A System Dynamics Model for the
Development of China's Air Transportation System
by
Chuanwen Quan

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:

[Signatures]
Antonio A. Trani, Ph.D., Chairman

[Signatures]
Donald R. Drew, Ph.D.
R. Sivanandan, Ph.D.

December 18, 1996
Blacksburg, Virginia

Keywords: Systems, Dynamics, Modeling, Air, Transportation
LO
5655
V855
MC
Q360
12
A System Dynamics Model for the
Development of China’s Air Transportation System

by
Chuanwen Quan

Dr. Antonio A. Trani, Committee Chairman
Civil Engineering

(Abstract)

The primary purpose of this thesis is to estimate the demands on the Air Transportation System in China and to establish a systematic framework for China’s Air Transportation System Development in the future. The Systems Dynamics Methodology is used to analyze and understand the relationships between policy variables dictating the future of China’s Air Transportation System and technological and economic variables to reach acceptable levels of service in a fast growing economy. Through alternative policy and sensitivity analysis, planners can gain insight into solving Air Transportation System development problems, understand how to operate the Air Transportation System, and to obtain the most efficient results through systems thinking. This model could be used to communicate relevant information to the decision makers in a readily understandable and useful form and in a timely fashion.

Two models are developed in this thesis: 1) A macroscopic China’s Socio-economic Development Model (CSEDM) and 2) A microscopic China’s Air transportation System Development Model (CATSDM). CSEDM is organized into the following components: Industry, Agriculture, Social, Infrastructure, Population, and Potential Air Demand and Air Subsidy sectors. The potential air demand is only referred to as the function of some socio-economic variables. The relationship between the potential air demand and some socio-economic variables is established by the macroscopic model. The potential air demand and air subsidy are estimated by the CSEDM.
The China's Air Transportation System Development Model (CATSDM) comprises of the Airlines, Air Routes and Airports sectors. The potential air demand will be calibrated by the elasticity coefficient of the air fare and the total annual delay. Both models have been developed in STELLA II, a computer software to develop Systems Dynamics models. The most important outputs of the model are the number of aircraft, airports and airspace routes to maintain pace with China's growing economy.

Various policies variables have been examined to estimate their effect in the air transportation demand and airport growth.
Acknowledgments

I would like to express my utmost gratitude to my advisor, Dr. Antonio A. Trani, for the valuable direction which he has provided. His time and patience are greatly appreciated.

I also wish to express thanks to Dr. Donald R. Drew, for the foundation knowledge of the transportation system and Systems Dynamics which he has given me.

I would like to thank Dr. Ramaswamy Sivanandan, who offered the helpful advice as my committee member.

I appreciate my parents, my brother and sister, my family, and my parents-in-law. I am thankful to Mr. Zhang Li and other transportation colleagues in Virginia Tech. I am grateful for my lovely daughter, Mengying, who always brings me happiness. This work is dedicated to my wife, Jingli Qu, who give me love, encouragement, patience, and confidence.
Table of Contents

1. Introduction 1
   1.1 Economic System and the Government in China 1
   1.1.1 Current Economic Situation 1
   1.1.2 Current Situation of the Government 2
   1.2 Existing Air Transportation System in China 3
   1.2.1 Airlines 4
   1.2.2 Airports 5
   1.2.3 Air Traffic Control System 5
   1.3 Problem Statement 6
   1.4 Research Objectives and Methodology 6
   1.5 Thesis Overview 7

2. Systems Perspective 9
   2.1 Systems Approach and Systems Methodology 9
   2.2 Systems Dynamic Modeling 9
   2.3 Causal Diagram and Equations 11
   2.3.1 Causal Diagram 11
   2.3.2 Equations 12

3. Description of China’s Socio-Economic Development Model 14
   3.1 Overview 14
   3.2 Industrial Sector 17
   3.3 Agriculture Sector 24
   3.4 Social Sector 32
   3.4 Infrastructure Sector 35
   3.6 Population Sector 38
3.7 Air Passenger and Air Subsidy Sector 44
3.7.1 Air Transportation Demand 44
3.7.2 The Supply of Air Transportation Service 45
3.7.3 Demand Estimation Models 46
3.7.4 Estimated Demand for China’s Air Transportation Using the Macroscopic Model 47

