS:

high_density_rate[Density] = IF(Aircraft_in_enroute_sector_in_voice[Density] >= 14)

THEN(DT)

ELSE(0)

Total_time_low_density_sector[Density](t) = Total_time_low_density_sector[Density](t - dt) +
(low_density_rate[Density]) * dt

INIT Total_time_low_density_sector[Density] = 0

INFLOWS:

low_density_rate[Density] = IF(Aircraft_in_enroute_sector_in_voice[Density] < 7)

THEN(DT)

ELSE(0)

Total_time_medium_density_sector[Density](t) = Total_time_medium_density_sector[Density](t -
dt) + (medium_density_rate[Density]) * dt

INIT Total_time_medium_density_sector[Density] = 0

INFLOWS:

medium_density_rate[Density] = IF(Aircraft_in_enroute_sector_in_voice[Density] >= 7) AND
(Aircraft_in_enroute_sector_in_voice[Density] < 14)

THEN(DT)

ELSE(0)

Total_time_spent_in_hearing_and_uploading_msg[Density](t) =

Total_time_spent_in_hearing_and_uploading_msg[Density](t - dt) + (Uploading_time_rate[Density]) * dt

INIT Total_time_spent_in_hearing_and_uploading_msg[Density] = 0

INFLOWS:

Uploading_time_rate[Density] = comm_rate_in_voice[Density]*Average_time_for_hearing_and_uploading_the_message*Proportion_of_msgs_to_be_fed_into_the_FMS

Total_time_spent_in_voice_comm_for_routine_comm[Density](t) = Total_time_spent_in_voice_comm_for_routine_comm[Density](t - dt) + (routine_voice_occupation_rate[Density]) * dt

INIT Total_time_spent_in_voice_comm_for_routine_comm[Density] = 0

INFLOWS:

routine_voice_occupation_rate[Density] = routine_voice_comm_rate[Density]*Average_time_per_routine_communication_via_voice

Acft_Injector[Density] = IF(Time_since_last_generation[Density] >= Inter_Arrival_Time[Density]) THEN(1)

ELSE(0)

acft_rate_in_voice[Density] = Total_acft_in_enroute_airspace_in_voice[Density]*10*60*24/TIME

Average_time_for_hearing_and_uploading_the_message = Typing_message_time + Average_time_per_routine_communication_via_voice

Average_time_per_conflict_by_voice_non_uret = Conflict_Perception_Time_in_non_uret_case + Conflict_Resolution_Finding_Time_non_trial_planning + Voice_Resolution_Time

Average_time_per_routine_communication_via_voice = 2.33

Capacity_of_enroute_sector = 20

Conflict_per_acft_MS_10[Density] = .00106*acft_rate_in_voice[Density]

Conflict_per_acft_MS_2[Density] = .000167*acft_rate_in_voice[Density]

Conflict_per_acft_MS_3[Density] = .000266*acft_rate_in_voice[Density]

Conflict_per_acft_MS_5[Density] = .0000004*acft_rate_in_voice[Density]*acft_rate_in_voice[Density] + .0003*acft_rate_in_voice[Density]

Conflict_per_acft_MS_75[Density] = .000733*acft_rate_in_voice[Density]

Controller_Activity_in_voice[Density] =

Aircraft_in_enroute_sector_in_voice[Density]*((Average_time_per_routine_communication_via_voice*(No_of_routine_communication_per_aircraft_in_enroute_sector + Extra_voice_comm_in_enroute_in_voice)) +

Average_time_per_conflict_by_voice_non_uret*Expected_no_of_conflicts_per_acft_in_voice[Density]/1.5)/Transit_time_in_voice[Density]

Diversion_time_per_conflict_in_voice_non_uret = 10

Diversion_time_per_routine_comm_in_voice = 20

Enroute_Controller_Utilization_in_voice[Density] =

(Total_time_spent_in_voice_comm_for_routine_comm[Density] +
 Total_conflict_time_in_enroute[Density])/14400
 Expected_no_of_conflicts_per_acft_in_voice[Density] = IF(Minimum_Separation <= 2)
 THEN((Conflict_per_acft_MS_2[Density]*Minimum_Separation/2)
 ELSE(IF(Minimum_Separation <= 3) AND (Minimum_Separation > 2)
 THEN((Conflict_per_acft_MS_3[Density] - Conflict_per_acft_MS_2[Density])*(Minimum_Separation - 2) + Conflict_per_acft_MS_2[Density])
 ELSE(IF(Minimum_Separation <= 5) AND (Minimum_Separation > 3)
 THEN((Conflict_per_acft_MS_5[Density] - Conflict_per_acft_MS_3[Density])*(Minimum_Separation - 3)/2 + Conflict_per_acft_MS_3[Density])
 ELSE(IF(Minimum_Separation <= 7.5) AND (Minimum_Separation > 5)
 THEN((Conflict_per_acft_MS_7_5[Density] - Conflict_per_acft_MS_5[Density])*(Minimum_Separation - 5)/2.5 + Conflict_per_acft_MS_5[Density])
 ELSE(IF(Minimum_Separation <= 10) AND (Minimum_Separation > 7.5)
 THEN((Conflict_per_acft_MS_10[Density] - Conflict_per_acft_MS_7_5[Density])*(Minimum_Separation - 7.5)/2.5 + Conflict_per_acft_MS_7_5[Density])
 ELSE(0))))))
 Extra_voice_comm_in_enroute_in_voice =
 Percentage_extra_comm_per_comm*No_of_routine_communication_per__aircraft_in_enroute_sector
 or
 Free_Flow_enroute_transit_time = 57
 IAT_0_6 = 600
 IAT_12_18 = 120
 IAT_18_24 = 240
 IAT_6_12 = 100
 Inter_Arrival_Time[Density] = IF(TIME <= 3600)
 THEN(ROUND(IAT_0_6/Traffic_scale_factor))
 ELSE(IF(TIME > 3600) AND (TIME <= 7200)
 THEN(ROUND(IAT_6_12/Traffic_scale_factor))
 ELSE(IF(TIME > 7200) AND (TIME <= 10800)
 THEN(ROUND(IAT_12_18/Traffic_scale_factor))
 ELSE(IF(TIME > 10800) AND (TIME <= 14400)
 THEN(ROUND(IAT_18_24/Traffic_scale_factor))
 ELSE(60000))))
 Mean_ST_in_voice[Density] = CTMEAN(Rate_out_enroute_sector[Density])
 Minimum_Separation = 5
 No_of_routine_communication_per__aircraft_in_enroute_sector = RANDOM(5,7)
 No_of_routine_diversions_per_sector = 1.75
 No_of_sectors_in_an_ARTCC = 40

Percentage_extra_comm_per_comm = .1
 Pilot_Utilization_in_voice[Density] = Total_time_spent_in_hearing_and_uploading_msg[Density]/
 ((Total_acft_in_enroute_airspace_in_voice[Density] + .001)*Transit_time_in_voice[Density])
 Proportion_of_msgs_to_be_fed_into_the_FMS = .5
 Proportion_of_time_high_density_sector[Density] = Total_time_high_density_sector[Density]/1440
 Proportion_of_time_low_density_sector[Density] = Total_time_low_density_sector[Density]/1440
 Proportion_of_time_medium_density_sector[Density] = Total_time_medium_density_sector[Density]/1440
 Sector_time_in_voice[Density] = CYCLETIME(Rate_out_enroute_sector[Density])
 Traffic_Growth = 0
 Traffic_scale_factor = 1 + Traffic_Growth
 Transit_time_in_voice[Density] = Free_Flow_enroute_transit_time +
 (No_of_routine_diversions_per_sector*Diversion_time_per_routine_comm_in_voice) +
 (Extra_voice_comm_in_enroute_in_voice*Average_time_per_routine_communication_via_voice) +
 (Expected_no_of_conflicts_per_acft_in_voice[Density]*Diversion_time_per_conflict_in_voice_non_uret)
 VCU_in_voice[Density] = Total_No_of_comm_in_voice[Density]*lag_time_in_voice_in_enroute/
 14400

Terminal Airspace (Datalink + Voice + DSTs(non))

Holding_Queue1_for_non_integrated[Density](t) = Holding_Queue1_for_non_integrated[Density](t
 - dt) + (Merging_out_rate1_for_non_integrated[Density] -
 Rate_of_holding_dissipation1_for_non_integrated[Density]) * dt
 INIT Holding_Queue1_for_non_integrated[Density] = 0

INFLOWS:

Merging_out_rate1_for_non_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_non_integrated[Density]

OUTFLOWS:

Rate_of_holding_dissipation1_for_non_integrated[Density] = QUEUE OUTFLOW

Holding_Queue2_for_non_integrated[Density](t) = Holding_Queue2_for_non_integrated[Density](t
 - dt) + (Merging_out_rate2_for_non_integrated[Density] -

Rate_of_holding_dissipation2_for_non_integrated[Density]) * dt

INIT Holding_Queue2_for_non_integrated[Density] = 0

INFLOWS:

Merging_out_rate2_for_non_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_non_integrated[Density]

OUTFLOWS:

Rate_of_holding_dissipation2_for_non_integrated[Density] = QUEUE OUTFLOW
Holding_Queue3_for_non_integrated[Density](t) = Holding_Queue3_for_non_integrated[Density](t - dt) + (Merging_out_rate3_for_non_integrated[Density] - Rate_of_holding_dissipation3_for_non_integrated[Density]) * dt
INIT Holding_Queue3_for_non_integrated[Density] = 0
INFLOWS:
Merging_out_rate3_for_non_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_non_integrated[Density]
OUTFLOWS:
Rate_of_holding_dissipation3_for_non_integrated[Density] = QUEUE OUTFLOW
Holding_Queue4_for_non_integrated[Density](t) = Holding_Queue4_for_non_integrated[Density](t - dt) + (Merging_out_rate4_for_non_integrated[Density] - Rate_of_holding_dissipation4_for_non_integrated[Density]) * dt
INIT Holding_Queue4_for_non_integrated[Density] = 0
INFLOWS:
Merging_out_rate4_for_non_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_non_integrated[Density]
OUTFLOWS:
Rate_of_holding_dissipation4_for_non_integrated[Density] = QUEUE OUTFLOW
Merging1_for_non_integrated[Density](t) = Merging1_for_non_integrated[Density](t - dt) + (QMDR1_for_non_integrated[Density,feeder1] - Merging_out_rate1_for_non_integrated[Density]) * dt
INIT Merging1_for_non_integrated[Density] = 0
INFLOWS:
QMDR1_for_non_integrated[Density,feeder1] = QUEUE OUTFLOW
OUTFLOWS:
Merging_out_rate1_for_non_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_non_integrated[Density]
Merging2_for_non_integrated[Density](t) = Merging2_for_non_integrated[Density](t - dt) + (QMDR2_for_non_integrated[Density,feeder2] - Merging_out_rate2_for_non_integrated[Density]) * dt
INIT Merging2_for_non_integrated[Density] = 0
INFLOWS:
QMDR2_for_non_integrated[Density,feeder2] = QUEUE OUTFLOW
OUTFLOWS:
Merging_out_rate2_for_non_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_non_integrated[Density]
Merging3_for_non_integrated[Density](t) = Merging3_for_non_integrated[Density](t - dt) +
(QMDR3_for_non_integrated[Density,feeder3] - Merging_out_rate3_for_non_integrated[Density]) *
dt
INIT Merging3_for_non_integrated[Density] = 0
INFLOWS:
QMDR3_for_non_integrated[Density,feeder3] = QUEUE OUTFLOW
OUTFLOWS:
Merging_out_rate3_for_non_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_non_integrated[Density]
Merging4_for_non_integrated[Density](t) = Merging4_for_non_integrated[Density](t - dt) +
(QMDR4_for_non_integrated[Density,feeder4] - Merging_out_rate4_for_non_integrated[Density]) *
dt
INIT Merging4_for_non_integrated[Density] = 0
INFLOWS:
QMDR4_for_non_integrated[Density,feeder4] = QUEUE OUTFLOW
OUTFLOWS:
Merging_out_rate4_for_non_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_non_integrated[Density]
Mer_Conflict1_for_non_integrated[Density,feeder1](t) = Mer_Conflict1_for_non_integrated[Density,feeder1](t - dt) + (Mer_conflict_rate1_for_non_integrated[Density,feeder1]) * dt
INIT Mer_Conflict1_for_non_integrated[Density,feeder1] = 0
INFLOWS:
Mer_conflict_rate1_for_non_integrated[Density,feeder1] = IF(Merging1_for_non_integrated[Density] > 0) AND (Rate_out_TA1_for_non_integrated[Density,feeder1] > 0)
THEN(1)
ELSE(IF(Rate_out_TA1_for_non_integrated[Density,feeder1] > 0) AND
(Queue_for_Merging1_for_non_integrated[Density,feeder1] > 0)
THEN(1)
ELSE(0))
Mer_Conflict2_for_non_integrated[Density,feeder2](t) = Mer_Conflict2_for_non_integrated[Density,feeder2](t - dt) + (Mer_conflict_rate2_for_non_integrated[Density,feeder2]) * dt
INIT Mer_Conflict2_for_non_integrated[Density,feeder2] = 0
INFLOWS:
Mer_conflict_rate2_for_non_integrated[Density,feeder2] = IF(Merging2_for_non_integrated[Density] > 0) AND (Rate_out_TA2_for_non_integrated[Density,feeder2] > 0)

THEN(1)
 ELSE(IF(Rate_out_TA2_for_non_integrated[Density,feeder2] > 0) AND
 (Queue_for_Merging2_for_non_integrated[Density,feeder2] > 0)
 THEN(1)
 ELSE(0))
 Mer_Conflict3_for_non_integrated[Density,feeder3](t) = Mer_Conflict3_for_non_integrated[Density,feeder3](t - dt) + (Mer_conflict_rate3_for_non_integrated[Density,feeder3]) * dt
 INIT Mer_Conflict3_for_non_integrated[Density,feeder3] = 0
 INFLOWS:
 Mer_conflict_rate3_for_non_integrated[Density,feeder3] = IF(Merging3_for_non_integrated[Density,feeder3] > 0) AND (Rate_out_TA3_for_non_integrated[Density,feeder3] > 0)
 THEN(1)
 ELSE(IF(Rate_out_TA3_for_non_integrated[Density,feeder3] > 0) AND
 (Queue_for_Merging3_for_non_integrated[Density,feeder3] > 0)
 THEN(1)
 ELSE(0))
 Mer_Conflict4_for_non_integrated[Density,feeder4](t) = Mer_Conflict4_for_non_integrated[Density,feeder4](t - dt) + (Mer_conflict_rate4_for_non_integrated[Density,feeder4]) * dt
 INIT Mer_Conflict4_for_non_integrated[Density,feeder4] = 0
 INFLOWS:
 Mer_conflict_rate4_for_non_integrated[Density,feeder4] = IF(Merging4_for_non_integrated[Density,feeder4] > 0) AND (Rate_out_TA4_for_non_integrated[Density,feeder4] > 0)
 THEN(1)
 ELSE(IF(Rate_out_TA4_for_non_integrated[Density,feeder4] > 0) AND
 (Queue_for_Merging4_for_non_integrated[Density,feeder4] > 0)
 THEN(1)
 ELSE(0))
 Queue_for_Merging1_for_non_integrated[Density,feeder1](t) =
 Queue_for_Merging1_for_non_integrated[Density,feeder1](t - dt) +
 (Rate_out_TA1_for_non_integrated[Density,feeder1] - QMDR1_for_non_integrated[Density,feeder1]) * dt
 INIT Queue_for_Merging1_for_non_integrated[Density,feeder1] = 0
 INFLOWS:
 Rate_out_TA1_for_non_integrated[Density,feeder1] = CONVEYOR OUTFLOW

 TRANSIT TIME = Transition_Area_Time_in_datalink[Density]
 OUTFLOWS:
 QMDR1_for_non_integrated[Density,feeder1] = QUEUE OUTFLOW
 Queue_for_Merging2_for_non_integrated[Density,feeder2](t) =

Queue_for_Merging2_for_non_integrated[Density,feeder2](t - dt) +
(Rate_out_TA2_for_non_integrated[Density,feeder2] - QMDR2_for_non_integrated[Density,feeder2]) * dt

INIT Queue_for_Merging2_for_non_integrated[Density,feeder2] = 0

INFLOWS:

Rate_out_TA2_for_non_integrated[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

OUTFLOWS:

QMDR2_for_non_integrated[Density,feeder2] = QUEUE OUTFLOW

Queue_for_Merging3_for_non_integrated[Density,feeder3](t) =
Queue_for_Merging3_for_non_integrated[Density,feeder3](t - dt) +
(Rate_out_TA3_for_non_integrated[Density,feeder3] - QMDR3_for_non_integrated[Density,feeder3]) * dt

INIT Queue_for_Merging3_for_non_integrated[Density,feeder3] = 0

INFLOWS:

Rate_out_TA3_for_non_integrated[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

OUTFLOWS:

QMDR3_for_non_integrated[Density,feeder3] = QUEUE OUTFLOW

Queue_for_Merging4_for_non_integrated[Density,feeder4](t) =
Queue_for_Merging4_for_non_integrated[Density,feeder4](t - dt) +
(Rate_out_TA4_for_non_integrated[Density,feeder4] - QMDR4_for_non_integrated[Density,feeder4]) * dt

INIT Queue_for_Merging4_for_non_integrated[Density,feeder4] = 0

INFLOWS:

Rate_out_TA4_for_non_integrated[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

OUTFLOWS:

QMDR4_for_non_integrated[Density,feeder4] = QUEUE OUTFLOW

Queue_for_S1_for_non_integrated[Density,feeder1](t) = Queue_for_S1_for_non_integrated[Density,feeder1](t - dt) + (Rate_in_TA1_for_non_integrated[Density,feeder1] - QSR1_for_non_integrated[Density,feeder1]) * dt

INIT Queue_for_S1_for_non_integrated[Density,feeder1] = 0

INFLOWS:

Rate_in_TA1_for_non_integrated[Density,feeder1] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,29) <= Proportion_of_flights_into_TA1[Density,feeder1])

THEN(1)
 ELSE(0)
 OUTFLOWS:
 QSR1_for_non_integrated[Density,feeder1] = IF(TA_Controller_Activity1_in_non_integrated[Density,feeder1] >= 1) OR (Seperation1_for_non_integrated[Density,feeder1] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S1_for_non_integrated[Density,feeder1] > 0) OR
 (Rate_in_TA1_for_non_integrated[Density,feeder1] > 0)
 THEN(1)
 ELSE(0))
 Queue_for_S2_for_non_integrated[Density,feeder2](t) = Queue_for_S2_for_non_integrated[Density,feeder2](t - dt) + (Rate_in_TA2_for_non_integrated[Density,feeder2] -
 QSR2_for_non_integrated[Density,feeder2]) * dt
 INIT Queue_for_S2_for_non_integrated[Density,feeder2] = 0
 INFLOWS:
 Rate_in_TA2_for_non_integrated[Density,feeder2] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,11) <= Proportion_of_flights_into_TA2[Density,feeder2])
 THEN(1)
 ELSE(0)
 OUTFLOWS:
 QSR2_for_non_integrated[Density,feeder2] = IF(TA_Controller_Activity2_in_non_integrated[Density,feeder2] >= 1) OR (Seperation2_for_non_integrated[Density,feeder2] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S2_for_non_integrated[Density,feeder2] > 0) OR
 (Rate_in_TA2_for_non_integrated[Density,feeder2] > 0)
 THEN(1)
 ELSE(0))
 Queue_for_S3_for_non_integrated[Density,feeder3](t) = Queue_for_S3_for_non_integrated[Density,feeder3](t - dt) + (Rate_in_TA3_for_non_integrated[Density,feeder3] -
 QSR3_for_non_integrated[Density,feeder3]) * dt
 INIT Queue_for_S3_for_non_integrated[Density,feeder3] = 0
 INFLOWS:
 Rate_in_TA3_for_non_integrated[Density,feeder3] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,111) <= Proportion_of_flights_into_TA3[Density,feeder3])
 THEN(1)
 ELSE(0)
 OUTFLOWS:
 QSR3_for_non_integrated[Density,feeder3] = IF(TA_Controller_Activity3_in_non_integrated[Density,feeder3] >= 1) OR (Seperation3_for_non_integrated[Density,feeder3] > 0)

THEN(0)
 ELSE(IF(Queue_for_S3_for_non_integrated[Density,feeder3] > 0) OR
 (Rate_in_TA3_for_non_integrated[Density,feeder3] > 0)
 THEN(1)
 ELSE(0))
 Queue_for_S4_for_non_integrated[Density,feeder4](t) = Queue_for_S4_for_non_integrated[Density,feeder4](t - dt) + (Rate_in_TA4_for_non_integrated[Density,feeder4] -
 QSR4_for_non_integrated[Density,feeder4]) * dt
 INIT Queue_for_S4_for_non_integrated[Density,feeder4] = 0
 INFLOWS:
 Rate_in_TA4_for_non_integrated[Density,feeder4] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,37) <= Proportion_of_flights_into_TA4[Density,feeder4])
 THEN(1)
 ELSE(0)
 OUTFLOWS:
 QSR4_for_non_integrated[Density,feeder4] = IF(TA_Controller_Activity4_in_non_integrated[Density,feeder4] >= 1) OR (Separation4_for_non_integrated[Density,feeder4] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S4_for_non_integrated[Density,feeder4] > 0) OR
 (Rate_in_TA4_for_non_integrated[Density,feeder4] > 0)
 THEN(1)
 ELSE(0))
 Separation3_for_non_integrated[Density,feeder3](t) = Separation3_for_non_integrated[Density,feeder3](t - dt) + (QSR3_for_non_integrated[Density,feeder3] -
 Separation_rate3_for_non_integrated[Density,feeder3]) * dt
 INIT Separation3_for_non_integrated[Density,feeder3] = 0
 INFLOWS:
 QSR3_for_non_integrated[Density,feeder3] = IF(TA_Controller_Activity3_in_non_integrated[Density,feeder3] >= 1) OR (Separation3_for_non_integrated[Density,feeder3] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S3_for_non_integrated[Density,feeder3] > 0) OR
 (Rate_in_TA3_for_non_integrated[Density,feeder3] > 0)
 THEN(1)
 ELSE(0))
 OUTFLOWS:
 Separation_rate3_for_non_integrated[Density,feeder3] = CONVEYOR OUTFLOW

 TRANSIT TIME = Average_Separation_Time_for_non_integrated[Density]
 Separation4_for_non_integrated[Density,feeder4](t) = Separation4_for_non_integrated[Density,feeder4](t - dt) + (Rate_in_TA4_for_non_integrated[Density,feeder4] -
 QSR4_for_non_integrated[Density,feeder4]) * dt
 INIT Separation4_for_non_integrated[Density,feeder4] = 0
 INFLOWS:
 Rate_in_TA4_for_non_integrated[Density,feeder4] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,37) <= Proportion_of_flights_into_TA4[Density,feeder4])
 THEN(1)
 ELSE(0)
 OUTFLOWS:
 QSR4_for_non_integrated[Density,feeder4] = IF(TA_Controller_Activity4_in_non_integrated[Density,feeder4] >= 1) OR (Separation4_for_non_integrated[Density,feeder4] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S4_for_non_integrated[Density,feeder4] > 0) OR
 (Rate_in_TA4_for_non_integrated[Density,feeder4] > 0)
 THEN(1)
 ELSE(0))
 Separation3_for_non_integrated[Density,feeder3](t) = Separation3_for_non_integrated[Density,feeder3](t - dt) + (QSR3_for_non_integrated[Density,feeder3] -
 Separation_rate3_for_non_integrated[Density,feeder3]) * dt
 INIT Separation3_for_non_integrated[Density,feeder3] = 0
 INFLOWS:
 QSR3_for_non_integrated[Density,feeder3] = IF(TA_Controller_Activity3_in_non_integrated[Density,feeder3] >= 1) OR (Separation3_for_non_integrated[Density,feeder3] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S3_for_non_integrated[Density,feeder3] > 0) OR
 (Rate_in_TA3_for_non_integrated[Density,feeder3] > 0)
 THEN(1)
 ELSE(0))
 OUTFLOWS:
 Separation_rate3_for_non_integrated[Density,feeder3] = CONVEYOR OUTFLOW

 TRANSIT TIME = Average_Separation_Time_for_non_integrated[Density]
 Separation4_for_non_integrated[Density,feeder4](t) = Separation4_for_non_integrated[Density,feeder4](t - dt) + (Rate_in_TA4_for_non_integrated[Density,feeder4] -
 QSR4_for_non_integrated[Density,feeder4]) * dt
 INIT Separation4_for_non_integrated[Density,feeder4] = 0
 INFLOWS:
 Rate_in_TA4_for_non_integrated[Density,feeder4] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,37) <= Proportion_of_flights_into_TA4[Density,feeder4])
 THEN(1)
 ELSE(0)
 OUTFLOWS:
 QSR4_for_non_integrated[Density,feeder4] = IF(TA_Controller_Activity4_in_non_integrated[Density,feeder4] >= 1) OR (Separation4_for_non_integrated[Density,feeder4] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S4_for_non_integrated[Density,feeder4] > 0) OR
 (Rate_in_TA4_for_non_integrated[Density,feeder4] > 0)
 THEN(1)
 ELSE(0))
 Separation3_for_non_integrated[Density,feeder3](t) = Separation3_for_non_integrated[Density,feeder3](t - dt) + (QSR3_for_non_integrated[Density,feeder3] -
 Separation_rate3_for_non_integrated[Density,feeder3]) * dt
 INIT Separation3_for_non_integrated[Density,feeder3] = 0
 INFLOWS:
 QSR3_for_non_integrated[Density,feeder3] = IF(TA_Controller_Activity3_in_non_integrated[Density,feeder3] >= 1) OR (Separation3_for_non_integrated[Density,feeder3] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S3_for_non_integrated[Density,feeder3] > 0) OR
 (Rate_in_TA3_for_non_integrated[Density,feeder3] > 0)
 THEN(1)
 ELSE(0))
 OUTFLOWS:
 Separation_rate3_for_non_integrated[Density,feeder3] = CONVEYOR OUTFLOW

 TRANSIT TIME = Average_Separation_Time_for_non_integrated[Density]

$\text{Density,feeder4}(t - dt) + (\text{QSR4_for_non_integrated}[\text{Density,feeder4}] - \text{Separation_rate4_for_non_integrated}[\text{Density,feeder4}]) * dt$
 INIT Separation4_for_non_integrated[Density,feeder4] = 0
 INFLOWS:
 QSR4_for_non_integrated[Density,feeder4] = IF(TA_Controller_Activity4_in_non_integrated[Density,feeder4] >= 1) OR (Separation4_for_non_integrated[Density,feeder4] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S4_for_non_integrated[Density,feeder4] > 0) OR (Rate_in_TA4_for_non_integrated[Density,feeder4] > 0))
 THEN(1)
 ELSE(0))
 OUTFLOWS:
 Separation_rate4_for_non_integrated[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_non_integrated[Density]
 $\text{Separation1_for_non_integrated}[\text{Density,feeder1}](t) = \text{Separation1_for_non_integrated}[\text{Density,feeder1}](t - dt) + (\text{QSR1_for_non_integrated}[\text{Density,feeder1}] - \text{Separation_rate1_for_non_integrated}[\text{Density,feeder1}]) * dt$
 INIT Separation1_for_non_integrated[Density,feeder1] = 0
 INFLOWS:
 QSR1_for_non_integrated[Density,feeder1] = IF(TA_Controller_Activity1_in_non_integrated[Density,feeder1] >= 1) OR (Separation1_for_non_integrated[Density,feeder1] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S1_for_non_integrated[Density,feeder1] > 0) OR (Rate_in_TA1_for_non_integrated[Density,feeder1] > 0))
 THEN(1)
 ELSE(0))
 OUTFLOWS:
 Separation_rate1_for_non_integrated[Density,feeder1] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_non_integrated[Density]
 $\text{Separation2_for_non_integrated}[\text{Density,feeder2}](t) = \text{Separation2_for_non_integrated}[\text{Density,feeder2}](t - dt) + (\text{QSR2_for_non_integrated}[\text{Density,feeder2}] - \text{Separation_rate2_for_non_integrated}[\text{Density,feeder2}]) * dt$
 INIT Separation2_for_non_integrated[Density,feeder2] = 0
 INFLOWS:
 QSR2_for_non_integrated[Density,feeder2] = IF(TA_Controller_Activity2_in_non_integrated[Density,feeder2] >= 1) OR (Separation2_for_non_integrated[Density,feeder2] > 0)
 THEN(0)

ELSE(IF(Queue_for_S2_for_non_integrated[Density,feeder2] > 0) OR
(Rate_in_TA2_for_non_integrated[Density,feeder2] > 0)
THEN(1)
ELSE(0))
OUTFLOWS:
Separation_rate2_for_non_integrated[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_non_integrated[Density]
Sep_Conflict1_for_non_integrated[Density,feeder1](t) = Sep_Conflict1_for_non_integrated[Density,feeder1](t - dt) + (Sep_Conflict_ratein1_for_non_integrated[Density,feeder1]) * dt
INIT Sep_Conflict1_for_non_integrated[Density,feeder1] = 0