4. Description of China’s Air Transportation System 54
   Development Model 54
   4.1 Overview 54
   4.2 Airlines Sector 56
   4.3 Air Routes Sector 70
   4.4 Airports Sector 80

5. Results and Policy Analysis 102
   5.1 Baseline Results 102
   5.1.1 CSEDM Output Results 102
   5.1.2 CATSDM Output Results 104
   5.2 Policy Analysis 107
   5.2.1 Scenario-I Air Fare Parameter 107
   5.2.2 Scenario-II Air Fuel Parameter 109
   5.2.3 Scenario-III Air Transportation System Investment Parameter 112
   5.2.4 Scenario-IV Aircraft Utilization 116
   5.2.5 Scenario-V Total Delay Parameter 117

6. Conclusions and Recommendations 121
   6.1 Conclusions of the Models 121
   6.2 Recommendations 122
References 123

Appendices 125

Appendix A: Socio-economic Characteristics in China 1978-1995 125
Appendix B: Characteristics of Air Transportation System in China 1978-1995 126
Appendix C: Main Commercial Airlines in China 127
Appendix D: Distribution of Air Routes in China 128
Appendix E: Brief Description of STELLA II 129
Appendix F: Causal Diagram of China's Socio-economic Development Model 133
Appendix G: CSED Model Equations (STELLA II Language) 134
Appendix H: Causal Diagram of China's Air Transportation System Development Model 144
Appendix I: CATSDM Model Equations (STELLA II Language) 145

Vita 161
### List of Figures

| Figure 1.1  | Civil Aviation System | 3 |
| Figure 2.1  | Basic Building Blocks in STELLA II | 12 |
| Figure 3.1  | Causal Diagram of China’s Socio-economic Development Model | 15 |
| Figure 3.2  | Causal Diagram of the Industry Sector | 17 |
| Figure 3.3  | Causal Diagram of the Agriculture Sector | 24 |
| Figure 3.4  | Causal Diagram of the Social Sector | 32 |
| Figure 3.5  | Causal Diagram of the Infrastructure Sector | 35 |
| Figure 3.6  | Causal Diagram of the Population Sector | 38 |
| Figure 3.7  | Potential Air Demand and the Air Subsidy Sector | 51 |
| Figure 4.1  | Causal Diagram of China’s Air Transportation System Development Model | 55 |
| Figure 4.2  | Causal Diagram of the Airlines | 56 |
| Figure 4.3  | Causal Diagram of the Air Routes | 70 |
| Figure 4.4  | Causal Diagram of the Airports | 81 |
| Figure 5.1  | Growth of Gross National Product | 103 |
| Figure 5.2  | Growth of Total Population, Jobs in Non-agriculture and Potential Air Demand | 103 |
| Figure 5.3  | Growth of Airline Fleet, Runway and Terminal | 106 |
| Figure 5.4  | Comparison of Actual and potential Air Demand | 106 |
| Figure 5.5  | Air Demand Change with the Changing of the price Air Fuel | 111 |
| Figure 5.6  | Curves of the Operation Costs of Airlines | 112 |
| Figure 5.7  | Aircraft Fleet Size Vs TPAD | 117 |
| Figure 5.8  | Air Demand Vs Total Delay | 118 |
List of Tables

Table 2.1 Systems Dynamics Variables 11
Table 3.1 International Standard Industrial Classification 16
Table 3.2 Analysis of Variance 49
Table 5.1 Socio-economic Characteristics and the Potential Air Demand 102
Table 5.2 Characteristics of the Air Transportation System 105
Table 5.3 Air Demand Change with the Changing of the Air Fare 108
Table 5.4 Airlines Revenue from the Air Passengers 109
Table 5.5 Air Demand Change with the Changing of the Air Fuel Price 110
Table 5.6 Operation Costs of the Airlines 111
Table 5.7 Characteristics of the Air Transportation System According to a 30% Increase Capital Investment 113
Table 5.8 Characteristics of the Air Transportation System According to the Existing Investment Level 114
Table 5.9 Characteristics of the Air Transportation System According to 70% of the Existing Investment Level 115
Table 5.10 Aircraft Fleet Size Vs TPAD 116
Table 5.11 Air Demand Vs Total Delay 119
1. Introduction

1.1 Economic System and the Government in China

China, 'the sleeping giant of Asia' as Napoleon referred to it, stepped on to the road of modern nation-building through a series of political, economic and social transformations, which began in 1949. But its economic development has been interrupted time and again by political turmoil. However, Deng Xiaoping's economic reforms have brought drastic changes to the Chinese economy. One indicator of the success of these reforms was the annual 10% growth rate of GNP in the 1980s and the substantial improvement in ordinary people's standard of living. Despite these successes many problems persist, including a cycle of deflation followed by abrupt inflation, growing inequality in the distribution of income and an increasing amount of illegal economic activity by government officials. If these problems are not properly addressed, all reform efforts will be jeopardized. However, a serious problem in the fast development of the economy has been high inflation, which reached two digits in some years. The central government took some economic measures to reduce inflation, such as the control of investment. Nevertheless, the Chinese economy is expected to grow at an annual rate of 6-8% well into the next century. Some statistical data of the socio-economic characteristics in China are shown in Appendix A.

1.1.1 Current Situation of the Economic System

From a planned economy to a market economy

"Before the implementation of economic reforms in 1978, the Chinese economy was administered by a Stalinesque centrally-planned economic system. Central planning was widely extolled as an important facet of the superiority of socialism over capitalism" (Ryoshin Minami, 1994). Market principles were rejected and economic activities ranging from production to distribution were under the direct command of the central
government. With the passage of time, the deficiencies of this economic structure became more and more apparent.

In a market-oriented system economic growth is achieved through the distribution of resources according to the demands of individuals, households and enterprises. It is almost impossible to replace all market mechanisms with a centrally-controlled plan. Even if a sophisticated computer system were employed, it would still be very difficult for state planners to monitor the market, handle all the related information and distribute resources accordingly.

China’s earliest introduction of market mechanisms focused on the production of goods and commodities. After 1978 there was a gradual transition from the people’s commune system to the “household responsibility system,” and farmers were free to decide what to produce on their family plots. Once the state’s mandatory production quotas had been fulfilled, excess production could be sold on the free market. Farmers were also encouraged to pursue other part-time economic activities.

1.1.2 Current Situation of the Government

As we have seen, the dominant role of the government in socialist planned economics generates many problems. In China the 1978 reforms reduced the role of the government, and both the ratio of state fiscal revenue to national income and the share of total domestic fixed investment made by the state decreased sharply in the 1980s. The share of commodities under government control has decreased and the share of commodities under government price control has decreased. Nevertheless problems remain. The government still plays a large part in the economy, the performance of the state institutions is extremely poor, local governments do not necessarily follow the guidance of Beijing and people do not always obey government rules.
1.2 Existing Air Transportation System in China

As the Figure 1.1 shows, Civil Aviation is comprised of at least five interconnected groups of individuals and organizations with an interest in the industry: 1) Airlines, 2) Airports and providers of Air Traffic Control, 3) Equipment Manufacturers, 4) Consumers, and 5) Third Parties.

![Diagram of the Civil Aviation System](image)

**Figure 1.1 The Civil Aviation System**

1) Airlines are referred to as a segment of the air transportation industry. Broadly defined, the airline industry consists of a vast network of routes that connect cities throughout the country, and indeed, the world. Over this network, a large number of airlines carry passengers and cargo on scheduled service.

2) Airport facilities are usually the responsibility of national or local governments. The operation of the “airlines” ‘track’- controlled airspace is again mainly a government task, and also requires a strong element of intergovernmental co-operation.

3) So far, the production of equipment for the airline industry is one of the world’s leading manufacturing industries.

4) Consumers of air transport clearly have an interest in the activities of the industry. They include both air passengers and the shippers of air freight.
5) It has been stated that "transport is the pre-eminent example of an external cost industry." Air transport is no exception to this general rule. Aviation can have an effect, both good and bad, on a large number of people and organizations having no direct concern with it. We shall, therefore, refer to these as third parties.