INFLOWS:
Sep_Conflict_ratein1_for_non_integrated[Density,feeder1] =
IF(Rate_in_TA1_for_non_integrated[Density,feeder1] > 0) AND
(Seperation1_for_non_integrated[Density,feeder1] > 0)
THEN(1)
ELSE(0)

Sep_Conflict2_for_non_integrated[Density,feeder2](t) = Sep_Conflict2_for_non_integrated[Density,feeder2](t - dt) + (Sep_Conflict_ratein2_for_non_integrated[Density,feeder2]) * dt
INIT Sep_Conflict2_for_non_integrated[Density,feeder2] = 0

INFLOWS:
Sep_Conflict_ratein2_for_non_integrated[Density,feeder2] =
IF(Rate_in_TA2_for_non_integrated[Density,feeder2] > 0) AND
(Seperation2_for_non_integrated[Density,feeder2] > 0)
THEN(1)
ELSE(0)

Sep_Conflict3_for_non_integrated[Density,feeder3](t) = Sep_Conflict3_for_non_integrated[Density,feeder3](t - dt) + (Sep_Conflict_ratein3_for_non_integrated[Density,feeder3]) * dt
INIT Sep_Conflict3_for_non_integrated[Density,feeder3] = 0

INFLOWS:
Sep_Conflict_ratein3_for_non_integrated[Density,feeder3] =
IF(Rate_in_TA3_for_non_integrated[Density,feeder3] > 0) AND
(Seperation3_for_non_integrated[Density,feeder3] > 0)
THEN(1)
ELSE(0)

Sep_Conflict4_for_non_integrated[Density,feeder4](t) = Sep_Conflict4_for_non_integrated[Density,feeder4](t - dt) + (Sep_Conflict_ratein4_for_non_integrated[Density,feeder4]) * dt
INIT Sep_Conflict4_for_non_integrated[Density,feeder4] = 0

INFLOWS:

Sep_Conflict_ratein4_for_non_integrated[Density,feeder4] =
IF(Rate_in_TA4_for_non_integrated[Density,feeder4] > 0) AND
(Separation4_for_non_integrated[Density,feeder4] > 0)
THEN(1)
ELSE(0)
Terminal_Airspace_for_non_integrated[High](t) = Terminal_Airspace_for_non_integrated[High](t -
dt) + (Rate_of_holding_dissipation1_for_non_integrated[High] +
Rate_of_holding_dissipation3_for_non_integrated[High] +
Rate_of_holding_dissipation2_for_non_integrated[High] +
Rate_of_holding_dissipation4_for_non_integrated[High] - AAR_for_non_integrated[High]) * dt
INIT Terminal_Airspace_for_non_integrated[High] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 8

Terminal_Airspace_for_non_integrated[Medium](t) =
Terminal_Airspace_for_non_integrated[Medium](t - dt) +
(Rate_of_holding_dissipation1_for_non_integrated[Medium] +
Rate_of_holding_dissipation3_for_non_integrated[Medium] +
Rate_of_holding_dissipation2_for_non_integrated[Medium] +
Rate_of_holding_dissipation4_for_non_integrated[Medium] - AAR_for_non_integrated[Medium]) *
dt
INIT Terminal_Airspace_for_non_integrated[Medium] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 4

Terminal_Airspace_for_non_integrated[Low](t) = Terminal_Airspace_for_non_integrated[Low](t -
dt) + (Rate_of_holding_dissipation1_for_non_integrated[Low] +
Rate_of_holding_dissipation3_for_non_integrated[Low] +
Rate_of_holding_dissipation2_for_non_integrated[Low] +
Rate_of_holding_dissipation4_for_non_integrated[Low] - AAR_for_non_integrated[Low]) * dt
INIT Terminal_Airspace_for_non_integrated[Low] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 2

INFLOWS:

Rate_of_holding_dissipation1_for_non_integrated[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation3_for_non_integrated[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation2_for_non_integrated[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation4_for_non_integrated[Density] = QUEUE OUTFLOW

OUTFLOWS:

AAR_for_non_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Terminal_Airspace_Time_in_non_integrated[Density]

Total_aircraft_in_terminal_airspace_in_non_integrated[Density](t) =

Total_aircraft_in_terminal_airspace_in_non_integrated[Density](t - dt) +

(rate_in_terminal_airspace_in_non_integrated[Density]) * dt

INIT Total_aircraft_in_terminal_airspace_in_non_integrated[Density] = 0

INFLOWS:

rate_in_terminal_airspace_in_non_integrated[Density] =

Rate_of_holding_dissipation1_for_non_integrated[Density] +

Rate_of_holding_dissipation2_for_non_integrated[Density] +

Rate_of_holding_dissipation3_for_non_integrated[Density] +

Rate_of_holding_dissipation4_for_non_integrated[Density]

Total_aircraft_in_tracon_airspace_in_non_integrated[Density](t) =

Total_aircraft_in_tracon_airspace_in_non_integrated[Density](t - dt) +

(rate_in_tracon_airspace_in_non_integrated[Density]) * dt

INIT Total_aircraft_in_tracon_airspace_in_non_integrated[Density] = 0

INFLOWS:

rate_in_tracon_airspace_in_non_integrated[Density] = Rate_in_TA1_for_non_integrated[Den-

sity,f11] + Rate_in_TA1_for_non_integrated[Density,f12] + Rate_in_TA2_for_non_integrated[Den-

sity,f21] + Rate_in_TA2_for_non_integrated[Density,f22] +

Rate_in_TA3_for_non_integrated[Density,f31] + Rate_in_TA3_for_non_integrated[Density,f32] +

Rate_in_TA4_for_non_integrated[Density,f41] + Rate_in_TA4_for_non_integrated[Density,f42]

Total_rc_for_feeder_controller1_non_integrated[Density,feeder1](t) =

Total_rc_for_feeder_controller1_non_integrated[Density,feeder1](t - dt) +

(rc_rate_for_feeder_controller1_for_non_integrated[Density,feeder1]) * dt

```

INIT Total_rc_for_feeder_controller1_non_integrated[Density,feeder1] = 0
INFLOWS:
rc_rate_for_feeder_controller1_for_non_integrated[Density,feeder1] =
Rate_in_TA1_for_non_integrated[Density,feeder1] + (Separation_rate1_for_non_integrated[Den-
sity,feeder1]*(No_of_routine_comm_in_transition_area +
Extra_voice_comm_due_to_comm_error_in_datalink))
Total_rc_for_feeder_controller3_for_non_integrated[Density,feeder3](t) =
Total_rc_for_feeder_controller3_for_non_integrated[Density,feeder3](t - dt) +
(rc_rate_for_feeder_controller3_non_integrated[Density,feeder3]) * dt
INIT Total_rc_for_feeder_controller3_for_non_integrated[Density,feeder3] = 0
INFLOWS:
rc_rate_for_feeder_controller3_non_integrated[Density,feeder3] =
Rate_in_TA3_for_non_integrated[Density,feeder3] + (Separation_rate3_for_non_integrated[Den-
sity,feeder3]*(No_of_routine_comm_in_transition_area +
Extra_voice_comm_due_to_comm_error_in_datalink))
Total_rdc_for_feeder_controller1_non_integrated[Density,feeder1](t) =
Total_rdc_for_feeder_controller1_non_integrated[Density,feeder1](t - dt) +
(rdc_rate_for_feeder_controller1_for_non_integrated[Density,feeder1]) * dt
INIT Total_rdc_for_feeder_controller1_non_integrated[Density,feeder1] = 0
INFLOWS:
rdc_rate_for_feeder_controller1_for_non_integrated[Density,feeder1] = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts)
THEN((Rate_in_TA1_for_non_integrated[Density,feeder1] +
Separation_rate1_for_non_integrated[Den-
sity,feeder1]*No_of_routine_comm_in_transition_area)*Datalink_Proportion_of_msgs)
ELSE(0)
Total_rdc_for_feeder_controller3_for_non_integrated[Density,feeder3](t) =
Total_rdc_for_feeder_controller3_for_non_integrated[Density,feeder3](t - dt) +
(rdc_rate_for_feeder_controller3_non_integrated[Density,feeder3]) * dt
INIT Total_rdc_for_feeder_controller3_for_non_integrated[Density,feeder3] = 0
INFLOWS:
rdc_rate_for_feeder_controller3_non_integrated[Density,feeder3] = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts)
THEN((Rate_in_TA3_for_non_integrated[Density,feeder3] +
Separation_rate3_for_non_integrated[Den-
sity,feeder3]*No_of_routine_comm_in_transition_area)*Datalink_Proportion_of_msgs)
ELSE(0)
Total_rdc_time_for_feeder_controller1_non_integrated[Density,feeder1](t) =
Total_rdc_time_for_feeder_controller1_non_integrated[Density,feeder1](t - dt) +

```

$(rdc_time_rate_for_feeder_controller1_for_non_integrated[Density,feeder1]) * dt$

INIT Total_rdc_time_for_feeder_controller1_non_integrated[Density,feeder1] = 0

INFLOWS:

$rdc_time_rate_for_feeder_controller1_for_non_integrated[Density,feeder1] =$

$rdc_rate_for_feeder_controller1_for_non_integrated[Den-$

$sity,feeder1]*Average_time_per_routine_communication_via_datalink$

Total_rdc_time_for_feeder_controller3_for_non_integrated[Density,feeder3](t) =

Total_rdc_time_for_feeder_controller3_for_non_integrated[Density,feeder3](t - dt) +

$(rdc_time_rate_for_feeder_controller3_for_non_integrated[Density,feeder3]) * dt$

INIT Total_rdc_time_for_feeder_controller3_for_non_integrated[Density,feeder3] = 0

INFLOWS:

$rdc_time_rate_for_feeder_controller3_for_non_integrated[Density,feeder3] =$

$rdc_rate_for_feeder_controller3_non_integrated[Den-$

$sity,feeder3]*Average_time_per_routine_communication_via_datalink$

Total_rvc_for_feeder_controller1_non_integrated[Density,feeder1](t) =

Total_rvc_for_feeder_controller1_non_integrated[Density,feeder1](t - dt) +

$(rvc_rate_for_feeder_controller1_for_non_integrated[Density,feeder1]) * dt$

INIT Total_rvc_for_feeder_controller1_non_integrated[Density,feeder1] = 0

INFLOWS:

$rvc_rate_for_feeder_controller1_for_non_integrated[Density,feeder1] =$

$rc_rate_for_feeder_controller1_for_non_integrated[Density,feeder1] -$

$rdc_rate_for_feeder_controller1_for_non_integrated[Density,feeder1]$

Total_rvc_for_feeder_controller3_for_non_integrated[Density,feeder3](t) =

Total_rvc_for_feeder_controller3_for_non_integrated[Density,feeder3](t - dt) +

$(rvc_rate_for_feeder_controller3_non_integrated[Density,feeder3]) * dt$

INIT Total_rvc_for_feeder_controller3_for_non_integrated[Density,feeder3] = 0

INFLOWS:

$rvc_rate_for_feeder_controller3_non_integrated[Density,feeder3] =$

$rc_rate_for_feeder_controller3_non_integrated[Density,feeder3] -$

$rdc_rate_for_feeder_controller3_non_integrated[Density,feeder3]$

Total_rvc_time_for_feeder_controller1_non_integrated[Density,feeder1](t) =

Total_rvc_time_for_feeder_controller1_non_integrated[Density,feeder1](t - dt) +

$(rvc_time_rate_for_feeder_controller1_for_non_integrated[Density,feeder1]) * dt$

INIT Total_rvc_time_for_feeder_controller1_non_integrated[Density,feeder1] = 0

INFLOWS:

$rvc_time_rate_for_feeder_controller1_for_non_integrated[Density,feeder1] =$

$rvc_rate_for_feeder_controller1_for_non_integrated[Den-$

$sity,feeder1]*Average_time_per_routine_communication_via_voice$

Total_rvc_time_for_feeder_controller3_for_non_integrated[Density,feeder3](t) =

Total_rvc_time_for_feeder_controller3_for_non_integrated[Density,feeder3](t - dt) +
(rvc_time_rate_for_feeder_controller3_for_non_integrated[Density,feeder3]) * dt
INIT Total_rvc_time_for_feeder_controller3_for_non_integrated[Density,feeder3] = 0

INFLOWS:

rvc_time_rate_for_feeder_controller3_for_non_integrated[Density,feeder3] =
rvc_rate_for_feeder_controller3_non_integrated[Den-
sity,feeder3]*Average_time_per_routine_communication_via_voice
Transition_Airspace1_for_non_integrated[Density,feeder1](t) =
Transition_Airspace1_for_non_integrated[Density,feeder1](t - dt) +
(Separation_rate1_for_non_integrated[Density,feeder1] - Rate_out_TA1_for_non_integrated[Den-
sity,feeder1]) * dt

INIT Transition_Airspace1_for_non_integrated[Density,feeder1] = 0

INFLOWS:

Separation_rate1_for_non_integrated[Density,feeder1] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_non_integrated[Density]

OUTFLOWS:

Rate_out_TA1_for_non_integrated[Density,feeder1] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

Transition_Airspace2_for_non_integrated[Density,feeder2](t) =
Transition_Airspace2_for_non_integrated[Density,feeder2](t - dt) +
(Separation_rate2_for_non_integrated[Density,feeder2] - Rate_out_TA2_for_non_integrated[Den-
sity,feeder2]) * dt

INIT Transition_Airspace2_for_non_integrated[Density,feeder2] = 0

INFLOWS:

Separation_rate2_for_non_integrated[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_non_integrated[Density]

OUTFLOWS:

Rate_out_TA2_for_non_integrated[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

Transition_Airspace3_for_non_integrated[Density,feeder3](t) =
Transition_Airspace3_for_non_integrated[Density,feeder3](t - dt) +
(Separation_rate3_for_non_integrated[Density,feeder3] - Rate_out_TA3_for_non_integrated[Den-
sity,feeder3]) * dt

INIT Transition_Airspace3_for_non_integrated[Density,feeder3] = 0

INFLOWS:

Separation_rate3_for_non_integrated[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_non_integrated[Density]

OUTFLOWS:

Rate_out_TA3_for_non_integrated[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

Transition_Airspace4_for_non_integrated[Density,feeder4](t) =

Transition_Airspace4_for_non_integrated[Density,feeder4](t - dt) +

(Separation_rate4_for_non_integrated[Density,feeder4] - Rate_out_TA4_for_non_integrated[Density,feeder4]) * dt

INIT Transition_Airspace4_for_non_integrated[Density,feeder4] = 0

INFLOWS:

Separation_rate4_for_non_integrated[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_non_integrated[Density]

OUTFLOWS:

Rate_out_TA4_for_non_integrated[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

acft_rate_in_terminal_airpace_in_non_integrated[Density] =

Total_aircraft_in_terminal_airpace_in_non_integrated[Density]*10*60/TIME

acft_rate_in_tracon_airpace_in_non_integrated[Density] =

Total_aircraft_in_tracon_airpace_in_non_integrated[Density]*10*60/TIME

ADF = 0.9

Average_Separation_Time_for_non_integrated[Density] = (Intrail_Separation[Density] +

ES_in_TA_in_non_integrated[Density])*60*10/Average__Speed[Density]

DR_due_to_TMA_in_non_integrated[Density] =

0.65*acft_rate_in_tracon_airpace_in_non_integrated[Density]

ES_in_TA_in_non_integrated[Density] =

MAX(0.4,0.000154*acft_rate_in_tracon_airpace_in_non_integrated[Density]*acft_rate_in_tracon_airpace_in_non_integrated[Density]*AMF + 0.4 - (DR_due_to_TMA_in_non_integrated[Density]*Average__Speed[Density]/3600))

ES_in_TEA_in_non_integrated[Density] =

0.0000933*acft_rate_in_terminal_airpace_in_non_integrated[Density]*acft_rate_in_terminal_airpace_in_non_integrated[Density]*AMF*(1 - ADF)/(1 - 0.9) + 0.4

Mean_Terminal_Times_for_non_integrated[Density] = CTMEAN(AAR_for_non_integrated[Density])

Merging_time_for_non_integrated[Density] = Merging_time_for_datalink[Density]

TA_Controller_Activity1_in_non_integrated[Density,feeder1] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Transition_Airspace1_for_non_integrated[Density,feeder1]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice + Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink - Average_time_per_routine_communication_via_voice))) + (Extra_voice_comm_due_to_comm_error_in_datalink *Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])
 ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink) *Transition_Airspace1_for_non_integrated[Density,feeder1]/Transition_Area_Time_in_datalink[Density])
 TA_Controller_Activity2_in_non_integrated[Density,feeder2] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Transition_Airspace2_for_non_integrated[Density,feeder2]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice + Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink - Average_time_per_routine_communication_via_voice))) + (Extra_voice_comm_due_to_comm_error_in_datalink *Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])
 ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink) *Transition_Airspace2_for_non_integrated[Density,feeder2]/Transition_Area_Time_in_datalink[Density])
 TA_Controller_Activity3_in_non_integrated[Density,feeder3] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Transition_Airspace3_for_non_integrated[Density,feeder3]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice + Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink - Average_time_per_routine_communication_via_voice))) + (Extra_voice_comm_due_to_comm_error_in_datalink *Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])
 ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink) *Transition_Airspace3_for_non_integrated[Density,feeder3]/Transition_Area_Time_in_datalink[Density])

TA_Controller_Activity4_in_non_integrated[Density,feeder4] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Transition_Airspace4_for_non_integrated[Density,feeder4]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice + Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink - Average_time_per_routine_communication_via_voice))) + (Extra_voice_comm_due_to_comm_error_in_datalink *Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])
 ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink) *Transition_Airspace4_for_non_integrated[Density,feeder4]/Transition_Area_Time_in_datalink[Density])
 Terminal_Airspace_Time_in_non_integrated[Density] = (Terminal_Airspace_Distance + ES_in_TEA_in_non_integrated[Density])*60*10/Average_Approach_Speed[Density]
 Terminal_Times_for_non_integrated[Density] = CYCLETIME(AAR_for_non_integrated[Density])
 terminal_time_difference_in_non_integrated[Density] = Mean_Terminal_Times_for_voice[Density] - Mean_Terminal_Times_for_non_integrated[Density]

Terminal Airspace (Datalink + Voice)

Conflict_time_for_feeder_controller1_by__datalink_in_datalink[Density,feeder1](t) = Conflict_time_for_feeder_controller1_by__datalink_in_datalink[Density,feeder1](t - dt) + (conflict_time_rate_feeder_controller1_by_datalink_in_datalink[Density,feeder1]) * dt
 INIT Conflict_time_for_feeder_controller1_by__datalink_in_datalink[Density,feeder1] = 0
 INFLOWS:
 conflict_time_rate_feeder_controller1_by_datalink_in_datalink[Density,feeder1] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(conflict_rate_for_feeder_controller1_in_datalink[Density,feeder1]*Percentage_of_conflicts_allocated_to_datalink*Average_time_per_conflict_by_datalink_non_uret)
 ELSE(0)
 Conflict_time_for_feeder_controller1_by__voice_in_datalink[Density,feeder1](t) = Conflict_time_for_feeder_controller1_by__voice_in_datalink[Density,feeder1](t - dt) + (conflict_time_rate_feeder_controller1_by_voice_in_datalink[Density,feeder1]) * dt
 INIT Conflict_time_for_feeder_controller1_by__voice_in_datalink[Density,feeder1] = 0
 INFLOWS:
 conflict_time_rate_feeder_controller1_by_voice_in_datalink[Density,feeder1] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(conflict_rate_for_feeder_controller1_in_datalink[Density,feeder1]*(1 - Percentage_of_conflicts_allocated_to_datalink)*Average_time_per_conflict_by_voice_non_uret)

```

ELSE(conflict_rate_for_feeder_controller1_in_datalink[Density,feeder1]*Average_time_per_conflict_by_voice_non_uret)
Conflict_time_for_feeder_controller2_by_datalink_in_datalink[Density,feeder2](t) =
Conflict_time_for_feeder_controller2_by_datalink_in_datalink[Density,feeder2](t - dt) +
(conflict_time_rate_for_feeder_controller2_by_datalink_in_datalink[Density,feeder2]) * dt
INIT Conflict_time_for_feeder_controller2_by_datalink_in_datalink[Density,feeder2] = 0
INFLOWS:
conflict_time_rate_for_feeder_controller2_by_datalink_in_datalink[Density,feeder2] = IF(RAN-
DOM(0,1) <= Equipage_level_for_aircrafts)
THEN(conflict_rate_for_feeder_controller2_in_datalink[Density,feeder2]*Percentage_of_conflicts_
allocated_to_datalink*Average_time_per_conflict_by_datalink_non_uret)
ELSE(0)
Conflict_time_for_feeder_controller2_by_voice_in_datalink[Density,feeder2](t) =
Conflict_time_for_feeder_controller2_by_voice_in_datalink[Density,feeder2](t - dt) +
(conflict_time_rate_for_feeder_controller2_by_voice_in_datalink[Density,feeder2]) * dt
INIT Conflict_time_for_feeder_controller2_by_voice_in_datalink[Density,feeder2] = 0
INFLOWS:
conflict_time_rate_for_feeder_controller2_by_voice_in_datalink[Density,feeder2] = IF(RAN-
DOM(0,1) <= Equipage_level_for_aircrafts)
THEN(conflict_rate_for_feeder_controller2_in_datalink[Density,feeder2]*(1 -
Percentage_of_conflicts_allocated_to_datalink)*Average_time_per_conflict_by_voice_non_uret)
ELSE(conflict_rate_for_feeder_controller2_in_datalink[Density,feeder2]*Average_time_per_conflict_by_voice_non_uret)
Conflict_time_for_feeder_controller3_by_voice_in_datalink[Density,feeder3](t) =
Conflict_time_for_feeder_controller3_by_voice_in_datalink[Density,feeder3](t - dt) +
(conflict_time_rate_for_feeder_controller3_by_voice_in_datalink[Density,feeder3]) * dt
INIT Conflict_time_for_feeder_controller3_by_voice_in_datalink[Density,feeder3] = 0
INFLOWS:
conflict_time_rate_for_feeder_controller3_by_voice_in_datalink[Density,feeder3] = IF(RANDOM(0,1)
<= Equipage_level_for_aircrafts)
THEN(conflict_rate_for_feeder_controller3_in_datalink[Density,feeder3]*(1 -
Percentage_of_conflicts_allocated_to_datalink)*Average_time_per_conflict_by_voice_non_uret)
ELSE(conflict_rate_for_feeder_controller3_in_datalink[Density,feeder3]*Average_time_per_conflict_by_voice_non_uret)
Conflict_time_for_feeder_controller4_by_datalink_in_datalink[Density,feeder4](t) =
Conflict_time_for_feeder_controller4_by_datalink_in_datalink[Density,feeder4](t - dt) +
(conflict_time_rate_for_feeder_controller4_by_datalink_in_datalink[Density,feeder4]) * dt
INIT Conflict_time_for_feeder_controller4_by_datalink_in_datalink[Density,feeder4] = 0
INFLOWS:

```

$\text{conflict_time_rate_for_feeder_controller4_by_datalink_in_datalink}[\text{Density,feeder4}] = \text{IF}(\text{RANDOM}(0,1) \leq \text{Equipage_level_for_aircrafts})$
 $\text{THEN}(\text{conflict_rate_for_feeder_controller4_in_datalink}[\text{Density,feeder4}] * \text{Percentage_of_conflicts_allocated_to_datalink} * \text{Average_time_per_conflict_by_datalink_non_uret})$
 $\text{ELSE}(0)$
 $\text{Conflict_time_for_feeder_controller4_by_voice_in_datalink}[\text{Density,feeder4}](t) =$
 $\text{Conflict_time_for_feeder_controller4_by_voice_in_datalink}[\text{Density,feeder4}](t - dt) +$
 $(\text{conflict_time_rate_for_feeder_controller4_by_voice_in_datalink}[\text{Density,feeder4}]) * dt$
 $\text{INIT Conflict_time_for_feeder_controller4_by_voice_in_datalink}[\text{Density,feeder4}] = 0$
 INFLOWS:
 $\text{conflict_time_rate_for_feeder_controller4_by_voice_in_datalink}[\text{Density,feeder4}] = \text{IF}(\text{RANDOM}(0,1) \leq \text{Equipage_level_for_aircrafts})$
 $\text{THEN}(\text{conflict_rate_for_feeder_controller4_in_datalink}[\text{Density,feeder4}] * (1 -$
 $\text{Percentage_of_conflicts_allocated_to_datalink}) * \text{Average_time_per_conflict_by_voice_non_uret})$
 $\text{ELSE}(\text{conflict_rate_for_feeder_controller4_in_datalink}[\text{Density,feeder4}] * \text{Average_time_per_conflict_by_voice_non_uret})$
 $\text{Conflict_time_for_feeder_controller3_by_datalink_in_datalink}[\text{Density,feeder3}](t) =$
 $\text{Conflict_time_for_feeder_controller3_by_datalink_in_datalink}[\text{Density,feeder3}](t - dt) +$
 $(\text{conflict_time_rate_feeder_controller3_by_datalink_in_datalink}[\text{Density,feeder3}]) * dt$
 $\text{INIT Conflict_time_for_feeder_controller3_by_datalink_in_datalink}[\text{Density,feeder3}] = 0$
 INFLOWS:
 $\text{conflict_time_rate_feeder_controller3_by_datalink_in_datalink}[\text{Density,feeder3}] = \text{IF}(\text{RANDOM}(0,1) \leq \text{Equipage_level_for_aircrafts})$
 $\text{THEN}(\text{conflict_rate_for_feeder_controller3_in_datalink}[\text{Density,feeder3}] * \text{Percentage_of_conflicts_allocated_to_datalink} * \text{Average_time_per_conflict_by_datalink_non_uret})$
 $\text{ELSE}(0)$
 $\text{Holding_Queue1_for_datalink}[\text{Density}](t) = \text{Holding_Queue1_for_datalink}[\text{Density}](t - dt) +$
 $(\text{Merging_out_rate1_for_datalink}[\text{Density}] - \text{Rate_of_holding_dissipation1_for_datalink}[\text{Density}]) * dt$
 $\text{INIT Holding_Queue1_for_datalink}[\text{Density}] = 0$
 INFLOWS:
 $\text{Merging_out_rate1_for_datalink}[\text{Density}] = \text{CONVEYOR OUTFLOW}$

 $\text{TRANSIT TIME} = \text{Merging_time_for_datalink}[\text{Density}]$
 OUTFLOWS:
 $\text{Rate_of_holding_dissipation1_for_datalink}[\text{Density}] = \text{QUEUE OUTFLOW}$
 $\text{Holding_Queue2_for_datalink}[\text{Density}](t) = \text{Holding_Queue2_for_datalink}[\text{Density}](t - dt) +$
 $(\text{Merging_out_rate2_for_datalink}[\text{Density}] - \text{Rate_of_holding_dissipation2_for_datalink}[\text{Density}]) * dt$

INIT Holding_Queue2_for_datalink[Density] = 0

INFLOWS:

Merging_out_rate2_for_datalink[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_datalink[Density]

OUTFLOWS:

Rate_of_holding_dissipation2_for_datalink[Density] = QUEUE OUTFLOW

Holding_Queue3_for_datalink[Density](t) = Holding_Queue3_for_datalink[Density](t - dt) +
(Merging_out_rate3_for_datalink[Density] - Rate_of_holding_dissipation3_for_datalink[Density]) *
dt

INIT Holding_Queue3_for_datalink[Density] = 0

INFLOWS:

Merging_out_rate3_for_datalink[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_datalink[Density]

OUTFLOWS:

Rate_of_holding_dissipation3_for_datalink[Density] = QUEUE OUTFLOW

Holding_Queue4_for_datalink[Density](t) = Holding_Queue4_for_datalink[Density](t - dt) +
(Merging_out_rate4_for_datalink[Density] - Rate_of_holding_dissipation4_for_datalink[Density]) *
dt

INIT Holding_Queue4_for_datalink[Density] = 0

INFLOWS:

Merging_out_rate4_for_datalink[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_datalink[Density]

OUTFLOWS:

Rate_of_holding_dissipation4_for_datalink[Density] = QUEUE OUTFLOW

Merging1_for_datalink[Density](t) = Merging1_for_datalink[Density](t - dt) +
(QMDR1_for_datalink[Density,feeder1] - Merging_out_rate1_for_datalink[Density]) * dt

INIT Merging1_for_datalink[Density] = 0

INFLOWS:

QMDR1_for_datalink[Density,feeder1] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate1_for_datalink[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_datalink[Density]

Merging2_for_datalink[Density](t) = Merging2_for_datalink[Density](t - dt) +
(QMDR2_for_datalink[Density,feeder2] - Merging_out_rate2_for_datalink[Density]) * dt

INIT Merging2_for_datalink[Density] = 0

INFLOWS:

QMDR2_for_datalink[Density,feeder2] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate2_for_datalink[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_datalink[Density]

Merging3_for_datalink[Density](t) = Merging3_for_datalink[Density](t - dt) +
(QMDR3_for_datalink[Density,feeder3] - Merging_out_rate3_for_datalink[Density]) * dt