Being one of the fastest-growing economies in the world, China's average annual economic growth rate has been over 10% during the past 10 years. The booming economy in China has caused a tremendous increase in the aviation industry sector in the last two decades. Since 1978, this sector has continued to expand rapidly, with a growth rate of 20%. Chinese officials have been considering measures to try to control the pace of this industry's expansion. However, according to Mr. Chen Guangyi, the chief of Civil Aviation Administration of China (CAAC), the aviation industry will continue to grow at double digits till the year 2000. Some characteristics of the air transportation system in China is given in Appendix B.

1.2.1 Airlines

In 1978, China’s aviation system had about 42 large aircraft including 9 Boeing 707, 18 now-scraped Tridents, 15 IL-62 and IL-18, and 80 small aircraft, such as AN-24, IL-12 etc. The total of 46,776 commercial flights were made by all aircraft, with a total of 231 million passengers and 638,16 tons of cargo transported.

The entire unit of China’s aviation system was controlled by the central government before 1990. Right now, China’s air transportation system encompasses more than 30 airlines (shown in appendix C) which were controlled by the central government and local governments and with a total of 416 aircraft. The current fleet mix includes 66 heavy aircraft including 1 Boeing 777, 16 Boeing 747, 17 Boeing 767, 6 MD-11, 23 Airbus 300 or 310 and 3 IL-86; 264 large aircraft including 44 Boeing 757, 115 Boeing 737, 39 MD-82, 33 TU-154, 10 Fokker-100, 14 BAe-146, and Yak-42 etc.; and about 86 small aircraft (CAAC, 1995). The total passengers transported in the air transportation system
increased by 22 fold from 1978 to 1995. Cargo statistics show a 14 fold increase in the same period. In 1995 there were 51.17 million passengers and 880,858 tons of cargo transported throughout the complete air transportation system in China. The total number of commercial flights was 437,787.

### 1.2.2 Airports

There were only 34 commercial airports in all of China in 1978. The radar, navigation and communications equipment at the airports was minimal at the time.

The current airport infrastructure in China encompasses about 138 airports that support scheduled air carrier operations by the end of 1995. There were 1.019 million operations on the 139 runways (two runways in Beijing airport) in 1995. More than five hundred thousand of commercial flights were accommodated by terminals. The radar, navigation and communication equipment and take-off and landing system were improved. So far, there are about 70 instrument landing systems (ILS), 73 sets of distance-measuring equipment (DME), 65 very high-frequency omnirange radio (VOR), and 53 radar distributed among 138 airports (CAAC, 1995). According to the ninth five-year plan of the CAAC, China's aviation system will build 13 new airports including Shanghai, Guangzhou, Zhengzhou, Guiyang, Guyin, Fuzhou, Nanjing, Haikou, Hangzhou, Nanchang, Yanchian, Wuhan and Sijiazhuang (the last two airports have been built in 1996) and reconstruct and expand 18 airports including Chengdu, Urumqi, Harbin, Xiamen, Lanzhou, Taiyuan, Shenzhen, Nanning, Xian, Shenyang, Chongqing, Chansha, Hefei, Ningbo, Weizhou, Qingdao, Yichang and Beijing.

### 1.2.3 Air Traffic Control System

In 1978, there were 162 air routes, the distance of all air routes was about 236,660 km, and the equipment to control the airspace was outdated. The number of air routes have reached 797, and the total distance of all routes was 1,420,600 km by the end of 1995.
The equipment of earoute and terminal areas has been improved. The capacity of the air route system is limited because the air space in China has been traditionally controlled by the military. Beginning January 1, 1997, the Civil Aviation Administration of China (CAAC) will take over control of the airways in China from the military. Plans are presently under way to improve the handling capacity and speed of the Chinese ATC system along with the modernization of ATC, communications, navigation and meteorology equipment. It is believed that the capacity of air routes will be enhanced further.

1.3 Problem Statement

The China’s aviation system’s rapid growth has resulted in some problems: insufficient aircraft, outdated technology, bad infrastructure and a chronic shortage of qualified pilots. Furthermore, the purchasing of modern equipment and technical training has been hindered by the lack of coordination, priority and funding. These factors have contributed to the rather shoddy safety reputation of China’s airlines.

Many models have been developed and applied to transportation investments and policies. However, there is not a complete development model in the China’s air transportation system till now. The purpose of this thesis to establish a framework for China’s air transportation system development model.

1.4 Research Objectives and Methodology

The motivation behind the development of a comprehensive air transportation system model is to provide aviation authorities with an accessible tool that serve as an experimental laboratory for decision making. The Systems Dynamics methodology is used to capture decisions as they take place in an information feedback system. Here we illustrate an air transportation system development model to estimate the influence of policy decisions such as capital investment and their effect on the capacity and level of
service of the Chinese aviation system. The main goal of this model is to study possible alternatives available to the Chinese government regarding the investment of capital into their existing air transportation system to achieve a balance between a fast-growing demand for air transportation services and the supply side maintaining a reasonable level of service and safety.

We also have built a socio-economic development model of China applying the same methodology. Some variables of socio-economic order included in this model are; the Gross National Product (GNP), Total Population (TP), Jobs in Non-agriculture (JOBNA), etc. The main purpose of this model is to estimate the potential air demand in China derived from socio-economic characteristics.

The ultimate goal of the simulation planning model described here is to serve as a living laboratory where policies can be tried before implementing them into the real system. Benefits of such a model are clear if one realizes the costly enterprise of developing air transportation system infrastructure without synergistically looking at the regional economies tied to it. Moreover, a computer model can evolve dynamically through time allowing decision makers to exercise policies at various points in time and quantify results immediately.

1.5 Thesis Overview

This thesis is comprised of six chapters: Chapter 1 reviewed the current economic situation including the government and the air transportation system in China.

Chapter 2 provides the theoretical background of the Systems Dynamic Methodology. It covers the concepts of system, systems dynamic, systems approach and feedback structures and the equations used in the development of Systems Dynamics models. In this chapter we also introduce the computer software STELLA II.
In Chapter 3, China’s Socio-Economic Development Model is introduced. The model includes six sectors: Industrial, Agriculture, Infrastructure, Social, Population and Potential Air Passenger and Air Subsidy. The amount of potential air transportation demand is in this respect affected by some Socio-economic variables in the model. The relationship between potential air demand and some socio-economic variables is established using a multiple regression technique.

In Chapter 4, China’s Air Transportation System Development Model is developed. It consists of three sectors: Air Traffic Control, Airline and Airport sectors. From this model, we can estimate the airport infrastructure, air fleet, etc. are needed to meet the demand of passengers in the future.

Chapter 5, presents results and policy analyses in China’s Socio-economic Development and China’s Air Transportation Development Models.

Chapter 6, presents the conclusions and recommendations of this work.
2. Systems Perspective

2.1 Systems Approach and Systems Methodology

"The system approach is the modus operandi of dealing with complex system. It is holistic in scope, creative in manner and rational in execution. Thus, it is based on looking at a total activity, project, design or system, rather than considering the efficiency of the component tasks independently. It is innovative, in that rather than seeking modifications of older solutions to similar problems, new problem definitions are sought, new alternative solutions generated and new measures of evaluation are employed if necessary" [Drew,D.R.].

A methodology is a system of rules which guides scientific inquiry. A methodology is usually comprised of procedures (orders of action for defining problems in terms of variables); tools, or elements of communication in the form of verbal, graphical and mathematical constructs, that aid in the execution to “models” representing the problems. A model is an idealized representation of reality developed with the aid of a methodology. Three components of a methodology for creating and utilizing a model are: (1) a substantive component which specifies how the model’s variables and relations are selected (2) a set of criteria that can be used to determine whether the results generated by the model are acceptable; and (3) a scheme for structuring and manipulating the model for performing policy analysis.

2.2 Systems Dynamic Modeling

Systems Dynamics is a relatively new methodology for policy modeling. It is based on the foundations of (1) decision making, (2) feedback systems analysis, and (3) simulation. Decision making is stating how action is to be taken. Feedback deals with the way information is to be used for the decision making. Simulation permits decision makers to view the implications of their decisions over the future.
The difficulty in solving the problem of the interrelationships between regional development and transportation investment is that the problem is the object of two different disciplines, development planning and transportation economics, using different languages. The system Dynamics methodology is used to bridge the gap between the two disciplines by establishing a chain of causality from variables within the decision makers’ control (level of investment, price, etc.) to socio-economic development indicators (industrial growth, job market, population increase and land use).