INIT Merging3_for_datalink[Density] = 0

INFLOWS:

QMDR3_for_datalink[Density,feeder3] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate3_for_datalink[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_datalink[Density]

Merging4_for_datalink[Density](t) = Merging4_for_datalink[Density](t - dt) +
(QMDR4_for_datalink[Density,feeder4] - Merging_out_rate4_for_datalink[Density]) * dt

INIT Merging4_for_datalink[Density] = 0

INFLOWS:

QMDR4_for_datalink[Density,feeder4] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate4_for_datalink[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_datalink[Density]

Mer_Conflict1_for_datalink[Density,feeder1](t) = Mer_Conflict1_for_datalink[Density,feeder1](t -
dt) + (Mer_Conflict_rate1_for_datalink[Density,feeder1]) * dt

INIT Mer_Conflict1_for_datalink[Density,feeder1] = 0

INFLOWS:

Mer_Conflict_rate1_for_datalink[Density,feeder1] = IF(Merging1_for_datalink[Density] > 0) AND
(Rate_out_TA1_for_datalink[Density,feeder1] > 0)

THEN(1)

ELSE(IF(Rate_out_TA1_for_datalink[Density,feeder1] > 0) AND

(Queue_for_Merging1_for_datalink[Density,feeder1] > 0)

THEN(1)

ELSE(0))

Mer_Conflict2_for_datalink[Density,feeder2](t) = Mer_Conflict2_for_datalink[Density,feeder2](t -
dt) + (Mer_Conflict_rate2_for_datalink[Density,feeder2]) * dt

INIT Mer_Conflict2_for_datalink[Density,feeder2] = 0

INFLOWS:

$Mer_Conflict_rate2_for_datalink[Density,feeder2] = IF(Merging2_for_datalink[Density] > 0) AND$
 $(Rate_out_TA2_for_datalink[Density,feeder2] > 0)$
 THEN(1)
 ELSE(IF(Rate_out_TA2_for_datalink[Density,feeder2] > 0) AND
 (Queue_for_Merging2_for_datalink[Density,feeder2] > 0)
 THEN(1)
 ELSE(0))
 $Mer_Conflict3_for_datalink[Density,feeder3](t) = Mer_Conflict3_for_datalink[Density,feeder3](t -$
 $dt) + (Mer_Conflict_rate3_for_datalink[Density,feeder3]) * dt$
 INIT $Mer_Conflict3_for_datalink[Density,feeder3] = 0$
 INFLOWS:
 $Mer_Conflict_rate3_for_datalink[Density,feeder3] = IF(Merging3_for_datalink[Density] > 0) AND$
 $(Rate_out_TA3_for_datalink[Density,feeder3] > 0)$
 THEN(1)
 ELSE(IF(Rate_out_TA3_for_datalink[Density,feeder3] > 0) AND
 (Queue_for_Merging3_for_datalink[Density,feeder3] > 0)
 THEN(1)
 ELSE(0))
 $Mer_Conflict4_for_datalink[Density,feeder4](t) = Mer_Conflict4_for_datalink[Density,feeder4](t -$
 $dt) + (Mer_Conflict_rate4_for_datalink[Density,feeder4]) * dt$
 INIT $Mer_Conflict4_for_datalink[Density,feeder4] = 0$
 INFLOWS:
 $Mer_Conflict_rate4_for_datalink[Density,feeder4] = IF(Merging4_for_datalink[Density] > 0) AND$
 $(Rate_out_TA4_for_datalink[Density,feeder4] > 0)$
 THEN(1)
 ELSE(IF(Rate_out_TA4_for_datalink[Density,feeder4] > 0) AND
 (Queue_for_Merging4_for_datalink[Density,feeder4] > 0)
 THEN(1)
 ELSE(0))
 $Queue_for_Merging1_for_datalink[Density,feeder1](t) = Queue_for_Merging1_for_datalink[Density,$
 $feeder1](t - dt) + (Rate_out_TA1_for_datalink[Density,feeder1] - QMDR1_for_datalink[Density,$
 $feeder1]) * dt$
 INIT $Queue_for_Merging1_for_datalink[Density,feeder1] = 0$
 INFLOWS:
 $Rate_out_TA1_for_datalink[Density,feeder1] = CONVEYOR OUTFLOW$

TRANSIT TIME = $Transition_Area_Time_in_datalink[Density]$
 OUTFLOWS:
 $QMDR1_for_datalink[Density,feeder1] = QUEUE OUTFLOW$

Queue_for_Merging2_for_datalink[Density,feeder2](t) = Queue_for_Merging2_for_datalink[Density,feeder2](t - dt) + (Rate_out_TA2_for_datalink[Density,feeder2] - QMDR2_for_datalink[Density,feeder2]) * dt

INIT Queue_for_Merging2_for_datalink[Density,feeder2] = 0

INFLOWS:

Rate_out_TA2_for_datalink[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

OUTFLOWS:

QMDR2_for_datalink[Density,feeder2] = QUEUE OUTFLOW

Queue_for_Merging3_for_datalink[Density,feeder3](t) = Queue_for_Merging3_for_datalink[Density,feeder3](t - dt) + (Rate_out_TA3_for_datalink[Density,feeder3] - QMDR3_for_datalink[Density,feeder3]) * dt

INIT Queue_for_Merging3_for_datalink[Density,feeder3] = 0

INFLOWS:

Rate_out_TA3_for_datalink[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

OUTFLOWS:

QMDR3_for_datalink[Density,feeder3] = QUEUE OUTFLOW

Queue_for_Merging4_for_datalink[Density,feeder4](t) = Queue_for_Merging4_for_datalink[Density,feeder4](t - dt) + (Rate_out_TA4_for_datalink[Density,feeder4] - QMDR4_for_datalink[Density,feeder4]) * dt

INIT Queue_for_Merging4_for_datalink[Density,feeder4] = 0

INFLOWS:

Rate_out_TA4_for_datalink[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

OUTFLOWS:

QMDR4_for_datalink[Density,feeder4] = QUEUE OUTFLOW

Queue_for_S1_for_datalink[Density,feeder1](t) = Queue_for_S1_for_datalink[Density,feeder1](t - dt) + (Rate_in_TA1_for_datalink[Density,feeder1] - QSR1_for_datalink[Density,feeder1]) * dt

INIT Queue_for_S1_for_datalink[Density,feeder1] = 0

INFLOWS:

Rate_in_TA1_for_datalink[Density,feeder1] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,29) <= Proportion_of_flights_into_TA1[Density,feeder1])

THEN(1)

ELSE(0)

OUTFLOWS:

QSR1_for_datalink[Density,feeder1] = IF(TA_Controller_Activity1_in_datalink[Density,feeder1] >= 1) OR (Separation1_for_datalink[Density,feeder1] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S1_for_datalink[Density,feeder1] > 0) OR (Rate_in_TA1_for_datalink[Density,feeder1] > 0))
 THEN(1)
 ELSE(0))
 Queue_for_S21_for_datalink[Density,feeder3](t) = Queue_for_S21_for_datalink[Density,feeder3](t - dt) + (Rate_in_TA3_for_datalink[Density,feeder3] - QSR3_for_datalink[Density,feeder3]) * dt
 INIT Queue_for_S21_for_datalink[Density,feeder3] = 0
 INFLOWS:
 Rate_in_TA3_for_datalink[Density,feeder3] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,111) <= Proportion_of_flights_into_TA3[Density,feeder3])
 THEN(1)
 ELSE(0)
 OUTFLOWS:
 QSR3_for_datalink[Density,feeder3] = IF(TA_Controller_Activity3_in_datalink[Density,feeder3] >= 1) OR (Separation3_for_datalink[Density,feeder3] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S21_for_datalink[Density,feeder3] > 0) OR (Rate_in_TA3_for_datalink[Density,feeder3] > 0))
 THEN(1)
 ELSE(0))
 Queue_for_S2_for_datalink[Density,feeder2](t) = Queue_for_S2_for_datalink[Density,feeder2](t - dt) + (Rate_in_TA2_for_datalink[Density,feeder2] - QSR2_for_datalink[Density,feeder2]) * dt
 INIT Queue_for_S2_for_datalink[Density,feeder2] = 0
 INFLOWS:
 Rate_in_TA2_for_datalink[Density,feeder2] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,11) <= Proportion_of_flights_into_TA2[Density,feeder2])
 THEN(1)
 ELSE(0)
 OUTFLOWS:
 QSR2_for_datalink[Density,feeder2] = IF(TA_Controller_Activity2_in_datalink[Density,feeder2] >= 1) OR (Separation2_for_datalink[Density,feeder2] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S2_for_datalink[Density,feeder2] > 0) OR (Rate_in_TA2_for_datalink[Density,feeder2] > 0))
 THEN(1)
 ELSE(0))

Queue_for_S4_for_datalink[Density,feeder4](t) = Queue_for_S4_for_datalink[Density,feeder4](t - dt) + (Rate_in_TA4_for_datalink[Density,feeder4] - QSR4_for_datalink[Density,feeder4]) * dt
INIT Queue_for_S4_for_datalink[Density,feeder4] = 0

INFLOWS:

Rate_in_TA4_for_datalink[Density,feeder4] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,37) <= Proportion_of_flights_into_TA4[Density,feeder4])

THEN(1)

ELSE(0)

OUTFLOWS:

QSR4_for_datalink[Density,feeder4] = IF(TA_Controller_Activity4_in_datalink[Density,feeder4] >= 1) OR (Separation4_for_datalink[Density,feeder4] > 0)

THEN(0)

ELSE(IF(Queue_for_S4_for_datalink[Density,feeder4] > 0) OR (Rate_in_TA4_for_datalink[Density,feeder4] > 0))

THEN(1)

ELSE(0))

Separation1_for_datalink[Density,feeder1](t) = Separation1_for_datalink[Density,feeder1](t - dt) + (QSR1_for_datalink[Density,feeder1] - Separation_Rate1_for_datalink[Density,feeder1]) * dt

INIT Separation1_for_datalink[Density,feeder1] = 0

INFLOWS:

QSR1_for_datalink[Density,feeder1] = IF(TA_Controller_Activity1_in_datalink[Density,feeder1] >= 1) OR (Separation1_for_datalink[Density,feeder1] > 0)

THEN(0)

ELSE(IF(Queue_for_S1_for_datalink[Density,feeder1] > 0) OR (Rate_in_TA1_for_datalink[Density,feeder1] > 0))

THEN(1)

ELSE(0))

OUTFLOWS:

Separation_Rate1_for_datalink[Density,feeder1] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_datalink[Density]

Separation2_for_datalink[Density,feeder2](t) = Separation2_for_datalink[Density,feeder2](t - dt) + (QSR2_for_datalink[Density,feeder2] - Separation_Rate2_for_datalink[Density,feeder2]) * dt

INIT Separation2_for_datalink[Density,feeder2] = 0

INFLOWS:

QSR2_for_datalink[Density,feeder2] = IF(TA_Controller_Activity2_in_datalink[Density,feeder2] >= 1) OR (Separation2_for_datalink[Density,feeder2] > 0)

THEN(0)

ELSE(IF(Queue_for_S2_for_datalink[Density,feeder2] > 0) OR (Rate_in_TA2_for_datalink[Density,feeder2] > 0))

sity,feeder2] > 0)

THEN(1)

ELSE(0))

OUTFLOWS:

Separation_Rate2_for_datalink[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_datalink[Density]

Separation3_for_datalink[Density,feeder3](t) = Separation3_for_datalink[Density,feeder3](t - dt) + (QSR3_for_datalink[Density,feeder3] - Separation_Rate3_for_datalink[Density,feeder3]) * dt

INIT Separation3_for_datalink[Density,feeder3] = 0

INFLOWS:

QSR3_for_datalink[Density,feeder3] = IF(TA_Controller_Activity3_in_datalink[Density,feeder3] >= 1) OR (Separation3_for_datalink[Density,feeder3] > 0)

THEN(0)

ELSE(IF(Queue_for_S21_for_datalink[Density,feeder3] > 0) OR (Rate_in_TA3_for_datalink[Density,feeder3] > 0))

THEN(1)

ELSE(0))

OUTFLOWS:

Separation_Rate3_for_datalink[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_datalink[Density]

Separation4_for_datalink[Density,feeder4](t) = Separation4_for_datalink[Density,feeder4](t - dt) + (QSR4_for_datalink[Density,feeder4] - Separation_Rate4_for_datalink[Density,feeder4]) * dt

INIT Separation4_for_datalink[Density,feeder4] = 0

INFLOWS:

QSR4_for_datalink[Density,feeder4] = IF(TA_Controller_Activity4_in_datalink[Density,feeder4] >= 1) OR (Separation4_for_datalink[Density,feeder4] > 0)

THEN(0)

ELSE(IF(Queue_for_S4_for_datalink[Density,feeder4] > 0) OR (Rate_in_TA4_for_datalink[Density,feeder4] > 0))

THEN(1)

ELSE(0))

OUTFLOWS:

Separation_Rate4_for_datalink[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_datalink[Density]

Sep_Conflict1_for_datalink[Density,feeder1](t) = Sep_Conflict1_for_datalink[Density,feeder1](t - dt) + (Sep_Conflict_ratein1_for_datalink[Density,feeder1]) * dt

INIT Sep_Conflict1_for_datalink[Density,feeder1] = 0
 INFLOWS:
 Sep_Conflict_ratein1_for_datalink[Density,feeder1] = IF(Rate_in_TA1_for_datalink[Density,feeder1] > 0) AND (Separation1_for_datalink[Density,feeder1] > 0)
 THEN(1)
 ELSE(0)
 Sep_Conflict2_for_datalink[Density,feeder2](t) = Sep_Conflict2_for_datalink[Density,feeder2](t - dt) + (Sep_Conflict_ratein2_for_datalink[Density,feeder2]) * dt
 INIT Sep_Conflict2_for_datalink[Density,feeder2] = 0
 INFLOWS:
 Sep_Conflict_ratein2_for_datalink[Density,feeder2] = IF(Rate_in_TA2_for_datalink[Density,feeder2] > 0) AND (Separation2_for_datalink[Density,feeder2] > 0)
 THEN(1)
 ELSE(0)
 Sep_Conflict3_for_datalink[Density,feeder3](t) = Sep_Conflict3_for_datalink[Density,feeder3](t - dt) + (Sep_Conflict_ratein3_for_datalink[Density,feeder3]) * dt
 INIT Sep_Conflict3_for_datalink[Density,feeder3] = 0
 INFLOWS:
 Sep_Conflict_ratein3_for_datalink[Density,feeder3] = IF(Rate_in_TA3_for_datalink[Density,feeder3] > 0) AND (Separation3_for_datalink[Density,feeder3] > 0)
 THEN(1)
 ELSE(0)
 Sep_Conflict4_for_datalink[Density,feeder4](t) = Sep_Conflict4_for_datalink[Density,feeder4](t - dt) + (Sep_Conflict_ratein4_for_datalink[Density,feeder4]) * dt
 INIT Sep_Conflict4_for_datalink[Density,feeder4] = 0
 INFLOWS:
 Sep_Conflict_ratein4_for_datalink[Density,feeder4] = IF(Rate_in_TA4_for_datalink[Density,feeder4] > 0) AND (Separation4_for_datalink[Density,feeder4] > 0)
 THEN(1)
 ELSE(0)
 Terminal_Airspace_for_datalink[High](t) = Terminal_Airspace_for_datalink[High](t - dt) + (Rate_of_holding_dissipation1_for_datalink[High] + Rate_of_holding_dissipation3_for_datalink[High] + Rate_of_holding_dissipation2_for_datalink[High] + Rate_of_holding_dissipation4_for_datalink[High] - AAR[High]) * dt
 INIT Terminal_Airspace_for_datalink[High] = 0

 TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 8

Terminal_Airspace_for_datalink[Medium](t) = Terminal_Airspace_for_datalink[Medium](t - dt) +
(Rate_of_holding_dissipation1_for_datalink[Medium] +
Rate_of_holding_dissipation3_for_datalink[Medium] +
Rate_of_holding_dissipation2_for_datalink[Medium] +
Rate_of_holding_dissipation4_for_datalink[Medium] - AAR[Medium]) * dt
INIT Terminal_Airspace_for_datalink[Medium] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 4

Terminal_Airspace_for_datalink[Low](t) = Terminal_Airspace_for_datalink[Low](t - dt) +
(Rate_of_holding_dissipation1_for_datalink[Low] +
Rate_of_holding_dissipation3_for_datalink[Low] +
Rate_of_holding_dissipation2_for_datalink[Low] +
Rate_of_holding_dissipation4_for_datalink[Low] - AAR[Low]) * dt
INIT Terminal_Airspace_for_datalink[Low] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 2

INFLOWS:

Rate_of_holding_dissipation1_for_datalink[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation3_for_datalink[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation2_for_datalink[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation4_for_datalink[Density] = QUEUE OUTFLOW

OUTFLOWS:

AAR[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Terminal_Airspace_Time_in_datalink[Density]

Total_aircraft_in_terminal_airspace_in_datalink[Density](t) =
Total_aircraft_in_terminal_airspace_in_datalink[Density](t - dt) +
(rate_in_terminal_airspace_in_datalink[Density]) * dt
INIT Total_aircraft_in_terminal_airspace_in_datalink[Density] = 0

INFLOWS:

rate_in_terminal_airspace_in_datalink[Density] = Rate_of_holding_dissipation1_for_datalink[Density] +
Rate_of_holding_dissipation2_for_datalink[Density] +
Rate_of_holding_dissipation3_for_datalink[Density] +
Rate_of_holding_dissipation4_for_datalink[Density]

Total_aircraft_in_tracon_airspace_in_datalink[Density](t) =
Total_aircraft_in_tracon_airspace_in_datalink[Density](t - dt) +
(rate_in_tracon_airspace_in_datalink[Density]) * dt
INIT Total_aircraft_in_tracon_airspace_in_datalink[Density] = 0

INFLOWS:

rate_in_tracon_airspace_in_datalink[Density] = Rate_in_TA1_for_datalink[Density,f11] +
Rate_in_TA1_for_datalink[Density,f12] + Rate_in_TA2_for_datalink[Density,f21] +
Rate_in_TA2_for_datalink[Density,f22] + Rate_in_TA3_for_datalink[Density,f31] +
Rate_in_TA3_for_datalink[Density,f32] + Rate_in_TA4_for_datalink[Density,f41] +
Rate_in_TA4_for_datalink[Density,f42]

Total_Conflicts_for_feeder_controller1_in_datalink[Density,feeder1](t) =
Total_Conflicts_for_feeder_controller1_in_datalink[Density,feeder1](t - dt) +
(conflict_rate_for_feeder_controller1_in_datalink[Density,feeder1]) * dt
INIT Total_Conflicts_for_feeder_controller1_in_datalink[Density,feeder1] = 0

INFLOWS:

conflict_rate_for_feeder_controller1_in_datalink[Density,feeder1] =
Sep_Conflict_ratein1_for_datalink[Density,feeder1] + Mer_Conflict_rate1_for_datalink[Density,feeder1]

Total_Conflicts_for_feeder_controller3_in_datalink[Density,feeder3](t) =
Total_Conflicts_for_feeder_controller3_in_datalink[Density,feeder3](t - dt) +
(conflict_rate_for_feeder_controller3_in_datalink[Density,feeder3]) * dt
INIT Total_Conflicts_for_feeder_controller3_in_datalink[Density,feeder3] = 0

INFLOWS:

conflict_rate_for_feeder_controller3_in_datalink[Density,feeder3] =
Sep_Conflict_ratein3_for_datalink[Density,feeder3] + Mer_Conflict_rate3_for_datalink[Density,feeder3]

Total_conflicts_for_feeder_controller4_in_datalink[Density,feeder4](t) =
Total_conflicts_for_feeder_controller4_in_datalink[Density,feeder4](t - dt) +
(conflict_rate_for_feeder_controller4_in_datalink[Density,feeder4]) * dt
INIT Total_conflicts_for_feeder_controller4_in_datalink[Density,feeder4] = 0

INFLOWS:

conflict_rate_for_feeder_controller4_in_datalink[Density,feeder4] =
Sep_Conflict_ratein4_for_datalink[Density,feeder4] + Mer_Conflict_rate4_for_datalink[Density,feeder4]

Total_no_of_rc_for_feeder_controller1_in_datalink[Density,feeder1](t) =
Total_no_of_rc_for_feeder_controller1_in_datalink[Density,feeder1](t - dt) +
(rc_rate_feeder_controller1_in_datalink[Density,feeder1]) * dt
INIT Total_no_of_rc_for_feeder_controller1_in_datalink[Density,feeder1] = 0

INFLOWS:

rc_rate_feeder_controller1_in_datalink[Density,feeder1] = Rate_in_TA1_for_datalink[Density,feeder1] + (Separation_Rate1_for_datalink[Density,feeder1]*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink))

Total_no_of_rc_for_feeder_controller2_in_datalink[Density,feeder2](t) =
Total_no_of_rc_for_feeder_controller2_in_datalink[Density,feeder2](t - dt) +
(rc_rate_for_feeder_controller2_in_datalink[Density,feeder2]) * dt
INIT Total_no_of_rc_for_feeder_controller2_in_datalink[Density,feeder2] = 0

INFLOWS:

rc_rate_for_feeder_controller2_in_datalink[Density,feeder2] = Rate_in_TA2_for_datalink[Density,feeder2] + (Separation_Rate2_for_datalink[Density,feeder2]*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink))

Total_no_of_rc_for_feeder_controller3_in_datalink[Density,feeder3](t) =
Total_no_of_rc_for_feeder_controller3_in_datalink[Density,feeder3](t - dt) +
(rc_rate_for_feeder_controller3_in_datalink[Density,feeder3]) * dt
INIT Total_no_of_rc_for_feeder_controller3_in_datalink[Density,feeder3] = 0

INFLOWS:

rc_rate_for_feeder_controller3_in_datalink[Density,feeder3] = Rate_in_TA3_for_datalink[Density,feeder3] + (Separation_Rate3_for_datalink[Density,feeder3]*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink))

Total_no_of_rc_for_feeder_controller4_in_datalink[Density,feeder4](t) =
Total_no_of_rc_for_feeder_controller4_in_datalink[Density,feeder4](t - dt) +
(rc_rate_for_feeder_controller4_in_datalink[Density,feeder4]) * dt
INIT Total_no_of_rc_for_feeder_controller4_in_datalink[Density,feeder4] = 0

INFLOWS:

rc_rate_for_feeder_controller4_in_datalink[Density,feeder4] = Rate_in_TA4_for_datalink[Density,feeder4] + (Separation_Rate4_for_datalink[Density,feeder4]*(No_of_routine_comm_in_transition_area +

Extra_voice_comm_due_to_comm_error_in_datalink))
 Total_no_of_rdc_for_feeder_controller1_in_datalink[Density,feeder1](t) =
 Total_no_of_rdc_for_feeder_controller1_in_datalink[Density,feeder1](t - dt) +
 (rdc_rate_feeder_controller1_in_datalink[Density,feeder1]) * dt
 INIT Total_no_of_rdc_for_feeder_controller1_in_datalink[Density,feeder1] = 0
 INFLOWS:
 rdc_rate_feeder_controller1_in_datalink[Density,feeder1] = IF(RANDOM(0,1) <=
 Equipage_level_for_aircrafts)
 THEN((Rate_in_TA1_for_datalink[Density,feeder1] + Separation_Rate1_for_datalink[Den-
 sity,feeder1]*No_of_routine_comm_in_transition_area)*Datalink_Proportion_of_msgs)
 ELSE(0)
 Total_no_of_rdc_for_feeder_controller2_in_datalink[Density,feeder2](t) =
 Total_no_of_rdc_for_feeder_controller2_in_datalink[Density,feeder2](t - dt) +
 (rdc_rate_for_feeder_controller2_in_datalink[Density,feeder2]) * dt
 INIT Total_no_of_rdc_for_feeder_controller2_in_datalink[Density,feeder2] = 0
 INFLOWS:
 rdc_rate_for_feeder_controller2_in_datalink[Density,feeder2] = IF(RANDOM(0,1) <=
 Equipage_level_for_aircrafts)
 THEN((Rate_in_TA2_for_datalink[Density,feeder2] + Separation_Rate2_for_datalink[Den-
 sity,feeder2]*No_of_routine_comm_in_transition_area)*Datalink_Proportion_of_msgs)
 ELSE(0)
 Total_no_of_rdc_for_feeder_controller3_in_datalink[Density,feeder3](t) =
 Total_no_of_rdc_for_feeder_controller3_in_datalink[Density,feeder3](t - dt) +
 (rdc_rate_for_feeder_controller3_in_datalink[Density,feeder3]) * dt
 INIT Total_no_of_rdc_for_feeder_controller3_in_datalink[Density,feeder3] = 0
 INFLOWS:
 rdc_rate_for_feeder_controller3_in_datalink[Density,feeder3] = IF(RANDOM(0,1) <=
 Equipage_level_for_aircrafts)
 THEN((Rate_in_TA3_for_datalink[Density,feeder3] + Separation_Rate3_for_datalink[Den-
 sity,feeder3]*No_of_routine_comm_in_transition_area)*Datalink_Proportion_of_msgs)
 ELSE(0)
 Total_no_of_rdc_for_feeder_controller4_in_datalink[Density,feeder4](t) =
 Total_no_of_rdc_for_feeder_controller4_in_datalink[Density,feeder4](t - dt) +
 (rdc_rate_for_feeder_controller4_in_datalink[Density,feeder4]) * dt
 INIT Total_no_of_rdc_for_feeder_controller4_in_datalink[Density,feeder4] = 0
 INFLOWS:
 rdc_rate_for_feeder_controller4_in_datalink[Density,feeder4] = IF(RANDOM(0,1) <=
 Equipage_level_for_aircrafts)
 THEN((Rate_in_TA4_for_datalink[Density,feeder4] + Separation_Rate4_for_datalink[Den-

sity,feeder4]*No_of_routine_comm_in_transition_area)*Datalink_Proportion_of_msgs)

ELSE(0)

Total_no_of_rvc_for_feeder_controller1_in_datalink[Density,feeder1](t) =

Total_no_of_rvc_for_feeder_controller1_in_datalink[Density,feeder1](t - dt) +

(rvc_rate_feeder_controller1_in_datalink[Density,feeder1]) * dt

INIT Total_no_of_rvc_for_feeder_controller1_in_datalink[Density,feeder1] = 0

INFLOWS:

rvc_rate_feeder_controller1_in_datalink[Density,feeder1] =

rc_rate_feeder_controller1_in_datalink[Density,feeder1] -

rdc_rate_feeder_controller1_in_datalink[Density,feeder1]

Total_no_of_rvc_for_feeder_controller2_in_datalink[Density,feeder2](t) =

Total_no_of_rvc_for_feeder_controller2_in_datalink[Density,feeder2](t - dt) +

(rvc_rate_for_feeder_controller2_in_datalink[Density,feeder2]) * dt

INIT Total_no_of_rvc_for_feeder_controller2_in_datalink[Density,feeder2] = 0

INFLOWS:

rvc_rate_for_feeder_controller2_in_datalink[Density,feeder2] =

rc_rate_for_feeder_controller2_in_datalink[Density,feeder2] -

rdc_rate_for_feeder_controller2_in_datalink[Density,feeder2]

Total_no_of_rvc_for_feeder_controller3_in_datalink[Density,feeder3](t) =

Total_no_of_rvc_for_feeder_controller3_in_datalink[Density,feeder3](t - dt) +

(rvc_rate_for_feeder_controller3_in_datalink[Density,feeder3]) * dt

INIT Total_no_of_rvc_for_feeder_controller3_in_datalink[Density,feeder3] = 0

INFLOWS:

rvc_rate_for_feeder_controller3_in_datalink[Density,feeder3] =

rc_rate_for_feeder_controller3_in_datalink[Density,feeder3] -

rdc_rate_for_feeder_controller3_in_datalink[Density,feeder3]

Total_no_of_rvc_for_feeder_controller4_in_datalink[Density,feeder4](t) =

Total_no_of_rvc_for_feeder_controller4_in_datalink[Density,feeder4](t - dt) +

(rvc_rate_for_feeder_controller4_in_datalink[Density,feeder4]) * dt

INIT Total_no_of_rvc_for_feeder_controller4_in_datalink[Density,feeder4] = 0

INFLOWS:

rvc_rate_for_feeder_controller4_in_datalink[Density,feeder4] =

rc_rate_for_feeder_controller4_in_datalink[Density,feeder4] -

rdc_rate_for_feeder_controller4_in_datalink[Density,feeder4]

Total_time_for_rdc_for_feeder_controller1_in_datalink[Density,feeder1](t) =

Total_time_for_rdc_for_feeder_controller1_in_datalink[Density,feeder1](t - dt) +

(rdc_time_rate_feeder_controller1_in_datalink[Density,feeder1]) * dt

INIT Total_time_for_rdc_for_feeder_controller1_in_datalink[Density,feeder1] = 0

INFLOWS:

$\text{rdc_time_rate_feeder_controller1_in_datalink}[\text{Density,feeder1}] =$
 $\text{rdc_rate_feeder_controller1_in_datalink}[\text{Den-}$
 $\text{sity,feeder1}] * \text{Average_time_per_routine_communication_via_datalink}$
 $\text{Total_time_for_rdc_for_feeder_controller2_in_datalink}[\text{Density,feeder2}](t) =$
 $\text{Total_time_for_rdc_for_feeder_controller2_in_datalink}[\text{Density,feeder2}](t - dt) +$
 $(\text{rdc_time_rate_for_feeder_controller2_in_datalink}[\text{Density,feeder2}]) * dt$
 $\text{INIT Total_time_for_rdc_for_feeder_controller2_in_datalink}[\text{Density,feeder2}] = 0$
INFLOWS:
 $\text{rdc_time_rate_for_feeder_controller2_in_datalink}[\text{Density,feeder2}] =$
 $\text{rdc_rate_for_feeder_controller2_in_datalink}[\text{Den-}$
 $\text{sity,feeder2}] * \text{Average_time_per_routine_communication_via_datalink}$
 $\text{Total_time_for_rdc_for_feeder_controller3_in_datalink}[\text{Density,feeder3}](t) =$
 $\text{Total_time_for_rdc_for_feeder_controller3_in_datalink}[\text{Density,feeder3}](t - dt) +$
 $(\text{rdc_time_rate_for_feeder_controller3_in_datalink}[\text{Density,feeder3}]) * dt$
 $\text{INIT Total_time_for_rdc_for_feeder_controller3_in_datalink}[\text{Density,feeder3}] = 0$
INFLOWS:
 $\text{rdc_time_rate_for_feeder_controller3_in_datalink}[\text{Density,feeder3}] =$
 $\text{rdc_rate_for_feeder_controller3_in_datalink}[\text{Den-}$
 $\text{sity,feeder3}] * \text{Average_time_per_routine_communication_via_datalink}$
 $\text{Total_time_for_rdc_for_feeder_controller4_in_datalink}[\text{Density,feeder4}](t) =$
 $\text{Total_time_for_rdc_for_feeder_controller4_in_datalink}[\text{Density,feeder4}](t - dt) +$
 $(\text{rdc_time_rate_for_feeder_controller4_in_datalink}[\text{Density,feeder4}]) * dt$
 $\text{INIT Total_time_for_rdc_for_feeder_controller4_in_datalink}[\text{Density,feeder4}] = 0$
INFLOWS:
 $\text{rdc_time_rate_for_feeder_controller4_in_datalink}[\text{Density,feeder4}] =$
 $\text{rdc_rate_for_feeder_controller4_in_datalink}[\text{Den-}$
 $\text{sity,feeder4}] * \text{Average_time_per_routine_communication_via_datalink}$
 $\text{Total_time_for_rvc_for_feeder_controller1_in_datalink}[\text{Density,feeder1}](t) =$
 $\text{Total_time_for_rvc_for_feeder_controller1_in_datalink}[\text{Density,feeder1}](t - dt) +$
 $(\text{rvc_time_rate_feeder_controller1_in_datalink}[\text{Density,feeder1}]) * dt$
 $\text{INIT Total_time_for_rvc_for_feeder_controller1_in_datalink}[\text{Density,feeder1}] = 0$
INFLOWS:
 $\text{rvc_time_rate_feeder_controller1_in_datalink}[\text{Density,feeder1}] =$
 $\text{rvc_rate_feeder_controller1_in_datalink}[\text{Den-}$
 $\text{sity,feeder1}] * \text{Average_time_per_routine_communication_via_voice}$
 $\text{Total_time_for_rvc_for_feeder_controller2_in_datalink}[\text{Density,feeder2}](t) =$
 $\text{Total_time_for_rvc_for_feeder_controller2_in_datalink}[\text{Density,feeder2}](t - dt) +$
 $(\text{rvc_time_rate_for_feeder_controller2_in_datalink}[\text{Density,feeder2}]) * dt$
 $\text{INIT Total_time_for_rvc_for_feeder_controller2_in_datalink}[\text{Density,feeder2}] = 0$

INFLOWS:

$rvc_time_rate_for_feeder_controller2_in_datalink[Density,feeder2] =$
 $rvc_rate_for_feeder_controller2_in_datalink[Den-$
 $sity,feeder2]*Average_time_per_routine_communication_via_voice$
 $Total_time_for_rvc_for_feeder_controller3_in_datalink[Density,feeder3](t) =$
 $Total_time_for_rvc_for_feeder_controller3_in_datalink[Density,feeder3](t - dt) +$
 $(rvc_time_rate_for_feeder_controller3_in_datalink[Density,feeder3]) * dt$
INIT $Total_time_for_rvc_for_feeder_controller3_in_datalink[Density,feeder3] = 0$

INFLOWS:

$rvc_time_rate_for_feeder_controller3_in_datalink[Density,feeder3] =$
 $rvc_rate_for_feeder_controller3_in_datalink[Den-$
 $sity,feeder3]*Average_time_per_routine_communication_via_voice$
 $Total_time_for_rvc_for_feeder_controller4_in_datalink[Density,feeder4](t) =$
 $Total_time_for_rvc_for_feeder_controller4_in_datalink[Density,feeder4](t - dt) +$
 $(rvc_time_rate_for_feeder_controller4_in_datalink[Density,feeder4]) * dt$
INIT $Total_time_for_rvc_for_feeder_controller4_in_datalink[Density,feeder4] = 0$

INFLOWS:

$rvc_time_rate_for_feeder_controller4_in_datalink[Density,feeder4] =$
 $rvc_rate_for_feeder_controller4_in_datalink[Den-$
 $sity,feeder4]*Average_time_per_routine_communication_via_voice$
 $Total_no_of_conflicts_for_feeder_controller2_in_datalink[Density,feeder2](t) =$
 $Total_no_of_conflicts_for_feeder_controller2_in_datalink[Density,feeder2](t - dt) +$
 $(conflict_rate_for_feeder_controller2_in_datalink[Density,feeder2]) * dt$
INIT $Total_no_of_conflicts_for_feeder_controller2_in_datalink[Density,feeder2] = 0$

INFLOWS:

$conflict_rate_for_feeder_controller2_in_datalink[Density,feeder2] =$
 $Sep_Conflict_ratein2_for_datalink[Density,feeder2] + Mer_Conflict_rate2_for_datalink[Den-$
 $sity,feeder2]$
 $Transition_Airspace1_for_datalink[Density,feeder1](t) = Transition_Airspace1_for_datalink[Den-$
 $sity,feeder1](t - dt) + (Separation_Rate1_for_datalink[Density,feeder1] -$
 $Rate_out_TA1_for_datalink[Density,feeder1]) * dt$
INIT $Transition_Airspace1_for_datalink[Density,feeder1] = 0$

INFLOWS:

$Separation_Rate1_for_datalink[Density,feeder1] = CONVEYOR OUTFLOW$

$TRANSIT_TIME = Average_Separation_Time_for_datalink[Density]$

OUTFLOWS:

$Rate_out_TA1_for_datalink[Density,feeder1] = CONVEYOR OUTFLOW$

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]
Transition_Airspace2_for_datalink[Density,feeder2](t) = Transition_Airspace2_for_datalink[Density,feeder2](t - dt) + (Separation_Rate2_for_datalink[Density,feeder2] - Rate_out_TA2_for_datalink[Density,feeder2]) * dt
INIT Transition_Airspace2_for_datalink[Density,feeder2] = 0
INFLOWS:
Separation_Rate2_for_datalink[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_datalink[Density]
OUTFLOWS:
Rate_out_TA2_for_datalink[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]
Transition_Airspace3_for_datalink[Density,feeder3](t) = Transition_Airspace3_for_datalink[Density,feeder3](t - dt) + (Separation_Rate3_for_datalink[Density,feeder3] - Rate_out_TA3_for_datalink[Density,feeder3]) * dt
INIT Transition_Airspace3_for_datalink[Density,feeder3] = 0
INFLOWS:
Separation_Rate3_for_datalink[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_datalink[Density]
OUTFLOWS:
Rate_out_TA3_for_datalink[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]
Transition_Airspace4_for_datalink[Density,feeder4](t) = Transition_Airspace4_for_datalink[Density,feeder4](t - dt) + (Separation_Rate4_for_datalink[Density,feeder4] - Rate_out_TA4_for_datalink[Density,feeder4]) * dt
INIT Transition_Airspace4_for_datalink[Density,feeder4] = 0
INFLOWS:
Separation_Rate4_for_datalink[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_datalink[Density]
OUTFLOWS:
Rate_out_TA4_for_datalink[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]
acft_rate_in_terminal_airspace_in_datalink[Density] =
Total_aircraft_in_terminal_airspace_in_datalink[Density]*60*10/TIME

acft_rate_in_tracon_airspace_in_datalink[Density] =
Total_aircraft_in_tracon_airspace_in_datalink[Density]*60*10/TIME
Average_Separation_Time_for_datalink[Density] = (Intrail_Separation[Density] +
ES_in_TA_in_datalink[Density])*60*10/Average__Speed[Density]
Datalink_Proportion_of_msgs =
(CPDLC_Build_I_Switch*Proportion_of_comm_by_datalink_for_Build_I) +
(CPDLC_Build_IA_Switch*Addn_Proportion_of_comm_by_datalink_for_Build_IA) +
(CPDLC_Build_II_Switch*Addn_Proportion_of_comm_by_datalink_for_Build_II)
ES_in_TA_in_datalink[Density] = 0.000154*acft_rate_in_tracon_airspace_in_datalink[Density]*acft_rate_in_tracon_airspace_in_datalink[Density]*AMF + 0.4
ES_in_TES_in_datalink[Density] = 0.000154*acft_rate_in_terminal_airspace_in_datalink[Density]*acft_rate_in_terminal_airspace_in_datalink[Density]*AMF + 0.4
Extra_voice_comm_due_to_comm_error_in_datalink = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts) THEN(Extra_voice_comm_due_to_comm_error_in_voice*(1 -
Datalink_Proportion_of_msgs))
ELSE(Extra_voice_comm_due_to_comm_error_in_voice)
feeder_controller1_Utilization_in_datalink[Density,feeder1] =
(Conflict_time_for_feeder_controller1_by__datalink_in_datalink[Density,feeder1] +
Conflict_time_for_feeder_controller1_by__voice_in_datalink[Density,feeder1] +
Total_time_for_rdc_for_feeder_controller1_in_datalink[Density,feeder1] +
Total_time_for_rvc_for_feeder_controller1_in_datalink[Density,feeder1])/(TIME + 1)
feeder_controller2_Utilization_in_datalink[Density,feeder2] =
(Conflict_time_for_feeder_controller2_by_datalink_in_datalink[Density,feeder2] +
Conflict_time_for_feeder_controller2_by_voice_in_datalink[Density,feeder2] +
Total_time_for_rdc_for_feeder_controller2_in_datalink[Density,feeder2] +
Total_time_for_rvc_for_feeder_controller2_in_datalink[Density,feeder2])/(TIME + 1)
feeder_controller3_Utilization_in_datalink[Density,feeder3] =
(Conflict_time_for_feeder_controller3_by_voice_in_datalink[Density,feeder3] +
Conflict_time_for__feeder_controller3_by_datalink_in_datalink[Density,feeder3] +
Total_time_for_rdc_for_feeder_controller3_in_datalink[Density,feeder3] +
Total_time_for_rvc_for_feeder_controller3_in_datalink[Density,feeder3])/(TIME + 1)
feeder_controller4_Utilization_in_datalink[Density,feeder4] =
(Conflict_time_for_feeder_controller4_by_datalink_in_datalink[Density,feeder4] +
Conflict_time_for_feeder_controller4_by_voice__in_datalink[Density,feeder4] +
Total_time_for_rdc_for_feeder_controller4_in_datalink[Density,feeder4] +
Total_time_for_rvc_for_feeder_controller4_in_datalink[Density,feeder4])/(TIME + 1)
lag_time_in_datalink_in_terminal_airspace = 5/6
lag_time_in__voice_in_terminal_airspace = RANDOM(1,2)
Mean_Terminal_Times_for_datalink[Density] = CTMEAN(AAR[Density])

Merging_time_for_datalink[Density] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
THEN(Merging_time_for_voice[Density] +
Average_time_per_conflict_by_datalink_non_trial_planning -
Average_time_per_conflict_by_voice_non_uret + lag_time_in_datalink_in_terminal airspace -
lag_time_in_voice_in_terminal_airspace +Average_time_for_reading_and_uploading_message -
Average_time_for_hearing_and_uploading_the_message)
ELSE(Merging_time_for_voice[Density])
Proportion_of_flights_into_TA3[High,f31] = .4
Proportion_of_flights_into_TA3[High,f32] = .3
Proportion_of_flights_into_TA3[Medium,f31] = 0
Proportion_of_flights_into_TA3[Medium,f32] = 0
Proportion_of_flights_into_TA3[Low,f31] = 0
Proportion_of_flights_into_TA3[Low,f32] = 0
Proportion_of_flights_into_TA4[High,f41] = .3
Proportion_of_flights_into_TA4[High,f42] = .2
Proportion_of_flights_into_TA4[Medium,f41] = 0
Proportion_of_flights_into_TA4[Medium,f42] = 0
Proportion_of_flights_into_TA4[Low,f41] = 0
Proportion_of_flights_into_TA4[Low,f42] = 0
TA_Controller_Activity1_in_datalink[Density,feeder1] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
THEN(Transition_Airspace1_for_datalink[Density,feeder1]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice + Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink - Average_time_per_routine_communication_via_voice))) + (Extra_voice_comm_due_to_comm_error_in_datalink *Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])
ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink) *Transition_Airspace1_for_datalink[Density,feeder1]/Transition_Area_Time_in_datalink[Density])
TA_Controller_Activity2_in_datalink[Density,feeder2] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
THEN(Transition_Airspace2_for_datalink[Density,feeder2]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice + Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink - Average_time_per_routine_communication_via_voice))) + (Extra_voice_comm_due_to_comm_error_in_datalink *Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])

sity))
 ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink)
 *Transition_Airspace2_for_datalink[Density,feeder2]/Transition_Area_Time_in_datalink[Density])
 TA_Controller_Activity3_in_datalink[Density,feeder3] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Transition_Airspace3_for_datalink[Density,feeder3]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice +
 Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink - Average_time_per_routine_communication_via_voice))) +
 (Extra_voice_comm_due_to_comm_error_in_datalink
 *Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])
 ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink)
 *Transition_Airspace3_for_datalink[Density,feeder3]/Transition_Area_Time_in_datalink[Density])
 TA_Controller_Activity4_in_datalink[Density,feeder4] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Transition_Airspace4_for_datalink[Density,feeder4]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice +
 Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink - Average_time_per_routine_communication_via_voice))) +
 (Extra_voice_comm_due_to_comm_error_in_datalink
 *Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])
 ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink)
 *Transition_Airspace4_for_datalink[Density,feeder4]/Transition_Area_Time_in_datalink[Density])
 Terminal_Airspace_Time_in_datalink[Density] = (Terminal_Airspace_Distance + ES_in_TES_in_datalink[Density])*60*10/Average_Approach_Speed[Density]
 Terminal_Times_for_datalink[Density] = CYCLETIME(AAR[Density])
 terminal_time_difference_in_datalink[Density] = Mean_Terminal_Times_for_voice[Density] - Mean_Terminal_Times_for_datalink[Density]
 Transition_Area_Time_in_datalink[Density] = IF(RANDOM(0,1) <= Equipage_level_for_aircrafts)
 THEN(Free_flow_transition_time[Density] +
 (No_of_routine_diversions_per_sector*Number_of_sectors_in_tracon_airspace*(Diversion_time_per_routine_comm_in_voice +
 Datalink_Proportion_of_msgs*(Diversion_time_per_routine_comm_in_datalink_in_terminal_airspace - Diversion_time_per_routine_comm_in_voice))) +

(Extra_voice_comm_due_to_comm_error_in_datalink
*Average_time_per_routine_communication_via_voice))
ELSE(Transition_Area_Time_in_voice[Density])

Terminal Airspace (Voice only)

Holding_Queue1_for_voice[Density](t) = Holding_Queue1_for_voice[Density](t - dt) +
(Merging_out_rate1_for_voice[Density] - Rate_of_holding__dissipation1_for_voice[Density]) * dt
INIT Holding_Queue1_for_voice[Density] = 0

INFLOWS:

Merging_out_rate1_for_voice[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_voice[Density]

OUTFLOWS:

Rate_of_holding__dissipation1_for_voice[Density] = QUEUE OUTFLOW

Holding_Queue2_for_voice[Density](t) = Holding_Queue2_for_voice[Density](t - dt) +
(Merging_out_rate2_for_voice[Density] - Rate_of_holding__dissipation2_for_voice[Density]) * dt
INIT Holding_Queue2_for_voice[Density] = 0

INFLOWS:

Merging_out_rate2_for_voice[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_voice[Density]

OUTFLOWS:

Rate_of_holding__dissipation2_for_voice[Density] = QUEUE OUTFLOW

Holding_Queue3_for_voice[Density](t) = Holding_Queue3_for_voice[Density](t - dt) +
(Merging_out_rate3_for_voice[Density] - Rate_of_holding__dissipation3_for_voice[Density]) * dt
INIT Holding_Queue3_for_voice[Density] = 0

INFLOWS:

Merging_out_rate3_for_voice[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_voice[Density]

OUTFLOWS:

Rate_of_holding__dissipation3_for_voice[Density] = QUEUE OUTFLOW

Holding_Queue4_for_voice[Density](t) = Holding_Queue4_for_voice[Density](t - dt) +
(Merging_out_rate4_for_voice[Density] - Rate_of_holding__dissipation4_for_voice[Density]) * dt
INIT Holding_Queue4_for_voice[Density] = 0

INFLOWS:

Merging_out_rate4_for_voice[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_voice[Density]

OUTFLOWS:

Rate_of_holding_dissipation4_for_voice[Density] = QUEUE OUTFLOW

Merging1_for_voice[Density](t) = Merging1_for_voice[Density](t - dt) + (QMDR1_for_voice[Density,feeder1] - Merging_out_rate1_for_voice[Density]) * dt

INIT Merging1_for_voice[Density] = 0

INFLOWS:

QMDR1_for_voice[Density,feeder1] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate1_for_voice[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_voice[Density]

Merging2_for_voice[Density](t) = Merging2_for_voice[Density](t - dt) + (QMDR2_for_voice[Density,feeder2] - Merging_out_rate2_for_voice[Density]) * dt

INIT Merging2_for_voice[Density] = 0

INFLOWS:

QMDR2_for_voice[Density,feeder2] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate2_for_voice[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_voice[Density]

Merging3_for_voice[Density](t) = Merging3_for_voice[Density](t - dt) + (QMDR3_for_voice[Density,feeder3] - Merging_out_rate3_for_voice[Density]) * dt

INIT Merging3_for_voice[Density] = 0

INFLOWS:

QMDR3_for_voice[Density,feeder3] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate3_for_voice[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_voice[Density]

Merging4_for_voice[Density](t) = Merging4_for_voice[Density](t - dt) + (QMDR4_for_voice[Density,feeder4] - Merging_out_rate4_for_voice[Density]) * dt

INIT Merging4_for_voice[Density] = 0

INFLOWS:

QMDR4_for_voice[Density,feeder4] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate4_for_voice[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_voice[Density]

Mer_Conflict1[Density,feeder1](t) = Mer_Conflict1[Density,feeder1](t - dt) +

(Mer_Conflict_ratein1[Density,feeder1]) * dt
 INIT Mer_Conflict1[Density,feeder1] = 0
 INFLOWS:
 Mer_Conflict_ratein1[Density,feeder1] = IF(Merging1_for_voice[Density] > 0) AND
 (Rate_out_TA1_for_voice[Density,feeder1]> 0)
 THEN(1)
 ELSE(IF(Rate_out_TA1_for_voice[Density,feeder1] > 0) AND
 (Queue_for_Merging1_for_voice[Density,feeder1] > 0)
 THEN(1)
 ELSE(0))
 Mer_Conflict2[Density,feeder2](t) = Mer_Conflict2[Density,feeder2](t - dt) +
 (Mer_Conflict_ratein2[Density,feeder2]) * dt
 INIT Mer_Conflict2[Density,feeder2] = 0
 INFLOWS:
 Mer_Conflict_ratein2[Density,feeder2] = IF(Merging2_for_voice[Density] > 0) AND
 (Rate_out_TA2_for_voice[Density,feeder2]> 0)
 THEN(1)
 ELSE(IF(Rate_out_TA2_for_voice[Density,feeder2] > 0) AND
 (Queue_for_Merging2_for_voice[Density,feeder2] > 0)
 THEN(1)
 ELSE(0))
 Mer_Conflict3[Density,feeder3](t) = Mer_Conflict3[Density,feeder3](t - dt) +
 (Mer_Conflict_ratein3[Density,feeder3]) * dt
 INIT Mer_Conflict3[Density,feeder3] = 0
 INFLOWS:
 Mer_Conflict_ratein3[Density,feeder3] = IF(Merging3_for_voice[Density] > 0) AND
 (Rate_out_TA3_for_voice[Density,feeder3]> 0)
 THEN(1)
 ELSE(IF(Rate_out_TA3_for_voice[Density,feeder3] > 0) AND
 (Queue_for_Merging3_for_voice[Density,feeder3] > 0)
 THEN(1)
 ELSE(0))
 Mer_Conflict4[Density,feeder4](t) = Mer_Conflict4[Density,feeder4](t - dt) +
 (Mer_Conflict_ratein4[Density,feeder4]) * dt
 INIT Mer_Conflict4[Density,feeder4] = 0
 INFLOWS:
 Mer_Conflict_ratein4[Density,feeder4] = IF(Merging4_for_voice[Density] > 0) AND
 (Rate_out_TA4_for_voice[Density,feeder4]> 0)
 THEN(1)

ELSE(IF(Rate_out_TA4_for_voice[Density,feeder4] > 0) AND
(Queue_for_Merging4_for_voice[Density,feeder4] > 0)
THEN(1)
ELSE(0))
Queue_for_Merging1_for_voice[Density,feeder1](t) = Queue_for_Merging1_for_voice[Density,feeder1](t - dt) + (Rate_out_TA1_for_voice[Density,feeder1] - QMDR1_for_voice[Density,feeder1]) * dt
INIT Queue_for_Merging1_for_voice[Density,feeder1] = 0
INFLOWS:
Rate_out_TA1_for_voice[Density,feeder1] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_voice[Density]
OUTFLOWS:
QMDR1_for_voice[Density,feeder1] = QUEUE OUTFLOW
Queue_for_Merging2_for_voice[Density,feeder2](t) = Queue_for_Merging2_for_voice[Density,feeder2](t - dt) + (Rate_out_TA2_for_voice[Density,feeder2] - QMDR2_for_voice[Density,feeder2]) * dt
INIT Queue_for_Merging2_for_voice[Density,feeder2] = 0
INFLOWS:
Rate_out_TA2_for_voice[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_voice[Density]
OUTFLOWS:
QMDR2_for_voice[Density,feeder2] = QUEUE OUTFLOW
Queue_for_Merging3_for_voice[Density,feeder3](t) = Queue_for_Merging3_for_voice[Density,feeder3](t - dt) + (Rate_out_TA3_for_voice[Density,feeder3] - QMDR3_for_voice[Density,feeder3]) * dt
INIT Queue_for_Merging3_for_voice[Density,feeder3] = 0
INFLOWS:
Rate_out_TA3_for_voice[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_voice[Density]
OUTFLOWS:
QMDR3_for_voice[Density,feeder3] = QUEUE OUTFLOW
Queue_for_Merging4_for_voice[Density,feeder4](t) = Queue_for_Merging4_for_voice[Density,feeder4](t - dt) + (Rate_out_TA4_for_voice[Density,feeder4] - QMDR4_for_voice[Density,feeder4]) * dt
INIT Queue_for_Merging4_for_voice[Density,feeder4] = 0
INFLOWS:

Rate_out_TA4_for_voice[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_voice[Density]

OUTFLOWS:

QMDR4_for_voice[Density,feeder4] = QUEUE OUTFLOW

Queue_for_S11_for_voice[Density,feeder1](t) = Queue_for_S11_for_voice[Density,feeder1](t - dt) + (Rate_in_TA1_for_voice[Density,feeder1] - QSR11_for_voice[Density,feeder1]) * dt

INIT Queue_for_S11_for_voice[Density,feeder1] = 0

INFLOWS:

Rate_in_TA1_for_voice[Density,feeder1] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,29) <= Proportion_of_flights_into_TA1[Density,feeder1])

THEN(1)

ELSE(0)

OUTFLOWS:

QSR11_for_voice[Density,feeder1] = IF(TA_Controller_Activity1_in_voice[Density,feeder1] >= 1) OR (Separation1_for_voice[Density,feeder1] > 0)

THEN(0)

ELSE(IF(Queue_for_S11_for_voice[Density,feeder1] > 0) OR (Rate_in_TA1_for_voice[Density,feeder1] > 0))

THEN(1)

ELSE(0))

Queue_for_S12_for_voice[Density,feeder2](t) = Queue_for_S12_for_voice[Density,feeder2](t - dt) + (Rate_in_TA2_for_voice[Density,feeder2] - QSR12_for_voice[Density,feeder2]) * dt

INIT Queue_for_S12_for_voice[Density,feeder2] = 0

INFLOWS:

Rate_in_TA2_for_voice[Density,feeder2] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,11) <= Proportion_of_flights_into_TA2[Density,feeder2])

THEN(1)

ELSE(0)

OUTFLOWS:

QSR12_for_voice[Density,feeder2] = IF(TA_Controller_Activity2_in_voice[Density,feeder2] >= 1) OR (Separation2_for_voice[Density,feeder2] > 0)

THEN(0)

ELSE(IF(Queue_for_S12_for_voice[Density,feeder2] > 0) OR (Rate_in_TA2_for_voice[Density,feeder2] > 0))

THEN(1)

ELSE(0))

Queue_for_S21_for_voice[Density,feeder3](t) = Queue_for_S21_for_voice[Density,feeder3](t - dt) + (Rate_in_TA3_for_voice[Density,feeder3] - QSR21_for_voice[Density,feeder3]) * dt

```

INIT Queue_for_S21_for_voice[Density,feeder3] = 0
INFLOWS:
Rate_in_TA3_for_voice[Density,feeder3] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,111) <= Proportion_of_flights_into_TA3[Density,feeder3])
THEN(1)
ELSE(0)
OUTFLOWS:
QSR21_for_voice[Density,feeder3] = IF(TA_Controller_Activity3_in_voice[Density,feeder3] >= 1)
OR (Separation3_for_voice[Density,feeder3] > 0)
THEN(0)
ELSE(IF(Queue_for_S21_for_voice[Density,feeder3] > 0) OR (Rate_in_TA3_for_voice[Density,feeder3] > 0))
THEN(1)
ELSE(0))
Queue_for_S22_for_voice[Density,feeder4](t) = Queue_for_S22_for_voice[Density,feeder4](t - dt) +
(Rate_in_TA4_for_voice[Density,feeder4] - QSR22_for_voice[Density,feeder4]) * dt
INIT Queue_for_S22_for_voice[Density,feeder4] = 0
INFLOWS:
Rate_in_TA4_for_voice[Density,feeder4] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,37) <= Proportion_of_flights_into_TA4[Density,feeder4])
THEN(1)
ELSE(0)
OUTFLOWS:
QSR22_for_voice[Density,feeder4] = IF(TA_Controller_Activity4_in_voice[Density,feeder4] >= 1)
OR (Separation4_for_voice[Density,feeder4] > 0)
THEN(0)
ELSE(IF(Queue_for_S22_for_voice[Density,feeder4] > 0) OR (Rate_in_TA4_for_voice[Density,feeder4] > 0))
THEN(1)
ELSE(0))
Separation1_for_voice[Density,feeder1](t) = Separation1_for_voice[Density,feeder1](t - dt) +
(QSR11_for_voice[Density,feeder1] - Separation_Rate1_for_voice[Density,feeder1]) * dt
INIT Separation1_for_voice[Density,feeder1] = 0
INFLOWS:
QSR11_for_voice[Density,feeder1] = IF(TA_Controller_Activity1_in_voice[Density,feeder1] >= 1)
OR (Separation1_for_voice[Density,feeder1] > 0)
THEN(0)
ELSE(IF(Queue_for_S11_for_voice[Density,feeder1] > 0) OR (Rate_in_TA1_for_voice[Density,feeder1] > 0))

```

THEN(1)
 ELSE(0))
 OUTFLOWS:
 Separation_Rate1_for_voice[Density,feeder1] = CONVEYOR OUTFLOW

 TRANSIT TIME = Average_Separation_Time_for_voice[Density]
 Separation2_for_voice[Density,feeder2](t) = Separation2_for_voice[Density,feeder2](t - dt) +
 (QSR12_for_voice[Density,feeder2] - Separation_Rate2_for_voice[Density,feeder2]) * dt
 INIT Separation2_for_voice[Density,feeder2] = 0
 INFLOWS:
 QSR12_for_voice[Density,feeder2] = IF(TA_Controller_Activity2_in_voice[Density,feeder2] >= 1)
 OR (Separation2_for_voice[Density,feeder2] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S12_for_voice[Density,feeder2] > 0) OR (Rate_in_TA2_for_voice[Density,feeder2] > 0))
 THEN(1)
 ELSE(0))
 OUTFLOWS:
 Separation_Rate2_for_voice[Density,feeder2] = CONVEYOR OUTFLOW

 TRANSIT TIME = Average_Separation_Time_for_voice[Density]
 Separation3_for_voice[Density,feeder3](t) = Separation3_for_voice[Density,feeder3](t - dt) +
 (QSR21_for_voice[Density,feeder3] - Separation_Rate3_for_voice[Density,feeder3]) * dt
 INIT Separation3_for_voice[Density,feeder3] = 0
 INFLOWS:
 QSR21_for_voice[Density,feeder3] = IF(TA_Controller_Activity3_in_voice[Density,feeder3] >= 1)
 OR (Separation3_for_voice[Density,feeder3] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S21_for_voice[Density,feeder3] > 0) OR (Rate_in_TA3_for_voice[Density,feeder3] > 0))
 THEN(1)
 ELSE(0))
 OUTFLOWS:
 Separation_Rate3_for_voice[Density,feeder3] = CONVEYOR OUTFLOW

 TRANSIT TIME = Average_Separation_Time_for_voice[Density]
 Separation4_for_voice[Density,feeder4](t) = Separation4_for_voice[Density,feeder4](t - dt) +
 (QSR22_for_voice[Density,feeder4] - Separation_Rate4_for_voice[Density,feeder4]) * dt
 INIT Separation4_for_voice[Density,feeder4] = 0

INFLOWS:

QSR22_for_voice[Density,feeder4] = IF(TA_Controller_Activity4_in_voice[Density,feeder4] >= 1)
OR (Separation4_for_voice[Density,feeder4] > 0)

THEN(0)

ELSE(IF(Queue_for_S22_for_voice[Density,feeder4] > 0) OR (Rate_in_TA4_for_voice[Density,feeder4] > 0))

THEN(1)

ELSE(0))

OUTFLOWS:

Separation_Rate4_for_voice[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_voice[Density]

Sep_Conflict1[Density,feeder1](t) = Sep_Conflict1[Density,feeder1](t - dt) +
(Sep_Conflict_ratein1[Density,feeder1]) * dt

INIT Sep_Conflict1[Density,feeder1] = 0

INFLOWS:

Sep_Conflict_ratein1[Density,feeder1] = IF(Rate_in_TA1_for_voice[Density,feeder1] > 0) AND
(Separation1_for_voice[Density,feeder1] > 0)

THEN(1)

ELSE(0)

Sep_Conflict2[Density,feeder2](t) = Sep_Conflict2[Density,feeder2](t - dt) +
(Sep_Conflict_ratein2[Density,feeder2]) * dt

INIT Sep_Conflict2[Density,feeder2] = 0

INFLOWS:

Sep_Conflict_ratein2[Density,feeder2] = IF(Rate_in_TA2_for_voice[Density,feeder2] > 0) AND
(Separation2_for_voice[Density,feeder2] > 0)

THEN(1)

ELSE(0)

Sep_Conflict3[Density,feeder3](t) = Sep_Conflict3[Density,feeder3](t - dt) +
(Sep_Conflict_ratein3[Density,feeder3]) * dt

INIT Sep_Conflict3[Density,feeder3] = 0

INFLOWS:

Sep_Conflict_ratein3[Density,feeder3] = IF(Rate_in_TA3_for_voice[Density,feeder3] > 0) AND
(Separation3_for_voice[Density,feeder3] > 0)

THEN(1)

ELSE(0)

Sep_Conflict4[Density,feeder4](t) = Sep_Conflict4[Density,feeder4](t - dt) +
(Sep_Conflict_ratein4[Density,feeder4]) * dt

INIT Sep_Conflict4[Density,feeder4] = 0

INFLOWS:

Sep_Conflict_ratein4[Density,feeder4] = IF(Rate_in_TA4_for_voice[Density,feeder4] > 0) AND
(Separation4_for_voice[Density,feeder4] > 0)

THEN(1)

ELSE(0)

Terminal_Airspace[High](t) = Terminal_Airspace[High](t - dt) +
(Rate_of_holding__dissipation1_for_voice[High] + Rate_of_holding__dissipation3_for_voice[High]
+ Rate_of_holding_dissipation2_for_voice[High] + Rate_of_holding_dissipation4_for_voice[High] -
AAR_for_voice[High]) * dt

INIT Terminal_Airspace[High] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 8

Terminal_Airspace[Medium](t) = Terminal_Airspace[Medium](t - dt) +
(Rate_of_holding__dissipation1_for_voice[Medium] +
Rate_of_holding__dissipation3_for_voice[Medium] +
Rate_of_holding_dissipation2_for_voice[Medium] +
Rate_of_holding_dissipation4_for_voice[Medium] - AAR_for_voice[Medium]) * dt

INIT Terminal_Airspace[Medium] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 4

Terminal_Airspace[Low](t) = Terminal_Airspace[Low](t - dt) +
(Rate_of_holding__dissipation1_for_voice[Low] + Rate_of_holding__dissipation3_for_voice[Low]
+ Rate_of_holding_dissipation2_for_voice[Low] + Rate_of_holding_dissipation4_for_voice[Low] -
AAR_for_voice[Low]) * dt

INIT Terminal_Airspace[Low] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 2

INFLOWS:

Rate_of_holding__dissipation1_for_voice[Density] = QUEUE OUTFLOW

Rate_of_holding__dissipation3_for_voice[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation2_for_voice[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation4_for_voice[Density] = QUEUE OUTFLOW

OUTFLOWS:

AAR_for_voice[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Terminal_Airspace_Time_in_voice[Density]

Total_acft_in_terminal_in_voice[Density](t) = Total_acft_in_terminal_in_voice[Density](t - dt) +
(terminal_acft_rate_in_voice[Density]) * dt

INIT Total_acft_in_terminal_in_voice[Density] = 0

INFLOWS:

terminal_acft_rate_in_voice[Density] = AAR_for_voice[Density]

Total_aircraft_in_terminal_airspace_in_voice[Density](t) =

Total_aircraft_in_terminal_airspace_in_voice[Density](t - dt) +
(rate_in_terminal_airspace_in_voice[Density]) * dt

INIT Total_aircraft_in_terminal_airspace_in_voice[Density] = 0

INFLOWS:

rate_in_terminal_airspace_in_voice[Density] = Rate_of_holding__dissipation1_for_voice[Density]
+ Rate_of_holding_dissipation2_for_voice[Density] +

Rate_of_holding__dissipation3_for_voice[Density] + Rate_of_holding_dissipation4_for_voice[Density]

Total_aircraft_in_tracon_airspace_in_voice[Density](t) =

Total_aircraft_in_tracon_airspace_in_voice[Density](t - dt) +
(rate_in_tracon_airspace_in_voice[Density]) * dt

INIT Total_aircraft_in_tracon_airspace_in_voice[Density] = 0

INFLOWS:

rate_in_tracon_airspace_in_voice[Density] = Rate_in_TA1_for_voice[Density,f11] +

Rate_in_TA1_for_voice[Density,f12] + Rate_in_TA2_for_voice[Density,f21] +

Rate_in_TA2_for_voice[Density,f22] + Rate_in_TA3_for_voice[Density,f31] +

Rate_in_TA3_for_voice[Density,f32] + Rate_in_TA4_for_voice[Density,f41] +

Rate_in_TA4_for_voice[Density,f42]

Total_Conflict_time_for_fc3_in_voice[Density,feeder3](t) =

Total_Conflict_time_for_fc3_in_voice[Density,feeder3](t - dt) +
(Conflict_time_rate_for_fc21_in_voice[Density,feeder3]) * dt

INIT Total_Conflict_time_for_fc3_in_voice[Density,feeder3] = 0

INFLOWS:

Conflict_time_rate_for_fc21_in_voice[Density,feeder3] = Conflict_rate_for_fc3_in_voice[Density,feeder3]*Average_time_per_conflict_by_voice_non_uret

Total_conflict_time_for_fc4_in_voice[Density,feeder4](t) =
Total_conflict_time_for_fc4_in_voice[Density,feeder4](t - dt) +
(Conflict_time_rate_for_fc4_in_voice[Density,feeder4]) * dt

INIT Total_conflict_time_for_fc4_in_voice[Density,feeder4] = 0

INFLOWS:

Conflict_time_rate_for_fc4_in_voice[Density,feeder4] = Conflict_rate_for_fc4_in_voice[Density,feeder4]*Average_time_per_conflict_by_voice_non_uret

Total_conflict_time_for_feeder_controller1_in_voice[Density,feeder1](t) =
Total_conflict_time_for_feeder_controller1_in_voice[Density,feeder1](t - dt) +
(Conflict_time_rate_for_feeder_controller1_in_voice[Density,feeder1]) * dt

INIT Total_conflict_time_for_feeder_controller1_in_voice[Density,feeder1] = 0

INFLOWS:

Conflict_time_rate_for_feeder_controller1_in_voice[Density,feeder1] =
Conflict_rate_for_feeder_controller1_in_voice[Density,feeder1]*Average_time_per_conflict_by_voice_non_uret

Total_conflict_time_for_feeder_controller2_in_voice[Density,feeder2](t) =
Total_conflict_time_for_feeder_controller2_in_voice[Density,feeder2](t - dt) +
(Conflict_time_rate_for_feeder_controller2_in_voice[Density,feeder2]) * dt

INIT Total_conflict_time_for_feeder_controller2_in_voice[Density,feeder2] = 0

INFLOWS:

Conflict_time_rate_for_feeder_controller2_in_voice[Density,feeder2] =
Conflict_rate_for_feeder_controller2_in_voice[Density,feeder2]*Average_time_per_conflict_by_voice_non_uret

Total_no_of_conflicts_for_fc3_in_voice[Density,feeder3](t) =
Total_no_of_conflicts_for_fc3_in_voice[Density,feeder3](t - dt) +
(Conflict_rate_for_fc3_in_voice[Density,feeder3]) * dt

INIT Total_no_of_conflicts_for_fc3_in_voice[Density,feeder3] = 0

INFLOWS:

Conflict_rate_for_fc3_in_voice[Density,feeder3] = Sep_Conflict_ratein3[Density,feeder3] +
Mer_Conflict_ratein3[Density,feeder3]

Total_no_of_conflicts_for_fc4_in_voice[Density,feeder4](t) =
Total_no_of_conflicts_for_fc4_in_voice[Density,feeder4](t - dt) +
(Conflict_rate_for_fc4_in_voice[Density,feeder4]) * dt

INIT Total_no_of_conflicts_for_fc4_in_voice[Density,feeder4] = 0

INFLOWS:

Conflict_rate_for_fc4_in_voice[Density,feeder4] = Sep_Conflict_ratein4[Density,feeder4] + Mer_Conflict_ratein4[Density,feeder4]

Total_no_of_conflicts_for_feeder_controller1_in_voice[Density,feeder1](t) = Total_no_of_conflicts_for_feeder_controller1_in_voice[Density,feeder1](t - dt) + (Conflict_rate_for_feeder_controller1_in_voice[Density,feeder1]) * dt
INIT Total_no_of_conflicts_for_feeder_controller1_in_voice[Density,feeder1] = 0

INFLOWS:

Conflict_rate_for_feeder_controller1_in_voice[Density,feeder1] = Sep_Conflict_ratein1[Density,feeder1] + Mer_Conflict_ratein1[Density,feeder1]

Total_no_of_conflicts_for_feeder_controller2_in_voice[Density,feeder2](t) = Total_no_of_conflicts_for_feeder_controller2_in_voice[Density,feeder2](t - dt) + (Conflict_rate_for_feeder_controller2_in_voice[Density,feeder2]) * dt
INIT Total_no_of_conflicts_for_feeder_controller2_in_voice[Density,feeder2] = 0

INFLOWS:

Conflict_rate_for_feeder_controller2_in_voice[Density,feeder2] = Sep_Conflict_ratein2[Density,feeder2] + Mer_Conflict_ratein2[Density,feeder2]

Total_no_of_rvc_for_fc4_in_voice[Density,feeder4](t) = Total_no_of_rvc_for_fc4_in_voice[Density,feeder4](t - dt) + (rvc_rate_for_fc4_in_voice[Density,feeder4]) * dt
INIT Total_no_of_rvc_for_fc4_in_voice[Density,feeder4] = 0

INFLOWS:

rvc_rate_for_fc4_in_voice[Density,feeder4] = Separation_Rate4_for_voice[Density,feeder4]*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_voice) + Rate_in_TA4_for_voice[Density,feeder4]

Total_no_of_rvc_for_feeder_controller1_in_voice[Density,feeder1](t) = Total_no_of_rvc_for_feeder_controller1_in_voice[Density,feeder1](t - dt) + (rvc_rate_for_feeder_controller1_in_voice[Density,feeder1]) * dt
INIT Total_no_of_rvc_for_feeder_controller1_in_voice[Density,feeder1] = 0

INFLOWS:

rvc_rate_for_feeder_controller1_in_voice[Density,feeder1] = Rate_in_TA1_for_voice[Density,feeder1] + (Separation_Rate1_for_voice[Density,feeder1]*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_voice))

Total_no_of_rvc_for_feeder_controller2_in_voice[Density,feeder2](t) = Total_no_of_rvc_for_feeder_controller2_in_voice[Density,feeder2](t - dt) + (rvc_rate_for_feeder_controller2_in_voice[Density,feeder2]) * dt
INIT Total_no_of_rvc_for_feeder_controller2_in_voice[Density,feeder2] = 0

INFLOWS:

rvc_rate_for_feeder_controller2_in_voice[Density,feeder2] = Separation_Rate2_for_voice[Density,feeder2]*(No_of_routine_comm_in_transition_area +

$\text{Extra_voice_comm_due_to_comm_error_in_voice}) + \text{Rate_in_TA2_for_voice}[\text{Density,feeder2}]$
 $\text{Total_no_of_rvc_for_fc3_in_voice}[\text{Density,feeder3}](t) = \text{Total_no_of_rvc_for_fc3_in_voice}[\text{Den-}$
 $\text{sity,feeder3}](t - dt) + (\text{rvc_rate_for_fc3_in_voice}[\text{Density,feeder3}]) * dt$
 $\text{INIT Total_no_of_rvc_for_fc3_in_voice}[\text{Density,feeder3}] = 0$
INFLOWS:
 $\text{rvc_rate_for_fc3_in_voice}[\text{Density,feeder3}] = \text{Rate_in_TA3_for_voice}[\text{Density,feeder3}] +$
 $(\text{Separation_Rate3_for_voice}[\text{Density,feeder3}] * (\text{No_of_routine_comm_in_transition_area} +$
 $\text{Extra_voice_comm_due_to_comm_error_in_voice}))$
 $\text{Total_rvc_time_for_fc3_in_voice}[\text{Density,feeder3}](t) = \text{Total_rvc_time_for_fc3_in_voice}[\text{Den-}$
 $\text{sity,feeder3}](t - dt) + (\text{rvc_time_rate_for_fc3_in_voice}[\text{Density,feeder3}]) * dt$
 $\text{INIT Total_rvc_time_for_fc3_in_voice}[\text{Density,feeder3}] = 0$
INFLOWS:
 $\text{rvc_time_rate_for_fc3_in_voice}[\text{Density,feeder3}] = \text{rvc_rate_for_fc3_in_voice}[\text{Den-}$
 $\text{sity,feeder3}] * \text{Average_time_per_routine_communication_via_voice}$
 $\text{Total_rvc_time_for_fc4_in_voice}[\text{Density,feeder4}](t) = \text{Total_rvc_time_for_fc4_in_voice}[\text{Den-}$
 $\text{sity,feeder4}](t - dt) + (\text{rvc_time_rate_for_fc4_in_voice}[\text{Density,feeder4}]) * dt$
 $\text{INIT Total_rvc_time_for_fc4_in_voice}[\text{Density,feeder4}] = 0$
INFLOWS:
 $\text{rvc_time_rate_for_fc4_in_voice}[\text{Density,feeder4}] = \text{rvc_rate_for_fc4_in_voice}[\text{Den-}$
 $\text{sity,feeder4}] * \text{Average_time_per_routine_communication_via_voice}$
 $\text{Total_rvc_time_for_feeder_controller1_in_voice}[\text{Density,feeder1}](t) =$
 $\text{Total_rvc_time_for_feeder_controller1_in_voice}[\text{Density,feeder1}](t - dt) +$
 $(\text{rvc_time_rate_feeder_controller1_in_voice}[\text{Density,feeder1}]) * dt$
 $\text{INIT Total_rvc_time_for_feeder_controller1_in_voice}[\text{Density,feeder1}] = 0$
INFLOWS:
 $\text{rvc_time_rate_feeder_controller1_in_voice}[\text{Density,feeder1}] =$
 $\text{rvc_rate_for_feeder_controller1_in_voice}[\text{Den-}$
 $\text{sity,feeder1}] * \text{Average_time_per_routine_communication_via_voice}$
 $\text{Total_rvc_time_for_feeder_controller2_in_voice}[\text{Density,feeder2}](t) =$
 $\text{Total_rvc_time_for_feeder_controller2_in_voice}[\text{Density,feeder2}](t - dt) +$
 $(\text{rvc_time_rate_feeder_controller2_in_voice}[\text{Density,feeder2}]) * dt$
 $\text{INIT Total_rvc_time_for_feeder_controller2_in_voice}[\text{Density,feeder2}] = 0$
INFLOWS:
 $\text{rvc_time_rate_feeder_controller2_in_voice}[\text{Density,feeder2}] =$
 $\text{rvc_rate_for_feeder_controller2_in_voice}[\text{Den-}$
 $\text{sity,feeder2}] * \text{Average_time_per_routine_communication_via_voice}$
 $\text{Transition_Airspace1}[\text{Density,feeder1}](t) = \text{Transition_Airspace1}[\text{Density,feeder1}](t - dt) +$
 $(\text{Separation_Rate1_for_voice}[\text{Density,feeder1}] - \text{Rate_out_TA1_for_voice}[\text{Density,feeder1}]) * dt$
 $\text{INIT Transition_Airspace1}[\text{Density,feeder1}] = 0$

INFLOWS:

Separation_Rate1_for_voice[Density,feeder1] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_voice[Density]

OUTFLOWS:

Rate_out_TA1_for_voice[Density,feeder1] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_voice[Density]

Transition_Airspace2[Density,feeder2](t) = Transition_Airspace2[Density,feeder2](t - dt) +
(Separation_Rate2_for_voice[Density,feeder2] - Rate_out_TA2_for_voice[Density,feeder2]) * dt

INIT Transition_Airspace2[Density,feeder2] = 0

INFLOWS:

Separation_Rate2_for_voice[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_voice[Density]

OUTFLOWS:

Rate_out_TA2_for_voice[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_voice[Density]

Transition_Airspace3[Density,feeder3](t) = Transition_Airspace3[Density,feeder3](t - dt) +
(Separation_Rate3_for_voice[Density,feeder3] - Rate_out_TA3_for_voice[Density,feeder3]) * dt

INIT Transition_Airspace3[Density,feeder3] = 0

INFLOWS:

Separation_Rate3_for_voice[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_voice[Density]

OUTFLOWS:

Rate_out_TA3_for_voice[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_voice[Density]

Transition_Airspace4[Density,feeder4](t) = Transition_Airspace4[Density,feeder4](t - dt) +
(Separation_Rate4_for_voice[Density,feeder4] - Rate_out_TA4_for_voice[Density,feeder4]) * dt

INIT Transition_Airspace4[Density,feeder4] = 0

INFLOWS:

Separation_Rate4_for_voice[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_voice[Density]

OUTFLOWS:

Rate_out_TA4_for_voice[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_voice[Density]
 acft_rate_in_terminal_airspace_in_voice[Density] =
 Total_aircraft_in_terminal_airspace_in_voice[Density]*10*60/TIME
 acft_rate_in_tracon_airspace_in_voice[Density] = Total_aircraft_in_tracon_airspace_in_voice[Density]*10*60/TIME
 AMF = 1
 Approach_Speed_of_large_aircraft = 165
 Approach_Speed_of_medium_aircraft = 120
 Approach_Speed_of_small_aircraft = 95
 Arrival_Departure_Separation = 2
 Average_Approach_Speed[Density] =
 Approach_Speed_of_large_aircraft*Proportion_of__large_aircrafts[Density] +
 Approach_Speed_of_medium_aircraft*Proportion_of_medium_aircrafts[Density] +
 Approach_Speed_of_small_aircraft*Proportion_of_small_aircrafts[Density]
 Average_Departure_gap[Density] = (Dep_time_bw_l_l_acft*Proportion_of__large_aircrafts[Density]*Proportion_of__large_aircrafts[Density]) +
 (Dep_time_bw_l_m_acft*Proportion_of__large_aircrafts[Density]*Proportion_of_medium_aircrafts[Density]) +
 (Dep_time_bw_l_s_acft*Proportion_of__large_aircrafts[Density]*Proportion_of_small_aircrafts[Density]) +
 (Dep_time_bw_m_l_acft*Proportion_of_medium_aircrafts[Density]*Proportion_of__large_aircrafts[Density]) +
 (Dep_time_bw_m_m_acft*Proportion_of_medium_aircrafts[Density]*Proportion_of_medium_aircrafts[Density]) +
 (Dep_time_bw_m_s_acft*Proportion_of_medium_aircrafts[Density]*Proportion_of_small_aircrafts[Density]) +
 (Dep_time_bw_s_l_acft*Proportion_of_small_aircrafts[Density]*Proportion_of__large_aircrafts[Density]) +
 (Dep_time_bw_s_m_acft*Proportion_of_small_aircrafts[Density]*Proportion_of_medium_aircrafts[Density]) +
 (Dep_time_bw_s_s_acft*Proportion_of_small_aircrafts[Density]*Proportion_of_small_aircrafts[Density])
 Average_Separation_Time_for_voice[Density] = (Intrail_Separation[Density] +
 ES_in_TA_in_voice[Density])*60*10/Average__Speed[Density]
 Average__Speed[Density] = Speed_of_large_aircraft*Proportion_of__large_aircrafts[Density] +
 Speed_of_medium_aircraft*Proportion_of_medium_aircrafts[Density] +
 Speed_of_small_aircraft*Proportion_of_small_aircrafts[Density]
 Capacity_of_terminal_airspace = 2

$Dep_time_bw_l_l_acft = 90/60$
 $Dep_time_bw_l_m_acft = 90/60$
 $Dep_time_bw_l_s_acft = 120/60$
 $Dep_time_bw_m_l_acft = 60/60$
 $Dep_time_bw_m_m_acft = 90/60$
 $Dep_time_bw_m_s_acft = 90/60$
 $Dep_time_bw_s_l_acft = 60/60$
 $Dep_time_bw_s_m_acft = 60/60$
 $Dep_time_bw_s_s_acft = 60/60$
 $ES_in_TA_in_voice[Density] = 0.000154*acft_rate_in_tracon_airspace_in_voice[Density]*acft_rate_in_tracon_airspace_in_voice[Density]*AMF + 0.4$
 $ES_in_TEA_in_voice[Density] = 0.000154*acft_rate_in_terminal_airspace_in_voice[Density]*acft_rate_in_terminal_airspace_in_voice[Density]*AMF + 0.4$
 $Extra_voice_comm_due_to_comm_error_in_voice =$
 $Percentage_extra_comm_per_comm*No_of_routine_comm_in_transition_area$
 $feeder_controller1_Utilization[Density,feeder1] =$
 $(Total_rcv_time_for_feeder_controller1_in_voice[Density,feeder1] +$
 $Total_conflict_time_for_feeder_controller1_in_voice[Density,feeder1])/(TIME + 1)$
 $feeder_controller2_Utilization[Density,feeder2] =$
 $(Total_rcv_time_for_feeder_controller2_in_voice[Density,feeder2] +$
 $Total_conflict_time_for_feeder_controller2_in_voice[Density,feeder2])/(TIME + 1)$
 $feeder_controller3_Utilization[Density,feeder3] = (Total_rcv_time_for_fc3_in_voice[Density,feeder3] + Total_Conflict_time_for_fc3_in_voice[Density,feeder3])/(TIME + 1)$
 $feeder_controller4_Utilization[Density,feeder4] = (Total_rcv_time_for_fc4_in_voice[Density,feeder4] + Total_conflict_time_for_fc4_in_voice[Density,feeder4])/(TIME + 1)$
 $Free_flow_transition_time[Density] = (TRACON_AREA_DISTANCE/Average_Speed[Density])*60*10$
 $Intrail_Separation[Density] = (Separation_bw_large_and_large*Proportion_of_large_aircrafts[Density]*Proportion_of_large_aircrafts[Density]) +$
 $(Separation_bw_large_and_medium*Proportion_of_large_aircrafts[Density]*Proportion_of_medium_aircrafts[Density]) +$
 $(Separation_bw_large_and_small*Proportion_of_large_aircrafts[Density]*Proportion_of_small_aircrafts[Density]) +$
 $(Separation_bw_medium_and_large*Proportion_of_medium_aircrafts[Density]*Proportion_of_large_aircrafts[Density]) +$
 $(Separation_bw_medium_and_medium*Proportion_of_medium_aircrafts[Density]*Proportion_of_medium_aircrafts[Density]) +$
 $(Separation_bw_medium_and_small*Proportion_of_medium_aircrafts[Density]*Proportion_of_small_aircrafts[Density]) +$

(Separation_bw_small_and_large*Proportion_of_small_aircrafts[Density]*Proportion_of_large_aircrafts[Density]) +
 (Separation_bw_small_and_medium*Proportion_of_small_aircrafts[Density]*Proportion_of_medium_aircrafts[Density]) +
 (Separation_bw_small_and_small*Proportion_of_small_aircrafts[Density]*Proportion_of_small_aircrafts[Density])
 Mean_Terminal_Times_for_voice[Density] = CTMEAN(AAR_for_voice[Density])
 Merging_time_for_voice[Density] = Intrail_Separation[Density] *60*10/Average_Speed[Density]
 No_of_routine_comm_in_transition_area =
 No_of_routine_comm_per_sector_in_transition_area*Number_of_sectors_in_tracon_airspace
 No_of_routine_comm_per_sector_in_transition_area = RANDOM(3,7)
 Number_of_sectors_in_tracon_airspace = 5
 Proportion_of_flights_into_TA1[High,f11] = .8
 Proportion_of_flights_into_TA1[High,f12] = .7
 Proportion_of_flights_into_TA1[Medium,f11] = .8
 Proportion_of_flights_into_TA1[Medium,f12] = .7
 Proportion_of_flights_into_TA1[Low,f11] = .8
 Proportion_of_flights_into_TA1[Low,f12] = .7
 Proportion_of_flights_into_TA2[High,f21] = .6
 Proportion_of_flights_into_TA2[High,f22] = .5
 Proportion_of_flights_into_TA2[Medium,f21] = .6
 Proportion_of_flights_into_TA2[Medium,f22] = .5
 Proportion_of_flights_into_TA2[Low,f21] = 0
 Proportion_of_flights_into_TA2[Low,f22] = 0
 Proportion_of_medium_aircrafts[High] = .2264
 Proportion_of_medium_aircrafts[Medium] = .234
 Proportion_of_medium_aircrafts[Low] = .5018
 Proportion_of_small_aircrafts[High] = .0185
 Proportion_of_small_aircrafts[Medium] = .5285
 Proportion_of_small_aircrafts[Low] = .406
 Proportion_of_large_aircrafts[High] = .7551
 Proportion_of_large_aircrafts[Medium] = .2368
 Proportion_of_large_aircrafts[Low] = .0922
 Runway_Capacity = 1
 Separation_bw_large_and_large = 3
 Separation_bw_large_and_medium = 4
 Separation_bw_large_and_small = 5
 Separation_bw_medium_and_large = 3
 Separation_bw_medium_and_medium = 3

Separation_bw_medium_and_small = 4
 Separation_bw_small_and_large = 3
 Separation_bw_small_and_medium = 3
 Separation_bw_small_and_small = 3
 Speed_of_large_aircraft = 260
 Speed_of_medium_aircraft = 220
 Speed_of_small_aircraft = 140
 TA_Controller_Activity1_in_voice[Density,feeder1] =
 Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area +
 Extra_voice_comm_due_to_comm_error_in_voice)*Transition_Airspace1[Density,feeder1]/
 Transition_Area_Time_in_voice[Density]
 TA_Controller_Activity2_in_voice[Density,feeder2] =
 Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area +
 Extra_voice_comm_due_to_comm_error_in_voice)*Transition_Airspace2[Density,feeder2]/
 Transition_Area_Time_in_voice[Density]
 TA_Controller_Activity3_in_voice[Density,feeder3] =
 Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area +
 Extra_voice_comm_due_to_comm_error_in_voice)*Transition_Airspace3[Density,feeder3]/
 Transition_Area_Time_in_voice[Density]
 TA_Controller_Activity4_in_voice[Density,feeder4] =
 Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area +
 Extra_voice_comm_due_to_comm_error_in_voice)*Transition_Airspace4[Density,feeder4]/
 Transition_Area_Time_in_voice[Density]
 TD[Density] = (Arrival_Departure_Separation*60/(Approach_Speed_of_large_aircraft +
 Approach_Speed_of_medium_aircraft + Approach_Speed_of_small_aircraft/3)) +
 Average_Departure_gap[Density]
 Terminal_Airspace_Distance = 5
 Terminal_Airspace_Time_in_voice[Density] = (Terminal_Airspace_Distance +
 ES_in_TEA_in_voice[Density])*60*10/Average_Approach_Speed[Density]
 Terminal_Times_for_voice[Density] = CYCLETIME(AAR_for_voice[Density])
 TRACON_AREA_DISTANCE = 40
 Transition_Area_Time_in_voice[Density] = Free_flow_transition_time[Density] +
 (No_of_routine_diversions_per_sector*Number_of_sectors_in_tracon_airspace*Diversion_time_per
 _routine_comm_in_voice) +
 (Extra_voice_comm_due_to_comm_error_in_voice*Average_time_per_routine_communication_via
 _voice)

 Terminal_Airspace(Datalink + DSTs(int))
 Holding_Queue1_for_integrated[Density](t) = Holding_Queue1_for_integrated[Density](t - dt) +

(Merging_out_rate1_for_integrated[Density] - Rate_of_holding_dissipation1_in_integrated[Density]) * dt

INIT Holding_Queue1_for_integrated[Density] = 0

INFLOWS:

Merging_out_rate1_for_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_integrated[Density]

OUTFLOWS:

Rate_of_holding_dissipation1_in_integrated[Density] = QUEUE OUTFLOW

Holding_Queue2_for_integrated[Density](t) = Holding_Queue2_for_integrated[Density](t - dt) + (Merging_out_rate2_for_integrated[Density] - Rate_of_holding_dissipation2_in_integrated[Density]) * dt

INIT Holding_Queue2_for_integrated[Density] = 0

INFLOWS:

Merging_out_rate2_for_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_integrated[Density]

OUTFLOWS:

Rate_of_holding_dissipation2_in_integrated[Density] = QUEUE OUTFLOW

Holding_Queue3_for_integrated[Density](t) = Holding_Queue3_for_integrated[Density](t - dt) + (Merging_out_rate3_for_integrated[Density] - Rate_of_holding_dissipation3_in_integrated[Density]) * dt

INIT Holding_Queue3_for_integrated[Density] = 0

INFLOWS:

Merging_out_rate3_for_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_integrated[Density]

OUTFLOWS:

Rate_of_holding_dissipation3_in_integrated[Density] = QUEUE OUTFLOW

Holding_Queue4_for_integrated[Density](t) = Holding_Queue4_for_integrated[Density](t - dt) + (Merging_out_rate4_for_integrated[Density] - Rate_of_holding_dissipation4_in_integrated[Density]) * dt

INIT Holding_Queue4_for_integrated[Density] = 0

INFLOWS:

Merging_out_rate4_for_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_integrated[Density]

OUTFLOWS:

Rate_of_holding_dissipation4_in_integrated[Density] = QUEUE OUTFLOW

Merging1_for_integrated[Density](t) = Merging1_for_integrated[Density](t - dt) +
(QMDR1_for_integrated[Density,feeder1] - Merging_out_rate1_for_integrated[Density]) * dt
INIT Merging1_for_integrated[Density] = 0

INFLOWS:

QMDR1_for_integrated[Density,feeder1] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate1_for_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_integrated[Density]

Merging2_for_integrated[Density](t) = Merging2_for_integrated[Density](t - dt) +
(QMDR2_for_integrated[Density] - Merging_out_rate2_for_integrated[Density]) * dt

INIT Merging2_for_integrated[Density] = 0

INFLOWS:

QMDR2_for_integrated[Density] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate2_for_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_integrated[Density]

Merging3_for_integrated[Density](t) = Merging3_for_integrated[Density](t - dt) +
(QMDR3_for_integrated[Density,feeder3] - Merging_out_rate3_for_integrated[Density]) * dt

INIT Merging3_for_integrated[Density] = 0

INFLOWS:

QMDR3_for_integrated[Density,feeder3] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate3_for_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_integrated[Density]

Merging4_for_integrated[Density](t) = Merging4_for_integrated[Density](t - dt) +
(QMDR4_for_integrated[Density,feeder4] - Merging_out_rate4_for_integrated[Density]) * dt

INIT Merging4_for_integrated[Density] = 0

INFLOWS:

QMDR4_for_integrated[Density,feeder4] = QUEUE OUTFLOW

OUTFLOWS:

Merging_out_rate4_for_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Merging_time_for_integrated[Density]

Queue_for_Merging1_for_integrated[Density,feeder1](t) =

Queue_for_Merging1_for_integrated[Density,feeder1](t - dt) + (Rate_out_TA1_for_integrated[Density,feeder1] - QMDR1_for_integrated[Density,feeder1]) * dt

INIT Queue_for_Merging1_for_integrated[Density,feeder1] = 0

INFLOWS:

Rate_out_TA1_for_integrated[Density,feeder1] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

OUTFLOWS:

QMDR1_for_integrated[Density,feeder1] = QUEUE OUTFLOW

Queue_for_Merging2_for_integrated[Density](t) = Queue_for_Merging2_for_integrated[Density](t - dt) + (Rate_out_TA2_for_integrated[Density,feeder2] - QMDR2_for_integrated[Density]) * dt

INIT Queue_for_Merging2_for_integrated[Density] = 0

INFLOWS:

Rate_out_TA2_for_integrated[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

OUTFLOWS:

QMDR2_for_integrated[Density] = QUEUE OUTFLOW

Queue_for_Merging3_for_integrated[Density,feeder3](t) = Queue_for_Merging3_for_integrated[Density,feeder3](t - dt) + (Rate_out_TA3_for_integrated[Density,feeder3] - QMDR3_for_integrated[Density,feeder3]) * dt

INIT Queue_for_Merging3_for_integrated[Density,feeder3] = 0

INFLOWS:

Rate_out_TA3_for_integrated[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

OUTFLOWS:

QMDR3_for_integrated[Density,feeder3] = QUEUE OUTFLOW

Queue_for_Merging4_for_integrated[Density,feeder4](t) = Queue_for_Merging4_for_integrated[Density,feeder4](t - dt) + (Rate_out_TA4_for_integrated[Density,feeder4] - QMDR4_for_integrated[Density,feeder4]) * dt

INIT Queue_for_Merging4_for_integrated[Density,feeder4] = 0

INFLOWS:

Rate_out_TA4_for_integrated[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

OUTFLOWS:

QMDR4_for_integrated[Density,feeder4] = QUEUE OUTFLOW

Queue_for_S1_for_integrated[Density,feeder1](t) = Queue_for_S1_for_integrated[Density,feeder1](t - dt) + (Rate_in_TA1_for_integrated[Density,feeder1] - QSR1_for_integrated[Density,feeder1]) * dt

INIT Queue_for_S1_for_integrated[Density,feeder1] = 0

INFLOWS:

Rate_in_TA1_for_integrated[Density,feeder1] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,29) <= Proportion_of_flights_into_TA1[Density,feeder1])

THEN(1)

ELSE(0)

OUTFLOWS:

QSR1_for_integrated[Density,feeder1] = IF(TA_Controller_Activity1_in_integrated[Density,feeder1] >= 1) OR (Separation1_for_integrated[Density,feeder1] > 0)

THEN(0)

ELSE(IF(Queue_for_S1_for_integrated[Density,feeder1] > 0) OR

(Rate_in_TA1_for_integrated[Density,feeder1] > 0)

THEN(1)

ELSE(0))

Queue_for_S2_for_integrated[Density,feeder2](t) = Queue_for_S2_for_integrated[Density,feeder2](t - dt) + (Rate_in_TA2_for_integrated[Density,feeder2] - QSR2_for_integrated[Density,feeder2]) * dt

INIT Queue_for_S2_for_integrated[Density,feeder2] = 0

INFLOWS:

Rate_in_TA2_for_integrated[Density,feeder2] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,11) <= Proportion_of_flights_into_TA2[Density,feeder2])

THEN(1)

ELSE(0)

OUTFLOWS:

QSR2_for_integrated[Density,feeder2] = IF(TA_Controller_Activity2_in_integrated[Density,feeder2] >= 1) OR (Separation2_for_integrated[Density,feeder2] > 0)

THEN(0)

ELSE(IF(Queue_for_S2_for_integrated[Density,feeder2] > 0) OR

(Rate_in_TA2_for_integrated[Density,feeder2] > 0)

THEN(1)

ELSE(0))

Queue_for_S3_for_integrated[Density,feeder3](t) = Queue_for_S3_for_integrated[Density,feeder3](t - dt) + (Rate_in_TA3_for_integrated[Density,feeder3] - QSR3_for_integrated[Density,feeder3]) * dt

INIT Queue_for_S3_for_integrated[Density,feeder3] = 0

INFLOWS:

Rate_in_TA3_for_integrated[Density,feeder3] = IF(Acft_Injector[Density] > 0) AND (RANDOM(0,1,111) <= Proportion_of_flights_into_TA3[Density,feeder3])

THEN(1)

ELSE(0)

OUTFLOWS:

QSR3_for_integrated[Density,feeder3] = IF(TA_Controller3_in_integrated[Density,feeder3] >= 1)

OR (Separation3_for_integrated[Density,feeder3] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S3_for_integrated[Density,feeder3] > 0) OR
 (Rate_in_TA3_for_integrated[Density,feeder3] > 0)
 THEN(1)
 ELSE(0))
 Queue_for_S4_for_integrated[Density,feeder4](t) = Queue_for_S4_for_integrated[Density,feeder4](t
 - dt) + (Rate_in_TA4_for_integrated[Density,feeder4] - QSR4_for_integrated[Density,feeder4]) * dt
 INIT Queue_for_S4_for_integrated[Density,feeder4] = 0
 INFLOWS:
 Rate_in_TA4_for_integrated[Density,feeder4] = IF(Acft_Injector[Density] > 0) AND (RAN-
 DOM(0,1,37) <= Proportion_of_flights_into_TA4[Density,feeder4])
 THEN(1)
 ELSE(0)
 OUTFLOWS:
 QSR4_for_integrated[Density,feeder4] = IF(TA_Controller4_in_integrated[Density,feeder4] >= 1)
 OR (Separation4_for_integrated[Density,feeder4] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S4_for_integrated[Density,feeder4] > 0) OR
 (Rate_in_TA4_for_integrated[Density,feeder4] > 0)
 THEN(1)
 ELSE(0))
 Separation1_for_integrated[Density,feeder1](t) = Separation1_for_integrated[Density,feeder1](t - dt)
 + (QSR1_for_integrated[Density,feeder1] - Separation_rate1_for_integrated[Density,feeder1]) * dt
 INIT Separation1_for_integrated[Density,feeder1] = 0
 INFLOWS:
 QSR1_for_integrated[Density,feeder1] = IF(TA_Controller_Activity1_in_integrated[Density,feeder1] >= 1) OR (Separation1_for_integrated[Density,feeder1] > 0)
 THEN(0)
 ELSE(IF(Queue_for_S1_for_integrated[Density,feeder1] > 0) OR
 (Rate_in_TA1_for_integrated[Density,feeder1] > 0)
 THEN(1)
 ELSE(0))
 OUTFLOWS:
 Separation_rate1_for_integrated[Density,feeder1] = CONVEYOR OUTFLOW

 TRANSIT TIME = Average_Separation_Time_for_integrated[Density]
 Separation2_for_integrated[Density,feeder2](t) = Separation2_for_integrated[Density,feeder2](t - dt)
 + (QSR2_for_integrated[Density,feeder2] - Separation_rate2_for_integrated[Density,feeder2]) * dt

INIT Separation2_for_integrated[Density,feeder2] = 0

INFLOWS:

QSR2_for_integrated[Density,feeder2] = IF(TA_Controller_Activity2_in_integrated[Density,feeder2] >= 1) OR (Separation2_for_integrated[Density,feeder2] > 0)

THEN(0)

ELSE(IF(Queue_for_S2_for_integrated[Density,feeder2] > 0) OR

(Rate_in_TA2_for_integrated[Density,feeder2] > 0)

THEN(1)

ELSE(0))

OUTFLOWS:

Separation_rate2_for_integrated[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_integrated[Density]

Separation3_for_integrated[Density,feeder3](t) = Separation3_for_integrated[Density,feeder3](t - dt) + (QSR3_for_integrated[Density,feeder3] - Separation_rate3_for_integrated[Density,feeder3]) * dt

INIT Separation3_for_integrated[Density,feeder3] = 0

INFLOWS:

QSR3_for_integrated[Density,feeder3] = IF(TA_Controller3_in_integrated[Density,feeder3] >= 1)

OR (Separation3_for_integrated[Density,feeder3] > 0)

THEN(0)

ELSE(IF(Queue_for_S3_for_integrated[Density,feeder3] > 0) OR

(Rate_in_TA3_for_integrated[Density,feeder3] > 0)

THEN(1)

ELSE(0))

OUTFLOWS:

Separation_rate3_for_integrated[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_integrated[Density]

Separation4_for_integrated[Density,feeder4](t) = Separation4_for_integrated[Density,feeder4](t - dt) + (QSR4_for_integrated[Density,feeder4] - Separation_rate4_for_integrated[Density,feeder4]) * dt

INIT Separation4_for_integrated[Density,feeder4] = 0

INFLOWS:

QSR4_for_integrated[Density,feeder4] = IF(TA_Controller4_in_integrated[Density,feeder4] >= 1)

OR (Separation4_for_integrated[Density,feeder4] > 0)

THEN(0)

ELSE(IF(Queue_for_S4_for_integrated[Density,feeder4] > 0) OR

(Rate_in_TA4_for_integrated[Density,feeder4] > 0)

THEN(1)

ELSE(0))

OUTFLOWS:

Separation_rate4_for_integrated[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_integrated[Density]

Terminal_Airspace_for_integrated[High](t) = Terminal_Airspace_for_integrated[High](t - dt) +
(Rate_of_holding_dissipation1_in_integrated[High] +
Rate_of_holding_dissipation2_in_integrated[High] +
Rate_of_holding_dissipation3_in_integrated[High] +
Rate_of_holding_dissipation4_in_integrated[High] - AAR_for_integrated[High]) * dt
INIT Terminal_Airspace_for_integrated[High] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 8

Terminal_Airspace_for_integrated[Medium](t) = Terminal_Airspace_for_integrated[Medium](t - dt)
+ (Rate_of_holding_dissipation1_in_integrated[Medium] +
Rate_of_holding_dissipation2_in_integrated[Medium] +
Rate_of_holding_dissipation3_in_integrated[Medium] +
Rate_of_holding_dissipation4_in_integrated[Medium] - AAR_for_integrated[Medium]) * dt
INIT Terminal_Airspace_for_integrated[Medium] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 4

Terminal_Airspace_for_integrated[Low](t) = Terminal_Airspace_for_integrated[Low](t - dt) +
(Rate_of_holding_dissipation1_in_integrated[Low] +
Rate_of_holding_dissipation2_in_integrated[Low] +
Rate_of_holding_dissipation3_in_integrated[Low] +
Rate_of_holding_dissipation4_in_integrated[Low] - AAR_for_integrated[Low]) * dt
INIT Terminal_Airspace_for_integrated[Low] = 0

TRANSIT TIME = varies

INFLOW LIMIT = INF

CAPACITY = 2

INFLOWS:

Rate_of_holding_dissipation1_in_integrated[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation2_in_integrated[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation3_in_integrated[Density] = QUEUE OUTFLOW

Rate_of_holding_dissipation4_in_integrated[Density] = QUEUE OUTFLOW

OUTFLOWS:

AAR_for_integrated[Density] = CONVEYOR OUTFLOW

TRANSIT TIME = Terminal_Airspace_Time_in_integrated[Density]

Total_aircraft_in_terminal_airspace_in_integrated[Density](t) =

Total_aircraft_in_terminal_airspace_in_integrated[Density](t - dt) +

(rate_in_terminal_airspace_in_integrated[Density]) * dt

INIT Total_aircraft_in_terminal_airspace_in_integrated[Density] = 0

INFLOWS:

rate_in_terminal_airspace_in_integrated[Density] =

Rate_of_holding_dissipation1_in_integrated[Density] +

Rate_of_holding_dissipation2_in_integrated[Density] +

Rate_of_holding_dissipation3_in_integrated[Density] +

Rate_of_holding_dissipation4_in_integrated[Density]

Total_aircraft_in_tracon_airspace_in_integrated[Density](t) =

Total_aircraft_in_tracon_airspace_in_integrated[Density](t - dt) +

(rate_in_tracon_airspace_in_integrated[Density]) * dt

INIT Total_aircraft_in_tracon_airspace_in_integrated[Density] = 0

INFLOWS:

rate_in_tracon_airspace_in_integrated[Density] = Rate_in_TA1_for_integrated[Density,f11] +

Rate_in_TA1_for_integrated[Density,f12] + Rate_in_TA2_for_integrated[Density,f21] +

Rate_in_TA2_for_integrated[Density,f22] + Rate_in_TA3_for_integrated[Density,f31] +

Rate_in_TA3_for_integrated[Density,f32] + Rate_in_TA4_for_integrated[Density,f41] +

Rate_in_TA4_for_integrated[Density,f42]

Transition_Airspace1_for_integrated[Density,feeder1](t) =

Transition_Airspace1_for_integrated[Density,feeder1](t - dt) +

(Separation_rate1_for_integrated[Density,feeder1] - Rate_out_TA1_for_integrated[Density,feeder1]) * dt

INIT Transition_Airspace1_for_integrated[Density,feeder1] = 0

INFLOWS:

Separation_rate1_for_integrated[Density,feeder1] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_integrated[Density]

OUTFLOWS:

Rate_out_TA1_for_integrated[Density,feeder1] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

Transition_Airspace2_for_integrated[Density,feeder2](t) =

Transition_Airspace2_for_integrated[Density,feeder2](t - dt) +

(Separation_rate2_for_integrated[Density,feeder2] - Rate_out_TA2_for_integrated[Density,feeder2]) * dt

INIT Transition_Airspace2_for_integrated[Density,feeder2] = 0

INFLOWS:

Separation_rate2_for_integrated[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_integrated[Density]

OUTFLOWS:

Rate_out_TA2_for_integrated[Density,feeder2] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

Transition_Airspace3_for_integrated[Density,feeder3](t) =

Transition_Airspace3_for_integrated[Density,feeder3](t - dt) +

(Separation_rate3_for_integrated[Density,feeder3] - Rate_out_TA3_for_integrated[Density,feeder3]) * dt

INIT Transition_Airspace3_for_integrated[Density,feeder3] = 0

INFLOWS:

Separation_rate3_for_integrated[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_integrated[Density]

OUTFLOWS:

Rate_out_TA3_for_integrated[Density,feeder3] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

Transition_Airspace4_for_integrated[Density,feeder4](t) =

Transition_Airspace4_for_integrated[Density,feeder4](t - dt) +

(Separation_rate4_for_integrated[Density,feeder4] - Rate_out_TA4_for_integrated[Density,feeder4]) * dt

INIT Transition_Airspace4_for_integrated[Density,feeder4] = 0

INFLOWS:

Separation_rate4_for_integrated[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Average_Separation_Time_for_integrated[Density]

OUTFLOWS:

Rate_out_TA4_for_integrated[Density,feeder4] = CONVEYOR OUTFLOW

TRANSIT TIME = Transition_Area_Time_in_datalink[Density]

acft_rate_in_terminal_airpace_in_integrated[Density] =

Total_aircraft_in_terminal_airpace_in_integrated[Density]*10*60/TIME

acft_rate_in_tracon_airpace_in_integrated[Density] =

Total_aircraft_in_tracon_airpace_in_integrated[Density]*60*10/TIME

Average_Separation_Time_for_integrated[Density] = (Intrail_Separation[Density] +

ES_in_TA_in_integrated[Density])*60*10/Average_Speed[Density]

DR_due_to_TMA_in_integrated[Density] = 0.65*acft_rate_in_tracon_airpace_in_integrated[Density]

ES_in_TA_in_integrated[Density] = 0.000154*acft_rate_in_tracon_airpace_in_integrated[Density]*acft_rate_in_tracon_airpace_in_integrated[Density]*AMF + 0.4 -

(DR_due_to_TMA_in_integrated[Density]*Average_Speed[Density])/3600)

ES_in_TEA_in_integrated[Density] =

0.0000933*acft_rate_in_terminal_airpace_in_integrated[Density]*acft_rate_in_terminal_airpace_in_integrated[Density]*AMF*(1 - ADF)/(1 - 0.9) + 0.4

Mean_Terminal_Times_for_integrated[Density] = CTMEAN(AAR_for_integrated[Density])

Merging_time_for_integrated[Density] = Merging_time_for_datalink[Density]

TA_Controller3_in_integrated[Density,feeder3] = IF(RANDOM(0,1) <=

Equipage_level_for_aircrafts)

THEN(Transition_Airspace3_for_integrated[Density,feeder3]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice +

Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink - Average_time_per_routine_communication_via_voice))) +

(Extra_voice_comm_due_to_comm_error_in_datalink

*Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])

ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink)

*Transition_Airspace3_for_integrated[Density,feeder3]/Transition_Area_Time_in_datalink[Density])

TA_Controller4_in_integrated[Density,feeder4] = IF(RANDOM(0,1) <=

Equipage_level_for_aircrafts)

THEN(Transition_Airspace4_for_integrated[Density,feeder4]*((No_of_routine_comm_in_transition

```

_area*(Average_time_per_routine_communication_via_voice +
Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink -
Average_time_per_routine_communication_via_voice))) +
(Extra_voice_comm_due_to_comm_error_in_datalink
*Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])
ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink)
*Transition_Airspace4_for_integrated[Density,feeder4]/Transition_Area_Time_in_datalink[Density])
TA_Controller_Activity1_in_integrated[Density,feeder1] = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts)
THEN(Transition_Airspace1_for_integrated[Density,feeder1]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice +
Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink -
Average_time_per_routine_communication_via_voice))) +
(Extra_voice_comm_due_to_comm_error_in_datalink
*Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])
ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink)
*Transition_Airspace1_for_integrated[Density,feeder1]/Transition_Area_Time_in_datalink[Density])
TA_Controller_Activity2_in_integrated[Density,feeder2] = IF(RANDOM(0,1) <=
Equipage_level_for_aircrafts)
THEN(Transition_Airspace2_for_integrated[Density,feeder2]*((No_of_routine_comm_in_transition_area*(Average_time_per_routine_communication_via_voice +
Datalink_Proportion_of_msgs*(Average_time_per_routine_communication_via_datalink -
Average_time_per_routine_communication_via_voice))) +
(Extra_voice_comm_due_to_comm_error_in_datalink
*Average_time_per_routine_communication_via_voice))/Transition_Area_Time_in_datalink[Density])
ELSE(Average_time_per_routine_communication_via_voice*(No_of_routine_comm_in_transition_area + Extra_voice_comm_due_to_comm_error_in_datalink)
*Transition_Airspace2_for_integrated[Density,feeder2]/Transition_Area_Time_in_datalink[Density])
Terminal_Airspace_Time_in_integrated[Density] = (Terminal_Airspace_Distance +
ES_in_TEA_in_integrated[Density])*60*10/Average_Approach_Speed[Density]
Terminal_Times_for_integrated[Density] = CYCLETIME(AAR_for_integrated[Density])

```

terminal_time_difference_in_integrated[Density] = Mean_Terminal_Times_for_voice[Density] -
Mean_Terminal_Times_for_integrated[Density]

APPENDIX B Macroscopic Model Input Equations

Airline Operational Benefits

$$\text{Airline_Operational_Benefit_in_datalink_only}(t) = \text{Airline_Operational_Benefit_in_datalink_only}(t - dt) + (\text{Airline_Operational_Benefit_per_year_in_datalink}) * dt$$
$$\text{INIT Airline_Operational_Benefit_in_datalink_only} = 0$$

INFLOWS:

$$\text{Airline_Operational_Benefit_per_year_in_datalink} = ((\text{Base_year_traffic_over_NAS} * (1 + \text{Traffic_Growth} * (\text{Yr} + \text{TIME})) * \text{Cash_saved_per_flight_for_datalink}) / ((1 + \text{Interest_rate})^{(\text{Yr} + \text{TIME}))})$$
$$\text{Airline_Operational_Benefit_non_integrated}(t) = \text{Airline_Operational_Benefit_non_integrated}(t - dt) + (\text{Airline_operational_benefit_per_year_non_integrated}) * dt$$
$$\text{INIT Airline_Operational_Benefit_non_integrated} = 0$$

INFLOWS:

$$\text{Airline_operational_benefit_per_year_non_integrated} = ((\text{Base_year_traffic_over_NAS} * (1 + \text{Traffic_Growth} * (\text{Yr} + \text{TIME})) * \text{Cash_saved_per_flight_in_non_integrated}) / ((1 + \text{Interest_rate})^{(\text{Yr} + \text{TIME}))})$$
$$\text{Airline_operational_benefit_integrated}(t) = \text{Airline_operational_benefit_integrated}(t - dt) + (\text{Airline_operational_benefit_per_year_integrated}) * dt$$
$$\text{INIT Airline_operational_benefit_integrated} = 0$$

INFLOWS:

$$\text{Airline_operational_benefit_per_year_integrated} = ((\text{Base_year_traffic_over_NAS} * (1 + \text{Traffic_Growth} * (\text{Yr} + \text{TIME})) * \text{Cash_saved_per_flight_in_integrated}) / ((1 + \text{Interest_rate})^{(\text{Yr} + \text{TIME}))})$$

$$\text{Equipage_level_for_CPDLC_Build_I}(t) = \text{Equipage_level_for_CPDLC_Build_I}(t - dt) + (\text{Equipage_rate_for_CPDLC_Build_I}) * dt$$

INIT Equipage_level_for_CPDLC_Build_I = 0

INFLOWS:

$$\text{Equipage_rate_for_CPDLC_Build_I} =$$

$$\text{Equipping_rate_for_CPDLC_Build_I} * \text{CPDLC_Build_I_Switch}$$

$$\text{Equipage_level_for_CPDLC_Build_IA}(t) = \text{Equipage_level_for_CPDLC_Build_IA}(t - dt) + (\text{Equipage_rate_for_CPDLC_Build_IA}) * dt$$

INIT Equipage_level_for_CPDLC_Build_IA = 0

INFLOWS:

$$\text{Equipage_rate_for_CPDLC_Build_IA} =$$

$$\text{CPDLC_Build_IA_Switch} * \text{Equipping_rate_for_CPDLC_Build_IA}$$

$$\text{Equipage_level_for_CPDLC_Build_II}(t) = \text{Equipage_level_for_CPDLC_Build_II}(t - dt) + (\text{Equipage_rate_for_CPDLC_Build_II}) * dt$$

INIT Equipage_level_for_CPDLC_Build_II = 0

INFLOWS:

$$\text{Equipage_rate_for_CPDLC_Build_II} =$$

$$\text{CPDLC_Build_II_Switch} * \text{Equipping_rate_for_CPDLC_Build_II}$$

$$\text{Equipage_level_for_pFast}(t) = \text{Equipage_level_for_pFast}(t - dt) + (\text{Equipping_rate_for_pFast}) * dt$$

INIT Equipage_level_for_pFast = 0

INFLOWS:

$$\text{Equipping_rate_for_pFast} = \text{Equipage_rate_for_pFast} * \text{pFast_switch}$$

$$\text{Equipage_level_for_Tma}(t) = \text{Equipage_level_for_Tma}(t - dt) + (\text{Equipping_rate_for_Tma}) * dt$$

INIT Equipage_level_for_Tma = 0

INFLOWS:

$$\text{Equipping_rate_for_Tma} = \text{Equipage_rate_for_Tma} * \text{Tma_switch}$$

$$\text{Equipage_level_for_Uret}(t) = \text{Equipage_level_for_Uret}(t - dt) + (\text{Equipping_rate_for_uret}) * dt$$

INIT Equipage_level_for_Uret = 0

INFLOWS:

Equipping_rate_for_uret = Uret_Switch*Equipage_rate_of_uret
 Arrival_Traffic_volume_per_day_per_airport[Density] =
 Base_year_arrival_traffic_per_day_per_airport[Density]*((1 + Traffic_Growth)^(TIME + Yr))
 Base_year_arrival_traffic_per_day_per_airport[low] = 8000
 Base_year_arrival_traffic_per_day_per_airport[medium] = 15000
 Base_year_arrival_traffic_per_day_per_airport[high] = 25000
 Base_year_departure_traffic_per_day_per_airport[low] = 3000
 Base_year_departure_traffic_per_day_per_airport[medium] = 5000
 Base_year_departure_traffic_per_day_per_airport[high] = 10000
 Base_year_traffic_over_NAS = Initial_No_of_aircrafts*No_of_flights_per_aircraft_per_year
 Base_Year = 2002
 Cash_saved_per_flight_for_datalink = Savings_per_flight_for_datalink*DOC_per_minute
 Cash_saved_per_flight_in_integrated = Savings_per_flight_for_integrated*DOC_per_minute
 Cash_saved_per_flight_in_non_integrated =
 Savings_per_flight_for_non_integrated*DOC_per_minute
 CPDLC_Build_IA_and_integrated_uret_savings_per_enroute_sector[Density] = { Place right hand
 side of equation here... }
 CPDLC_Build_IA_and_non_integrated_uret_savings_per_enroute_sector[low] =
 Equipage_level_for_flights*Traffic_density_per_day_for_medium_density_sector
 CPDLC_Build_IA_and_non_integrated_uret_savings_per_enroute_sector[medi =
 Traffic_density_per_day_for_medium_density_sector/Equipage_level_for_flights
 CPDLC_Build_IA_and_non_integrated_uret_savings_per_enroute_sector[high =
 Equipage_level_for_flights/Traffic_density_per_day_for_medium_density_sector
 CPDLC_Build_IA_Savings_per_departure[Density] = TIME
 CPDLC_Build_IA_savings_per_enroute_sector[Density] = TIME
 CPDLC_Build_IA_saving_per_arrival[Density] = TIME
 CPDLC_Build_IA_Switch = IF(Year_of_simulation >=
 Yr_of_implementation_of_CPDLC_Build_IA)
 THEN(1)
 ELSE(0)
 CPDLC_Build_IA_and_non_integrated_pfast_saving_per_arrival[Density] = TIME
 CPDLC_Build_II_and_integrated_uret_savings_per_enroute_sector[Density] = { Place right hand
 side of equation here... }
 CPDLC_Build_II_and_non_integrated_pfast_saving_per_arrival[Density] = TIME
 CPDLC_Build_II_and_non_integrated_uret_savings_per_enroute_sector[low] =
 Equipage_level_for_flights*Traffic_density_per_day_for_medium_density_sector
 CPDLC_Build_II_and_non_integrated_uret_savings_per_enroute_sector[medi =
 Equipage_level_for_flights*Traffic_density_per_day_for_medium_density_sector
 CPDLC_Build_II_and_non_integrated_uret_savings_per_enroute_sector[high =

Equipage_level_for_flights*Traffic_density_per_day_for_medium_density_sector
 CPDLC_Build_II_Savings_per_departure[Density] = TIME
 CPDLC_Build_II_savings_per_enroute_sector[Density] = TIME
 CPDLC_Build_II_saving_per_arrival[Density] = TIME
 CPDLC_Build_II_Switch = IF(Year_of_simulation >= Yr_of_implementation_of_CPDLC_Build_II)
 THEN(1)
 ELSE(0)
 CPDLC_Build_I_and_integrated_uret_savings_per_enroute_sector[Density] = { Place right hand
 side of equation here... }
 CPDLC_Build_I_and_non_integrated_pfast_saving_arrival[Density] = TIME
 CPDLC_Build_I_and_non_integrated_uret_savings_per_enroute_sector[low] =
 Traffic_density_per_day
 CPDLC_Build_I_and_non_integrated_uret_savings_per_enroute_sector[mediu =
 Traffic_density_per_day
 CPDLC_Build_I_and_non_integrated_uret_savings_per_enroute_sector[high] =
 Traffic_density_per_day
 CPDLC_Build_I_Savings_per_departure[Density] = TIME
 CPDLC_Build_I_savings_per_enroute_sector[Density] = TIME
 CPDLC_Build_I_saving_per_arrival[Density] = TIME
 CPDLC_Build_I_Switch = IF(Year_of_simulation >= Yr_of_implementation_of_CPDLC_Build_I)
 THEN(1)
 ELSE(0)
 Departure_traffic_volume_per_day_per_airport[Density] =
 Base_year_departure_traffic_per_day_per_airport[Density]*((1 + Traffic_Growth)^(TIME + Yr))
 DOC_per_minute = 25
 Enroute_saving_II_per_flight_for_integrated =
 MAX(No_of_enroute_sectors_having_CPDLC_Build_I*(1 - No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC),0)*(CPDLC_Build_I_savings_per_enroute_sector[low]*Prop
 ortion_of_low_density_sectors +
 CPDLC_Build_I_savings_per_enroute_sector[medium]*Proportion_of__medium_density_sectors +
 CPDLC_Build_I_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors) +
 MAX(No_of_enroute_sectors_having_CPDLC_Build_IA*(1 - No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC),0)*(CPDLC_Build_IA_savings_per_enroute_sector[low]*Pr
 ortion_of_low_density_sectors +
 CPDLC_Build_IA_savings_per_enroute_sector[medium]*Proportion_of__medium_density_sectors
 + CPDLC_Build_IA_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors) +
 MAX(No_of_enroute_sectors_having_CPDLC_Build_II*(1 - No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC),0)*(CPDLC_Build_II_savings_per_enroute_sector[low]*Pro

portion_of_low_density_sectors +
 CPDLC_Build_II_savings_per_enroute_sector[medium]*Proportion_of__medium_density_sectors
 + CPDLC_Build_II_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors) +
 MAX(No_of_sectors_having_Uret -
 Total_no_of_sectors_having_CPDLC,0)*(Uret_integrated_savings_per_enroute_sector[low]*Propor
 tion_of_low_density_sectors +
 Uret_integrated_savings_per_enroute_sector[medium]*Proportion_of__medium_density_sectors +
 Uret_integrated_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors)
 Enroute_saving_II_per_flight_for_non_integrated =
 MAX(No_of_enroute_sectors_having_CPDLC_Build_I*(1 - No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC),0)*(CPDLC_Build_I_savings_per_enroute_sector[low]*Prop
 ortion_of_low_density_sectors +
 CPDLC_Build_I_savings_per_enroute_sector[medium]*Proportion_of__medium_density_sectors +
 CPDLC_Build_I_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors) +
 MAX(No_of_enroute_sectors_having_CPDLC_Build_IA*(1 - No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC),0)*(CPDLC_Build_IA_savings_per_enroute_sector[low]*Pr
 oportion_of_low_density_sectors +
 CPDLC_Build_IA_savings_per_enroute_sector[medium]*Proportion_of__medium_density_sectors
 + CPDLC_Build_IA_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors) +
 MAX(No_of_enroute_sectors_having_CPDLC_Build_II*(1 - No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC),0)*(CPDLC_Build_II_savings_per_enroute_sector[low]*Pro
 portion_of_low_density_sectors +
 CPDLC_Build_II_savings_per_enroute_sector[medium]*Proportion_of__medium_density_sectors
 + CPDLC_Build_II_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors) +
 MAX(No_of_sectors_having_Uret -
 Total_no_of_sectors_having_CPDLC,0)*(Uret_non_integrated_savings_per_enroute_sector[low]*Pr
 oportion_of_low_density_sectors +
 Uret_non_integrated_savings_per_enroute_sector[medium]*Proportion_of__medium_density_secto
 rs + Uret_non_integrated_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors)
 Enroute_saving_I_per_flight_for_integrated =
 MIN(No_of_enroute_sectors_having_CPDLC_Build_I*No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC,No_of_enroute_sectors_having_CPDLC_Build_I)*(CPDLC_
 Build_I_and_integrated_uret_savings_per_enroute_sector[low]*Proportion_of_low_density_sectors
 +
 CPDLC_Build_I_and_integrated_uret_savings_per_enroute_sector[medium]*Proportion_of__mediu
 m_density_sectors +
 CPDLC_Build_I_and_integrated_uret_savings_per_enroute_sector[high]*Proportion_of_high_densi
 ty_sectors) + MIN(No_of_enroute_sectors_having_CPDLC_Build_IA*No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC,No_of_enroute_sectors_having_CPDLC_Build_IA)*(CPDLC

_Build_IA_and_integrated_uret_savings_per_enroute_sector[low]*Proportion_of_low_density_sect
 ors +
 CPDLC_Build_IA_and_integrated_uret_savings_per_enroute_sector[medium]*Proportion_of__med
 ium_density_sectors +
 CPDLC_Build_IA_and_integrated_uret_savings_per_enroute_sector[high]*Proportion_of_high_den
 sity_sectors) +
 MIN(No_of_enroute_sectors_having_CPDLC_Build_II*No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC,No_of_enroute_sectors_having_CPDLC_Build_II)*(CPDLC_
 Build_II_and_integrated_uret_savings_per_enroute_sector[low]*Proportion_of_low_density_sectors
 +
 CPDLC_Build_II_and_integrated_uret_savings_per_enroute_sector[medium]*Proportion_of__medi
 um_density_sectors +
 CPDLC_Build_II_and_integrated_uret_savings_per_enroute_sector[high]*Proportion_of_high_dens
 ity_sectors)
 Enroute_Saving_I_per_flight_for_non_integrated =
 MIN(No_of_enroute_sectors_having_CPDLC_Build_I*No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC,No_of_enroute_sectors_having_CPDLC_Build_I)*(CPDLC_
 Build_I_and_non_integrated_uret_savings_per_enroute_sector[low]*Proportion_of_low_density_se
 ctors +
 CPDLC_Build_I_and_non_integrated_uret_savings_per_enroute_sector[medium]*Proportion_of__
 medium_density_sectors +
 CPDLC_Build_I_and_non_integrated_uret_savings_per_enroute_sector[high]*Proportion_of_high_
 density_sectors) +
 MIN(No_of_enroute_sectors_having_CPDLC_Build_IA*No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC,No_of_enroute_sectors_having_CPDLC_Build_IA)*(CPDLC_
 _Build_IA_and_non_integrated_uret_savings_per_enroute_sector[low]*Proportion_of_low_density
 _sectors +
 CPDLC_Build_IA_and_non_integrated_uret_savings_per_enroute_sector[medium]*Proportion_of_
 _medium_density_sectors +
 CPDLC_Build_IA_and_non_integrated_uret_savings_per_enroute_sector[high]*Proportion_of_high
 _density_sectors) +
 MIN(No_of_enroute_sectors_having_CPDLC_Build_II*No_of_sectors_having_Uret/
 Total_no_of_sectors_having_CPDLC,No_of_enroute_sectors_having_CPDLC_Build_II)*(CPDLC_
 Build_II_and_non_integrated_uret_savings_per_enroute_sector[low]*Proportion_of_low_density_s
 ectors +
 CPDLC_Build_II_and_non_integrated_uret_savings_per_enroute_sector[medium]*Proportion_of__
 medium_density_sectors +
 CPDLC_Build_II_and_non_integrated_uret_savings_per_enroute_sector[high]*Proportion_of_high
 _density_sectors)

Enroute_Saving_per_flight_for_datalink =
 No_of_enroute_sectors_having_CPDLC_Build_I*(CPDLC_Build_I_savings_per_enroute_sector[low]*Proportion_of_low_density_sectors +
 CPDLC_Build_I_savings_per_enroute_sector[medium]*Proportion_of__medium_density_sectors +
 CPDLC_Build_I_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors) +
 No_of_enroute_sectors_having_CPDLC_Build_IA*(CPDLC_Build_IA_savings_per_enroute_sector[low]*Proportion_of_low_density_sectors +
 CPDLC_Build_IA_savings_per_enroute_sector[medium]*Proportion_of__medium_density_sectors
 + CPDLC_Build_IA_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors) +
 No_of_enroute_sectors_having_CPDLC_Build_II*(CPDLC_Build_II_savings_per_enroute_sector[low]*Proportion_of_low_density_sectors +
 CPDLC_Build_II_savings_per_enroute_sector[medium]*Proportion_of__medium_density_sectors
 + CPDLC_Build_II_savings_per_enroute_sector[high]*Proportion_of_high_density_sectors)
 Enroute_saving_per_flight_for_integrated = Enroute_saving_I_per_flight_for_integrated +
 Enroute_saving_II_per_flight_for_integrated
 Enroute_saving_per_flight_for_non_integrated = Enroute_Saving_I_per_flight_for_non_integrated
 + Enroute_saving_II_per_flight_for_non_integrated
 Enroute_sectors_traversed_for_P2 = RANDOM(5,8)
 Enroute_sectors_traversed_for_P3 = RANDOM(8,11)
 Enroute_sectors_traversed_for_P4 = RANDOM(11,18)
 Enroute_sectors__traversed_for_P1 = RANDOM(3,5)
 Equipage_rate_for_pFast = .2
 Equipage_rate_for_Tma = .2
 Equipage_rate_of_uret = .2
 Equipping_rate_for_CPDLC_Build_I = .2
 Equipping_rate_for_CPDLC_Build_IA = .1
 Equipping_rate_for_CPDLC_Build_II = .1
 Equip_level_for_CPDLC_Build_I = MIN(Equipage_level_for_CPDLC_Build_I,1)
 Equip_level_for_CPDLC_Build_IA = MIN(Equipage_level_for_CPDLC_Build_IA,1)
 Equip_level_for_uret = MIN(Equipage_level_for_Uret,1)
 Equip_level__for_CPDLC_Build_II = MIN(Equipage_level_for_CPDLC_Build_II,1)
 Initial_No__of_aircrafts = 5194 +
 (5194*Percent_of_growth_due_to_aircraft_increase*Traffic_Growth*(Base__Year - 2000))
 Interest_rate = .1
 No_of_enroute_sectors_having_CPDLC_Build_I = (Equip_level_for_CPDLC_Build_I -
 Equip_level_for_CPDLC_Build_IA)*Weighed_Average_of_enroute_sectors__traversed
 No_of_enroute_sectors_having_CPDLC_Build_IA = (Equip_level_for_CPDLC_Build_IA -
 Equip_level__for_CPDLC_Build_II)*Weighed_Average_of_enroute_sectors__traversed
 No_of_enroute_sectors_having_CPDLC_Build_II =

Equip_level__for_CPDLC_Build_II*Weighed_Average_of_enroute_sectors__traversed
 No_of_flights_per_aircraft_per_year = 1570
 No_of_sectors_having_Uret =
 Equip_level_for_uret*Weighed_Average_of_enroute_sectors__traversed
 No_of_sectors_in_NAS = 800
 Pfast_non_integrated_savings_per_arrival[Density] = { Place right hand side of equation here... }
 pFast_switch = IF(Year_of_simulation >= Year_of_implementation_of_pFast)
 THEN(1)
 ELSE(0)
 Proportion_factor_for_density_sector[low] = 1/6
 Proportion_factor_for_density_sector[medium] = 2/6
 Proportion_factor_for_density_sector[high] = 3/6
 Proportion_of_flights_bw_1500_and_2250_nm = .3
 Proportion_of_flights_bw_750_and_1500_nm = .4
 Proportion_of_flights_from_hub_airports = .7
 Proportion_of_flights_from_midsize_airports = .25
 Proportion_of_flights_from_small_airports = MAX(1 -
 (Proportion_of_flights_from_midsize_airports + Proportion_of_flights_from_hub_airports),0)
 Proportion_of_flights_greater_than_2250_nm = .1
 Proportion_of_flights_less_than_750_nm = .2
 Proportion_of_high_density_sectors = .33
 Proportion_of_low_density_sectors = MAX(1 - Proportion_of_high_density_sectors -
 Proportion_of__medium_density_sectors,0)
 Proportion_of_sectors[low] = .33
 Proportion_of_sectors[medium] = .33
 Proportion_of_sectors[high] = .33
 Proportion_of__medium_density_sectors = .33
 Savings_per_arrival_for_non_integrated = Savings_per_arrival_I_for_non_integrated +
 Saving_per_arrival_II_for_non_integrated
 Savings_per_arrival_I_for_non_integrated = MIN((Equip_level_for_CPDLC_Build_I -
 Equip_level_for_CPDLC_Build_IA) *Equip_level_for_uret/
 Equip_level_for_CPDLC_Build_I,(Equip_level_for_CPDLC_Build_I -
 Equip_level_for_CPDLC_Build_IA))*(CPDLC_Build_I_and_non_integrated_pfast_saving_arrival[
 ow]*Proportion_of_flights_from_small_airports +
 CPDLC_Build_I_and_non_integrated_pfast_saving_arrival[medium]*Proportion_of_flights_from_
 midsize_airports +
 CPDLC_Build_I_and_non_integrated_pfast_saving_arrival[high]*Proportion_of_flights_from_hub_
 airports) + MIN((Equip_level_for_CPDLC_Build_IA -
 Equip_level__for_CPDLC_Build_II)*Equip_level_for_uret/

Equip_level_for_CPDLC_Build_I,(Equip_level_for_CPDLC_Build_IA -
Equip_level_for_CPDLC_Build_II))*(CPDLC_Build_IA_and_non_integrated_pfast_saving_per_
arrival[low]*Proportion_of_flights_from_small_airports +
CPDLC_Build_IA_and_non_integrated_pfast_saving_per_arrival[medium]*Proportion_of_flights_
from_midsize_airports +
CPDLC_Build_IA_and_non_integrated_pfast_saving_per_arrival[high]*Proportion_of_flights_fro
m_hub_airports) + MIN(Equip_level_for_CPDLC_Build_II*Equip_level_for_uret/
Equip_level_for_CPDLC_Build_I,Equip_level_for_CPDLC_Build_II)*(CPDLC_Build_II_and_no
n_integrated_pfast_saving_per_arrival[low]*Proportion_of_flights_from_small_airports +
CPDLC_Build_II_and_non_integrated_pfast_saving_per_arrival[medium]*Proportion_of_flights_fr
om_midsize_airports +
CPDLC_Build_II_and_non_integrated_pfast_saving_per_arrival[high]*Proportion_of_flights_from
_hub_airports)
Savings_per_departure_for_datalink =
Equip_level_for_CPDLC_Build_II*(Proportion_of_flights_from_small_airports*CPDLC_Build_II
_Savings_per_departure[low] +
Proportion_of_flights_from_midsize_airports*CPDLC_Build_II_Savings_per_departure[medium] +
Proportion_of_flights_from_hub_airports*CPDLC_Build_II_Savings_per_departure[high])
+ (Equip_level_for_CPDLC_Build_IA - Equip_level_for_CPDLC_Build_II)
*(Proportion_of_flights_from_small_airports*CPDLC_Build_IA_Savings_per_departure[low] +
Proportion_of_flights_from_midsize_airports*CPDLC_Build_IA_Savings_per_departure[medium]
+ Proportion_of_flights_from_hub_airports*CPDLC_Build_IA_Savings_per_departure[high]) +
(Equip_level_for_CPDLC_Build_I -
Equip_level_for_CPDLC_Build_IA)*(Proportion_of_flights_from_small_airports*
CPDLC_Build_I_Savings_per_departure[low] +
Proportion_of_flights_from_midsize_airports*CPDLC_Build_I_Savings_per_departure[medium] +
Proportion_of_flights_from_hub_airports*CPDLC_Build_I_Savings_per_departure[high])
Savings_per_flight_for_datalink = Enroute_Saving_per_flight_for_datalink +
Savings_per_arrival_for_datalink + Savings_per_departure_for_datalink
Savings_per_flight_for_integrated = Enroute_saving_per_flight_for_integrated
+Savings_per_arrival_for_non_integrated + Savings_per_departure_for_datalink
Savings_per_flight_for_non_integrated = Enroute_saving_per_flight_for_non_integrated +
Savings_per_arrival_for_non_integrated + Savings_per_departure_for_datalink
Savings_per_arrival_for_datalink =
Equip_level_for_CPDLC_Build_II*(Proportion_of_flights_from_small_airports*CPDLC_Build_II
_saving_per_arrival[low] +
Proportion_of_flights_from_midsize_airports*CPDLC_Build_II_saving_per_arrival[medium] +
Proportion_of_flights_from_hub_airports*CPDLC_Build_II_saving_per_arrival[high])
+ (Equip_level_for_CPDLC_Build_IA - Equip_level_for_CPDLC_Build_II)

*(Proportion_of_flights_from_small_airports*CPDLC_Build_IA_saving_per_arrival[low] +
 Proportion_of_flights_from_midsize_airports*CPDLC_Build_IA_saving_per_arrival[medium] +
 Proportion_of_flights_from_hub_airports*CPDLC_Build_IA_saving_per_arrival[high]) +
 (Equip_level_for_CPDLC_Build_I -
 Equip_level_for_CPDLC_Build_IA)*(Proportion_of_flights_from_small_airports*
 CPDLC_Build_I_saving_per_arrival[low] +
 Proportion_of_flights_from_midsize_airports*CPDLC_Build_I_saving_per_arrival[medium] +
 Proportion_of_flights_from_hub_airports*CPDLC_Build_I_saving_per_arrival[high])
 Saving_per_arrival_II_for_non_integrated = MAX((Equip_level_for_CPDLC_Build_I -
 Equip_level_for_CPDLC_Build_IA)*(1 - Equip_level_for_uret/
 Equip_level_for_CPDLC_Build_I),0)*(CPDLC_Build_I_saving_per_arrival[low]*Proportion_of_fli
 ghts_from_small_airports +
 CPDLC_Build_I_saving_per_arrival[medium]*Proportion_of_flights_from_midsize_airports +
 CPDLC_Build_I_saving_per_arrival[high]*Proportion_of_flights_from_hub_airports) +
 MAX((Equip_level_for_CPDLC_Build_IA - Equip_level_for_CPDLC_Build_II)*(1 -
 Equip_level_for_uret/
 Equip_level_for_CPDLC_Build_I),0)*(CPDLC_Build_IA_saving_per_arrival[low]*Proportion_of_
 flights_from_small_airports +
 CPDLC_Build_IA_saving_per_arrival[medium]*Proportion_of_flights_from_midsize_airports +
 CPDLC_Build_IA_saving_per_arrival[high]*Proportion_of_flights_from_hub_airports) +
 MAX(Equip_level_for_CPDLC_Build_II*(1 - Equip_level_for_uret/
 Equip_level_for_CPDLC_Build_I),0)*(CPDLC_Build_II_saving_per_arrival[low]*Proportion_of_f
 lights_from_small_airports +
 CPDLC_Build_II_saving_per_arrival[medium]*Proportion_of_flights_from_midsize_airports +
 CPDLC_Build_II_saving_per_arrival[high]*Proportion_of_flights_from_hub_airports) +
 MAX(Equip_level_for_uret -
 Equip_level_for_CPDLC_Build_I,0)*(Pfast_non_integrated_savings_per_arrival[low]*Proportion_
 of_flights_from_small_airports +
 Pfast_non_integrated_savings_per_arrival[medium]*Proportion_of_flights_from_midsize_airports +
 Pfast_non_integrated_savings_per_arrival[high]*Proportion_of_flights_from_hub_airports)
 Start_Year = 2002
 Tma_switch = IF(Year_of_simulation >= Year_of_implementation_of_Tma)
 THEN(1)
 ELSE(0)
 Total_no_of_sectors_having_CPDLC = No_of_enroute_sectors_having_CPDLC_Build_I +
 No_of_enroute_sectors_having_CPDLC_Build_IA +
 No_of_enroute_sectors_having_CPDLC_Build_II
 Traffic_density_per__day_per_sector[low] =
 Traffic_volume_per_day*Proportion_factor_for_density_sector[low]/

(No_of_sectors_in_NAS*Proportion_of_sectors[low])
 Traffic_density_per__day_per_sector[medium] =
 Traffic_volume_per_day*Proportion_factor_for_density_sector[medium]/
 (No_of_sectors_in_NAS*Proportion_of_sectors[medium])
 Traffic_density_per__day_per_sector[high] =
 Traffic_volume_per_day*Proportion_factor_for_density_sector[high]/
 (No_of_sectors_in_NAS*Proportion_of_sectors[high])
 Traffic_Growth = .05
 Traffic_volume_per_day = Base_year_traffic_over_NAS*((1 + Traffic_Growth)*(TIME + Yr))/
 (365)
 Uret_integrated_savings_per_enroute_sector[Density] = { Place right hand side of equation here... }
 Uret_non_integrated_savings_per_enroute_sector[Density] = TIME
 Uret_Switch = IF(Year_of_simulation >= Yr_of_implementation_of_Uret)
 THEN(1)
 ELSE(0)
 Weighed_Average_of_enroute_sectors__traversed =
 (Proportion_of_flights_less_than_750_nm*Enroute_sectors__traversed_for_P1) +
 (Proportion_of_flights_bw_750_and_1500_nm*Enroute_sectors_traversed_for_P2) +
 (Proportion_of_flights_bw_1500_and_2250_nm*Enroute_sectors_traversed_for_P3) +
 (Proportion_of_flights_greater_than_2250_nm*Enroute_sectors_traversed_for_P4)
 Year_of_implementation_of_pFast = 2003
 Year_of_implementation_of_Tma = 2003
 Year_of_simulation = Start_Year + TIME
 Yr = Start_Year- Base__Year
 Yr_of_implementation_of_CPDLC_Build_I = 2002
 Yr_of_implementation_of_CPDLC_Build_IA = 2006
 Yr_of_implementation_of_Uret = 2002
 Yr_of_implementation_of_CPDLC_Build_II = 2008
 CPDLC_Build_IA_Savings_per_departure[Density] = TIME
 CPDLC_Build_IA_savings_per_enroute_sector[Density] = TIME
 CPDLC_Build_IA_saving_per_arrival[Density] = TIME
 CPDLC_Build_IA__and_non_integrated_pfast_saving_per_arrival[Density] = TIME
 CPDLC_Build_II_and_non_integrated_pfast_saving_per_arrival[Density] = TIME
 CPDLC_Build_II_Savings_per_departure[Density] = TIME
 CPDLC_Build_II_savings_per_enroute_sector[Density] = TIME
 CPDLC_Build_II_saving_per_arrival[Density] = TIME
 CPDLC_Build_I_and_non_integrated_pfast_saving_arrival[Density] = TIME
 CPDLC_Build_I_Savings_per_departure[Density] = TIME
 CPDLC_Build_I_savings_per_enroute_sector[Density] = TIME

CPDLC_Build_I_saving_per_arrival[Density] = TIME
Uret_non_integrated_savings_per_enroute_sector[Density] = TIME

Main Model

NPV_of_Airline_Benefits_for_datalink_scenario(t) =
NPV_of_Airline_Benefits_for_datalink_scenario(t - dt) + (Airline_Benefit_per_year_in_datalink -
Airline_Cost_per_year_in_data_link) * dt
INIT NPV_of_Airline_Benefits_for_datalink_scenario = 0

INFLOWS:

Airline_Benefit_per_year_in_datalink = Airline_Operational_Benefit_per_year_in_datalink[Low]

OUTFLOWS:

Airline_Cost_per_year_in_data_link = Airline_Tech_Cost_per_Year

NPV_of_Airline_Benefits_for_integrated_scenario(t) =
NPV_of_Airline_Benefits_for_integrated_scenario(t - dt) + (Airline_Benefit_per_year_in_integrated
- Airline_Cost_per_year_in_integrated) * dt
INIT NPV_of_Airline_Benefits_for_integrated_scenario = 0

INFLOWS:

Airline_Benefit_per_year_in_integrated = Airline_operational_benefit__per_year_integrated

OUTFLOWS:

Airline_Cost_per_year_in_integrated = Airline_Cost_per_year_in_non_integrated

NPV_of_Airline_Benefits_for_non_integrated_scenario(t) =
NPV_of_Airline_Benefits_for_non_integrated_scenario(t - dt) +
(Airline_Benefit_per_year_in_non_integrated - Airline_Cost_per_year_in_non_integrated) * dt
INIT NPV_of_Airline_Benefits_for_non_integrated_scenario = 0

INFLOWS:

Airline_Benefit_per_year_in_non_integrated =
Airline_operational_benefit__per_year_non_integrated

OUTFLOWS:

Airline_Cost_per_year_in_non_integrated = Airline_Cost_per_year_in_data_link

NPV_of_Benefits_for_datalink_only_scenario(t) = NPV_of_Benefits_for_datalink_only_scenario(t -
dt) + (Benefits_for_datalink_only_scenario - Cost_for_datalink_only_scenario) * dt
INIT NPV_of_Benefits_for_datalink_only_scenario = - Initial_cost_for_datalink

INFLOWS:

Benefits_for_datalink_only_scenario = Airline_Benefit_per_year_in_datalink +
FAA_Benefit__per_year_in_datalink

OUTFLOWS:

Cost_for_datalink_only_scenario = Airline_Cost_per_year_in_data_link +
FAA_Cost_per_year_in_datalink

NPV_of_Benefits_for_integrated_scenario(t) = NPV_of_Benefits_for_integrated_scenario(t - dt) +
(Benefits_for_integrated_scenario - Cost_for_integrated_scenario) * dt

INIT NPV_of_Benefits_for_integrated_scenario = -Initial_cost_of_integration -

Initial_cost_for_datalink - Initial_cost_for_tma - Initial_Cost_for_pFast - Initial_cost_for_uret

INFLOWS:

Benefits_for_integrated_scenario = Airline_Benefit_per_year_in_integrated +
FAA_Benefit_per_year_integrated

OUTFLOWS:

Cost_for_integrated_scenario = Airline_Cost_per_year_in_integrated +
FAA_Cost_per_year_integrated

NPV_of_Benefits_for_non_integrated_scenario(t) =

NPV_of_Benefits_for_non_integrated_scenario(t - dt) + (Benefits_for_non_integrated_scenario -
Cost_for_non_integrated_scenario) * dt

INIT NPV_of_Benefits_for_non_integrated_scenario = -Initial_cost_for_datalink -

Initial_cost_for_tma - Initial_Cost_for_pFast - Initial_cost_for_uret

INFLOWS:

Benefits_for_non_integrated_scenario = Airline_Benefit_per_year_in_non_integrated +
FAA_Benefit_per_year_in_non_integrated

OUTFLOWS:

Cost_for_non_integrated_scenario = Airline_Cost_per_year_in_non_integrated +
FAA_Cost_per_year_in_non_integrated

NPV_of_FAA_Benefits_for_datalink_only_scenario(t) =

NPV_of_FAA_Benefits_for_datalink_only_scenario(t - dt) + (FAA_Benefit_per_year_in_datalink -
FAA_Cost_per_year_in_datalink) * dt

INIT NPV_of_FAA_Benefits_for_datalink_only_scenario = - Initial_cost_for_datalink

INFLOWS:

FAA_Benefit_per_year_in_datalink = Safety_benefit_per_year_data_link_only

OUTFLOWS:

FAA_Cost_per_year_in_datalink = FAA_Tech_cost_per_year_in_datalink

NPV_of_FAA_Benefits_for_integrated_scenario(t) =

NPV_of_FAA_Benefits_for_integrated_scenario(t - dt) + (FAA_Benefit_per_year_integrated -
FAA_Cost_per_year_integrated) * dt

INIT NPV_of_FAA_Benefits_for_integrated_scenario = -Initial_cost_of_integration -

Initial_cost_for_datalink - Initial_cost_for_tma - Initial_Cost__for_pFast -Initial_cost__for_uret

INFLOWS:

FAA_Benefit_per_year_integrated = Safety_benefit_per_year_integrated

OUTFLOWS:

FAA_Cost_per_year_integrated = FAA_Tech_cost_per_year_integrated_

NPV_of_FAA_Benefits_for_non_integrated_scenario(t) =

NPV_of_FAA_Benefits_for_non_integrated_scenario(t - dt) +

(FAA_Benefit_per_year_in_non_integrated - FAA_Cost_per__year_in_non_integrated) * dt

INIT NPV_of_FAA_Benefits_for_non_integrated_scenario = - Initial_cost_for_datalink -

Initial_cost_for_tma - Initial_Cost__for_pFast -Initial_cost__for_uret

INFLOWS:

FAA_Benefit_per_year_in_non_integrated = Safety_benefit_per__year_non_integrated

OUTFLOWS:

FAA_Cost_per__year_in_non_integrated = FAA_Tech_cost__per_year_non_integrated

Safety Benefit

Equipage_level_for_airplanes(t) = Equipage_level_for_airplanes(t - dt) +

(Equipage_rate__for_airplanes) * dt

INIT Equipage_level_for_airplanes = 0

INFLOWS:

Equipage_rate__for_airplanes = .1

Safety_benefit_integrated(t) = Safety_benefit_integrated(t - dt) +

(Safety_benefit_per__year_non_integrated) * dt

INIT Safety_benefit_integrated = 0

INFLOWS:

Safety_benefit_per__year_non_integrated =

Cost_per__operational_error*Reduction_in__operational_errors_in_non__integrated_scenario/((1 + Interest_rate)^(Yr + TIME))

Safety_benefit_non_integrated(t) = Safety_benefit_non_integrated(t - dt) +

(Safety_benefit_per_year_integrated) * dt

INIT Safety_benefit_non_integrated = 0

INFLOWS:

Safety_benefit_per_year_integrated =

Cost_per__operational_error*Reduction_in_operational_errors_in_integrated/((1 +

Interest_rate)^(Yr + TIME))

Safety_benefit_data_link(t) = Safety_benefit_data_link(t - dt) +

(Safety_benefit_per_year_data_link_only) * dt

INIT Safety_benefit_data_link = 0

INFLOWS:

Safety_benefit_per_year_data_link_only =

Cost_per_operational_error*Reduction_in_operational_errors_in_data_link/((1 + Interest_rate)^(Yr + TIME))

Additional_Message_ratio_set_for_Build_IA = Additional_Message_set_for_Build_IA/

(Additional_Message_set_for_Build_IA + Message_set_for_Build_I +

Additional_Message_set_for_Build_II)

Additional_Message_ratio_set_for_Build_II = Additional_Message_set_for_Build_II/

(Message_set_for_Build_I + Additional_Message_set_for_Build_IA +

Additional_Message_set_for_Build_II)

Additional_Message_set_for_Build_IA = 5

Additional_Message_set_for_Build_II = 3

Addn_Proportion_of_comm_by_datalink_for_build_IA =

Additional_Message_ratio_set_for_Build_IA*Percentage_of_messages_allocated_to_datalink

Addn_Proportion_of_comm_by_datalink_for_build_II =

Additional_Message_ratio_set_for_Build_II*Percentage_of_messages_allocated_to_datalink

Cost_per_operational_error = 500000

Datalink_proportion_of_messages = Proportion_of_comm_by_datalink_for_build_II

Equipage_level_for_flights = MIN(Equipage_level_for_airplanes,1)

Error_rate_per_100000_operations = 1.2

Message_set_for_Build_I = 4

Message_set_ratio_for_Build_I = Message_set_for_Build_I/(Message_set_for_Build_I +

Additional_Message_set_for_Build_II + Additional_Message_set_for_Build_IA)

Operational_Errors_in_voice_only = Base_year_traffic_over_NAS*(1 + Traffic_Growth*(Yr + TIME)) *Error_rate_per_100000_operations/100000

Percentage_of_messages_allocated_to_datalink = 0.58

Proportion_of_comm_by_datalink_for_build_IA = (Proportion_of_comm_by_data_link_for_build_I + Addn_Proportion_of_comm_by_datalink_for_build_IA)*CPDLC_Build_IA_Switch

Proportion_of_comm_by_datalink_for_build_II = (Proportion_of_comm_by_datalink_for_build_IA + Addn_Proportion_of_comm_by_datalink_for_build_II)*CPDLC_Build_II_Switch

Proportion_of_comm_by_data_link_for_build_I =

Message_set_ratio_for_Build_I*Percentage_of_messages_allocated_to_datalink*CPDLC_Build_I_Switch
 Proportion_of_conflicts_resolved_by_trial_planning_integrated = 0.8
 Proportion_of_conflicts_resolved_by_trial_planning_non_integrated = 0.6
 Proportion_of_errors__casued_due_to_lack_of_situational_awareness = .65
 Proportion_of_operational_errors__caused_by_communication_errors = .23
 Reduction_in_operational_errors_in_data_link =
 Operational_Errors_in_voice_only*Proportion_of_operational_errors__caused_by_communication_errors*Equipage_level_for_flights*(Proportion_of_comm_by_datalink_for_build_II*Equip_level_for_CPDL_C_Build_II + (Equip_level_for_CPDL_C_Build_IA - Equip_level_for_CPDL_C_Build_II)*Proportion_of_comm_by_datalink_for_build_IA + (Equip_level_for_CPDL_C_Build_I - Equip_level_for_CPDL_C_Build_IA)*Proportion_of_comm_by_data_link_for_build_I)
 Reduction_in_operational_errors_in_integrated = Reduction_in_operational_errors_in_data_link + (Proportion_of_errors__casued_due_to_lack_of_situational_awareness*Operational_Errors_in_voice_only*Proportion_of_conflicts_resolved_by_trial_planning_integrated*MIN(Equipage_level_for_Uret,1)) + (1 - Proportion_of_conflicts_resolved_by_trial_planning_integrated)*Operational_Errors_in_voice_only*Proportion_of_errors__casued_due_to_lack_of_situational_awareness*Proportion_of_reduction*MIN(Equipage_level_for_Uret,1)
 Reduction_in__operational_errors_in_non__integrated_scenario =
 Reduction_in_operational_errors_in_data_link + (Proportion_of_errors__casued_due_to_lack_of_situational_awareness*Operational_Errors_in_voice_only*Proportion_of_conflicts_resolved_by_trial_planning_non_integrated*MIN(Equipage_level_for_Uret,1)) + (1 - Proportion_of_conflicts_resolved_by_trial_planning_non_integrated)*Operational_Errors_in_voice_only*Proportion_of_errors__casued_due_to_lack_of_situational_awareness*Proportion_of_reduction*MIN(Equipage_level_for_Uret,1)
 Percentage_of_full_benefit = GRAPH(Equipage_level_for_flights)
 (0.00, 0.00), (0.1, 0.00), (0.2, 0.09), (0.3, 0.335), (0.4, 0.475), (0.5, 0.57), (0.6, 0.665), (0.7, 0.775), (0.8, 0.895), (0.9, 0.935), (1, 1.00)
 Proportion_of_reduction = GRAPH(Base_year_traffic_over_NAS*(1 + (Traffic_Growth*(Yr + TIME))))
 (0.00, 1.00), (1e+006, 1.00), (2e+006, 1.00), (3e+006, 0.95), (4e+006, 0.85), (5e+006, 0.77), (6e+006, 0.7), (7e+006, 0.63), (8e+006, 0.57), (9e+006, 0.5), (1e+007, 0.4)

Technology Cost

AOC_Benefit(t) = AOC_Benefit(t - dt) + (AOC_Benefit_per_year) * dt
 INIT AOC_Benefit = 0

INFLOWS:

AOC_Benefit_per_year =

No_of_aircraft_equipped_with_datalink*No_of_flights_per_aircraft_per_year*No_of_AOC_msgs_per_flight*Reduction_in_kbit_per_msg_due_to_VDL_Mode_2*Cost_per_kbit_of_datalink_msg

Equipage_cost_for_CPDLC_Build_I(t) = Equipage_cost_for_CPDLC_Build_I(t - dt) +

(Equipage_cost_rate_for_CPDLC_Build_I) * dt

INIT Equipage_cost_for_CPDLC_Build_I = Initial_cost_for_datalink

INFLOWS:

Equipage_cost_rate_for_CPDLC_Build_I =

IF(Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_I >=

Percentage_equipped_per_year_with_CPDLC_Build_I)

THEN(Percentage_equipped_per_year_with_CPDLC_Build_I*Cost_per_percent_equipage_of_CPDLC_Build_I)

ELSE(Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_I*Cost_per_percent_equipage_of_CPDLC_Build_I)

Equipage_cost_for_CPDLC_Build_IA(t) = Equipage_cost_for_CPDLC_Build_IA(t - dt) +

(Equipage_cost_rate_for_CPDLC_Build_IA) * dt

INIT Equipage_cost_for_CPDLC_Build_IA = 0

INFLOWS:

Equipage_cost_rate_for_CPDLC_Build_IA =

IF(Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_IA >=

Percentage_equipped_per_year_with_CPDLC_Build_IA)

THEN(Percentage_equipped_per_year_with_CPDLC_Build_IA*Additional_cost_per_percent_equipage_of_CPDLC_Build_IA)

ELSE(Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_IA*Additional_cost_per_percent_equipage_of_CPDLC_Build_IA)

Equipage_cost_for_CPDLC_Build_II(t) = Equipage_cost_for_CPDLC_Build_II(t - dt) +

(Equipage_cost_rate_CPDLC_Build_II) * dt

INIT Equipage_cost_for_CPDLC_Build_II = 0

INFLOWS:

Equipage_cost_rate_CPDLC_Build_II =

IF(Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_II >=

Percentage_equipped_per_year_with_CPDLC_Build_II)

THEN(Percentage_equipped_per_year_with_CPDLC_Build_II*Additional_cost_per_percent_equipage_of_CPDLC_Build_II)

ELSE(Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_II*Additional_cost_per_percent_ equipage_of_CPDLC_Build_II)

Equipage_cost_for_tma(t) = Equipage_cost_for_tma(t - dt) + (Equipage_cost_rate_for_tma) * dt

INIT Equipage_cost_for_tma = Initial_cost_for_tma

INFLOWS:

Equipage_cost_rate_for_tma = IF(Percentage_of_NAS_to__be_equipped_with_tma

>=Percentage_equipped_per__year_with_tma)

THEN(Percentage_equipped_per__year_with_tma*Cost_per_percent_equipage_of_tma)

ELSE(Percentage_of_NAS_to__be_equipped_with_tma*Cost_per_percent_equipage_of_tma)

Equipage_cost_for_uret(t) = Equipage_cost_for_uret(t - dt) + (Equipage_cost_rate_for_uret) * dt

INIT Equipage_cost_for_uret = Initial_cost__for_uret

INFLOWS:

Equipage_cost_rate_for_uret =

IF(Percentage_of_NAS_to_be_equipped_with_uret>=Percentage_equipped_per__year_with_uret)

THEN(Percentage_equipped_per__year_with_uret*Cost_per_percent_equipage_of_uret)

ELSE(Percentage_of_NAS_to_be_equipped_with_uret*Cost_per_percent_equipage_of_uret)

Equipage_cost__for_pFast(t) = Equipage_cost__for_pFast(t - dt) + (Equipage_cost_rate_for_pFast) * dt

INIT Equipage_cost__for_pFast = Initial_Cost__for_pFast

INFLOWS:

Equipage_cost_rate_for_pFast = IF(Percentage_of_NAS_to_be_equipped_with_pFast >= Percentage_equipped_per_year_with_pFast)

THEN(Percentage_equipped_per_year_with_pFast*Cost_per_percent_equipage_of_pFast)

ELSE(Cost_per_percent_equipage_of_pFast*Percentage_of_NAS_to_be_equipped_with_pFast)

No_of_aircraft_equipped_with_datalink(t) = No_of_aircraft_equipped_with_datalink(t - dt) + (Aircrafts_equipped_per_year) * dt

INIT No_of_aircraft_equipped_with_datalink = 0

INFLOWS:

Aircrafts_equipped_per_year = Equipage_rate__for_airplanes*Initial_No__of_aircrafts*(1 + Percent_of_growth_due_to_aircraft_increase*Traffic_Growth*Yr)

No_of_aircraft_to_be_equipped(t) = No_of_aircraft_to_be_equipped(t - dt) +

(Rate_of_increase_in_aircraft - Retiring_rate_for_aircrafts - Aircrafts_equipped_per_year) * dt

INIT No_of_aircraft_to_be_equipped = Initial_No__of_aircrafts*(1 +

(Percent_of_growth_due_to_aircraft_increase*Traffic_Growth*Yr))

INFLOWS:

Rate_of_increase_in_aircraft = Initial_No_of_aircrafts*(1 +
(Percent_of_growth_due_to_aircraft_increase*Traffic_Growth*Yr))*Traffic_Growth*Percent_of_growth_due_to_aircraft_increase

OUTFLOWS:

Retiring_rate_for_aircrafts = 100

Aircrafts_equipped_per_year = Equipage_rate_for_airplanes*Initial_No_of_aircrafts*(1 +
Percent_of_growth_due_to_aircraft_increase*Traffic_Growth*Yr)

Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_I(t) =
Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_I(t - dt) + (-
Percentage_equipped_per_year_with_CPDLC_Build_I) * dt

INIT Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_I = 100

OUTFLOWS:

Percentage_equipped_per_year_with_CPDLC_Build_I = Equipage_rate_for_CPDLC_Build_I*100

Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_IA(t) =
Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_IA(t - dt) + (-
Percentage_equipped_per_year_with_CPDLC_Build_IA) * dt

INIT Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_IA = 100

OUTFLOWS:

Percentage_equipped_per_year_with_CPDLC_Build_IA =
Equipage_rate_for_CPDLC_Build_IA*100

Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_II(t) =
Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_II(t - dt) + (-
Percentage_equipped_per_year_with_CPDLC_Build_II) * dt

INIT Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_II = 100

OUTFLOWS:

Percentage_equipped_per_year_with_CPDLC_Build_II = Equipage_rate_for_CPDLC_Build_II*100

Percentage_of_NAS_to_be_equipped_with_pFast(t) =
Percentage_of_NAS_to_be_equipped_with_pFast(t - dt) + (-
Percentage_equipped_per_year_with_pFast) * dt

INIT Percentage_of_NAS_to_be_equipped_with_pFast = 100

OUTFLOWS:

Percentage_equipped_per_year_with_pFast = Equipping_rate_for_pFast*100

Percentage_of_NAS_to_be_equipped_with_uret(t) =
Percentage_of_NAS_to_be_equipped_with_uret(t - dt) + (-

Percentage_equipped_per_year_with_uret) * dt
INIT Percentage_of_NAS_to_be_equipped_with_uret = 100

OUTFLOWS:

Percentage_equipped_per_year_with_uret = Equipping_rate_for_uret*100
Percentage_of_NAS_to_be_equipped_with_tma(t) =
Percentage_of_NAS_to_be_equipped_with_tma(t - dt) + (-
Percentage_equipped_per_year_with_tma) * dt
INIT Percentage_of_NAS_to_be_equipped_with_tma = 100

OUTFLOWS:

Percentage_equipped_per_year_with_tma = Equipping_rate_for_Tma*100
Technology_Cost_Integrated(t) = Technology_Cost_Integrated(t - dt) +
(FAA_Tech_cost_per_year_integrated_ + Airline_Tech_Cost) * dt
INIT Technology_Cost_Integrated = Initial_cost_of_integration + Initial_cost_for_datalink +
Initial_cost_for_tma + Initial_Cost_for_pFast + Initial_cost_for_uret

INFLOWS:

FAA_Tech_cost_per_year_integrated_ = FAA_Tech_cost_per_year_non_integrated +
(Additional_recurring_maintenance_cost_due_to_integration/((1 + Interest_rate)^(Yr + TIME)))
Airline_Tech_Cost = Airline_Tech_Cost_per_Year
Technology_Cost_in_datalink_only(t) = Technology_Cost_in_datalink_only(t - dt) +
(FAA_Tech_cost_per_year_in_datalink + Airline_Tech_Cost_per_year) * dt
INIT Technology_Cost_in_datalink_only = Initial_cost_for_datalink

INFLOWS:

FAA_Tech_cost_per_year_in_datalink = (Equipage_cost_rate_for_CPDLC_Build_I
+Equipage_cost_rate_for_CPDLC_Build_IA + Equipage_cost_rate_CPDLC_Build_II +
Recurring_maintenance_cost_in_datalink_only)/((1 + Interest_rate)^(Yr + TIME))
Airline_Tech_Cost_per_year = Airline_Tech_Cost
Technology_Cost_non_integrated(t) = Technology_Cost_non_integrated(t - dt) +
(FAA_Tech_cost_per_year_non_integrated + Airline_Tech_Cost_per_Year) * dt
INIT Technology_Cost_non_integrated = Initial_cost_for_datalink + Initial_cost_for_tma +
Initial_Cost_for_pFast + Initial_cost_for_uret

INFLOWS:

FAA_Tech_cost_per_year_non_integrated = (Equipage_cost_rate_for_CPDLC_Build_I
+Equipage_cost_rate_for_CPDLC_Build_IA + Equipage_cost_rate_for_pFast +
Equipage_cost_rate_for_tma + Equipage_cost_rate_for_uret +

Equipage_cost_rate__CPDLC_Build_II + Recurring_maintenance_cost_non_integration +
 (ATC_msg_cost_per_year*Proportion_of_ATC_msg_cost_for_FAA)/((1 + Interest_rate)^(Yr +
 TIME))
 Airline_Tech_Cost_per_Year = IF(No_of_aircraft_to_be_equipped + Rate_of_increase_in_aircraft -
 Retiring_rate_for_aircrafts >= Aircrafts_equipped_per_year)
 THEN(Infrastructure_cost_per_aircraft*Aircrafts_equipped_per_year +
 (ATC_msg_cost_per_year*Proportion_of_ATC_msg_cost_for_airline) +
 (No_of_aircraft_equipped_with_datalink*Maintenance_cost_per_aircraft)/((1 + Interest_rate)^(Yr +
 TIME)))
 ELSE(Infrastructure_cost_per_aircraft*(No_of_aircraft_to_be_equipped +
 Rate_of_increase_in_aircraft - Retiring_rate_for_aircrafts) +
 (ATC_msg_cost_per_year*Proportion_of_ATC_msg_cost_for_airline) +
 (No_of_aircraft_equipped_with_datalink*Maintenance_cost_per_aircraft)/((1 + Interest_rate)^(Yr +
 TIME)))
 Additional_cost_per_percent_equipage_of_CPDLC_Build_IA = 2.86*1000000
 Additional_cost_per_percent_equipage_of_CPDLC_Build_II = 2.86*1000000
 Additional_recurring_maintenance_cost_due_to_integration = (100 -
 Percentage_of_NAS_to_be_equipped_with_uret)*Recurring_maintenance_cost_per_percent_of_inte
 gration
 ATC_msg_cost_per_year =
 No_of_aircraft_equipped_with_datalink*No_of_flights_per_aircraft_per_year*No_of_ATC_msgs_p
 er_flight*Cost_per_kbit_of_datalink_msg*No_of_kbits_per_msg_in_VDL_Mode_2*Datalink_prop
 ortion_of_messages
 Cost_per_kbit_of_datalink_msg = IF(Total_number_of_kbits_per_year <= 1000000)
 THEN(.18)
 ELSE(IF(Total_number_of_kbits_per_year > 1000000) AND (Total_number_of_kbits_per_year
 <= 4*1000000)
 THEN(.14)
 ELSE(IF(Total_number_of_kbits_per_year > 4*1000000) AND (Total_number_of_kbits_per_year
 <= 8*1000000)
 THEN(.1)
 ELSE(.06)))
 Cost_per_percent_equipage_of_CPDLC_Build_I = 2.86*1000000
 Cost_per_percent_equipage_of_pFast = 4000000
 Cost_per_percent_equipage_of_tma = 4000000
 Cost_per_percent_equipage_of_uret = 4000000
 Infrastructure_cost_per_aircraft = 4000000
 Initial_cost_for_datalink = 420000000
 Initial_cost_for_tma = 112000000

Initial_cost_of_integration = 200000000
 Initial_Cost__for_pFast = 112000000
 Initial_cost__for_uret = 200000000
 Maintenance_cost_per_aircraft = 20000
 No_of_AOC_msgs_per_flight = 100
 No_of_ATC_msgs_per_flight = 229
 No_of_kbits_per_msg_in_VDL_Mode_2 = 5.6
 Percent_of_growth_due_to_aircraft_increase = .8
 Proportion_of_ATC_msg_cost_for_airline = .5
 Proportion_of_ATC_msg_cost_for_FAA = 1 - Proportion_of_ATC_msg_cost_for_airline
 Recurring_maintenance_cost_in_datalink_only = (300 -
 (Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_I +
 Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_IA +
 Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_II))*Recurring_maintenance_cost_per_
 percentage_of_equipage
 Recurring_maintenance_cost_non_integration = (600 -
 (Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_I +
 Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_IA
 +Percentage_of_NAS_to_be_equipped_with_CPDLC_Build_II +
 Percentage_of_NAS_to_be_equipped_with_pFast + Percentage_of_NAS_to_be_equipped_with_uret
 +
 Percentage_of_NAS_to__be_equipped_with_tma))*Recurring_maintenance_cost_per_percentage_o
 f_equipage
 Recurring_maintenance_cost_per_percentage_of_equipage = 100000
 Recurring_maintenance_cost_per_percent_of_integration = 50000
 Reduction_in_kbit_per_msg_due_to_VDL_Mode_2 = 2*No_of_kbits_per_msg_in_VDL_Mode_2/3
 Total_number_of__kbits_per_year =
 No_of_aircraft_equipped_with_datalink*No_of_flights_per_aircraft_per_year*No_of_ATC_msgs_p
 er_flight*No_of_kbits_per_msg_in_VDL_Mode_2

Training Cost

Controllers_to_be__trained_in_data_link(t) = Controllers_to_be__trained_in_data_link(t - dt) + (-
 data_link_training_rate) * dt
 INIT Controllers_to_be__trained_in_data_link = data_link_controllers

OUTFLOWS:

data_link_training_rate = data_link_controllers*Equipage_rate_for_CPDLC_Build_I
 Controllers_to_be__trained_in_pFast(t) = Controllers_to_be__trained_in_pFast(t - dt) + (-
 pFast_training_rate) * dt

INIT Controllers_to_be__trained_in_pFast = pFast_controllers

OUTFLOWS:

pFast_training_rate = Equipping_rate_for_pFast*pFast_controllers

Controllers_to_be__trained_in_tma(t) = Controllers_to_be__trained_in_tma(t - dt) + (-tma_training_rate) * dt

INIT Controllers_to_be__trained_in_tma = tma_controllers

OUTFLOWS:

tma_training_rate = Equipping_rate__for_Tma*tma_controllers

Controllers_to_be__trained_in_uret(t) = Controllers_to_be__trained_in_uret(t - dt) + (-uret_training_rate) * dt

INIT Controllers_to_be__trained_in_uret = Uret_Controllers

OUTFLOWS:

uret_training_rate = Equipping_rate_for_uret*Uret_Controllers

Cost_for_training_controllers_in_data_link(t) = Cost_for_training_controllers_in_data_link(t - dt) + (data_link_training_cost_rate) * dt

INIT Cost_for_training_controllers_in_data_link = 0

INFLOWS:

data_link_training_cost_rate = IF(Controllers_to_be__trained_in_data_link >= data_link_training_rate)

THEN(Cost_for_training_one_controller_data_link*data_link_training_rate)

ELSE(Controllers_to_be__trained_in_data_link*Cost_for_training_one_controller_data_link)

Cost_for_training_pilots(t) = Cost_for_training_pilots(t - dt) + (pilot_training_cost_rate) * dt

INIT Cost_for_training_pilots = 0

INFLOWS:

pilot_training_cost_rate = IF(No_of_pilots_to_be_trained + Pilot_Growth_Rate >= Pilots_trained_per_year)

THEN(Cost_for_training_pilot_in_data_link*Pilots_trained_per_year)

ELSE(Cost_for_training_pilot_in_data_link*(No_of_pilots_to_be_trained + Pilot_Growth_Rate))

Cost_for_training_tma_controllers(t) = Cost_for_training_tma_controllers(t - dt) + (tma_training_cost_rate) * dt

INIT Cost_for_training_tma_controllers = 0

INFLOWS:

tma_training_cost_rate = IF(Controllers_to_be__trained_in_tma >= tma_training_rate)

THEN(Cost_of_training_one_controller_in_tma*tma_training_rate)
ELSE(Controllers_to_be__trained_in_tma*Cost_of_training_one_controller_in_tma)
Cost_for_training__controllers_in_uret(t) = Cost_for_training__controllers_in_uret(t - dt) +
(uret_training__cost_rate) * dt
INIT Cost_for_training__controllers_in_uret = 0

INFLOWS:

uret_training__cost_rate = IF(Controllers_to_be__trained_in_uret>= uret_training_rate)
THEN(uret_training_rate*Cost_for_training_one_controller_uret)
ELSE(Controllers_to_be__trained_in_uret*Cost_for_training_one_controller_uret)
No_of_pilots_to_be_trained(t) = No_of_pilots_to_be_trained(t - dt) + (Pilot_Growth_Rate -
Pilots_trained_per_year) * dt
INIT No_of_pilots_to_be_trained = Initial_no_of_pilots*((1 + Traffic_Growth)^Yr)

INFLOWS:

Pilot_Growth_Rate = Initial_no_of_pilots*(1 +
(Percentage_of_pilot_increase_per_percent_increase_in_traffic_*Traffic_Growth*Yr))
*Traffic_Growth*Percentage_of_pilot_increase_per_percent_increase_in_traffic_

OUTFLOWS:

Pilots_trained_per_year = Equipage_rate__for_airplanes*Initial_no_of_pilots*(1 +
(Percentage_of_pilot_increase_per_percent_increase_in_traffic_*Traffic_Growth*Yr))
pFast_training_cost(t) = pFast_training_cost(t - dt) + (pFast_training_cost_rate) * dt
INIT pFast_training_cost = 0

INFLOWS:

pFast_training_cost_rate = IF(Controllers_to_be__trained_in_pFast>= pFast_training_rate)
THEN(pFast_training_rate*Cost_for_training_one_controller_in_pFast)
ELSE(Cost_for_training_one_controller_in_pFast*Controllers_to_be__trained_in_pFast)
Training_Cost(t) = Training_Cost(t - dt) + (FAA__training_Cost_per_year +
Airline_Training__Cost_per_Year) * dt
INIT Training_Cost = 0

INFLOWS:

FAA__training_Cost_per_year = (data_link_training_cost_rate + pFast_training_cost_rate +
tma_training_cost_rate + uret_training__cost_rate)/((1 + Interest_rate)^(Yr + TIME))
Airline_Training__Cost_per_Year = pilot_training_cost_rate/((1 + Interest_rate)^(Yr + TIME))
Cost_for_training_one_controller_data_link = 14000
Cost_for_training_one_controller_in_pFast = 14000
Cost_for_training_one_controller_uret = 14000

Cost_for_training_pilot_in_data_link = 24000
Cost_of_training_one_controller_in_tma = 14000
data_link_controllers = 13600
Initial_no_of_pilots = 55800
Percentage_of_pilot_increase_per_percent_increase_in_traffic_ = .2
pFast_controllers = 2115
tma_controllers = 60
Uret_Controllers = 400