A model of this process can be very complex and can consist of hundreds of variables. The model should have the following characteristics:

1. Be able to describe any statement of cause effect relationship that one wishes to include.

2. Be simple in mathematical nature.

3. Be closely synonymous in nomenclature to industrial, economic and social technology.

4. Be extensible to large numbers of variables without exceeding the practical limits of computers.

5. Be able to handle continuous interaction in the sense that any artificial discontinuities introduced by solution time intervals will not affect the results.

6. Should be able to generate discontinuous changes in decisions when these are needed [Forrester, J. W., 1961].

The three steps in the Systems Dynamics procedure are: (1) the formulation of a mental model of the problem in the form of a verbal description, (2) The verbal description is expressed as a flow diagram, also called a causal diagram. The basic building blocks for drawing a causal diagram is described in Table 2.1. The last step is to convert the causal diagram into mathematical form.
Table 2.1 Systems Dynamics Variables and Symbols

| 1. Level or Stock or State variables | They are accumulations in a system, such as aircraft, number of runways, and population etc. |
| 2. Rate or Flow Variables | The job of Rate or Flow Variables is to fill and drain accumulations, such as aircraft production rate and population growth rate. |
| 3. Auxiliary or Converters variables | They convert input into outputs. Generally they are used to estimate the rate variables in the simulation of the model. |
| 4. Constants or Converters | They are used to indicate static variables or the boundaries of the model. |
| 5. Connectors | The job of the connector is to connect model elements |

STELLA-II computer software (more detail information in Appendix E) is used to develop a causal diagram, build system dynamics equations and simulate the systems dynamics model in this paper.

2.3 Causal Diagram and Equations

2.3.1 Causal Diagram

Stocks, Flows, Converters, and Connectors are the basic building blocks in STELLA II. These are represented by icons depicted in Figure 2.1. Stocks or Levels variables represent accumulations and are represented by rectangles. Flows are rate of change variables that regulate the flow in and out of stocks. Flows are represented by a pipe through which the flow takes place. Attached to the pipe is a flow regulator or converter which contains the logic that determines the special flow volume. Converters can
represent auxiliary variables, constant parameters, supplementary variables and table functions. They are represented by circles. Converters can represent either information or material quantities. The other basic building block is the connector. Connectors link stocks to converters and converters to other converters. Connectors do not take on numerical values, they represent inputs.

![Diagram of Basic Building Blocks in STELLA II](image)

**Figure 2.1 Basic Building Blocks in STELLA II**

2.3.2 Equations

Integration (or Accumulation) is the basis of the level and rate structure used in System Dynamics. A level variable \( L(t) \) denotes the accumulation of some physical entity at time \( t \). Let \( R_I \) and \( R_O \) represent two rate variables, rate-in (in flow) and rate-out (out flow),
denoting the change in the level variable over the interval from \( t-1 \) to \( t \). The relationship between the level \( L(t) \) and the rate can be expressed mathematically by:

\[
L(t) = L(t-1) + \int_{t-1}^{t} [RI(t)-RO(t)] dt
\]  

(2.1)

In difference equation terminology, any level variable \( L_i \) is expressed as functions of rate variables \( R_j \) and the previous value of the level,

\[
L_i(t) = L(t-1) + (dt)\sum R_j(t) \quad i = 1,2,\ldots,m, \quad j = 1,2,\ldots,n
\]  

(2.2)

with the \( R_j \) is assumed to be constant over the interval from \( t.dt \) to \( t \). The rate variables are of the form

\[
R_j(t) = f[L_i(t),E_k(t),A_{ij}(t), A_{kj}(t)]
\]  

(2.3)

where \( E_k \) is the set of exogenous inputs that affect \( R_j \) directly and \( A_{ij} \) and \( A_{kj} \) are the impacts of auxiliary variables in the causal streams from the \( i \)th level to the \( k \)th exogenous input, respectively. Since the exogenous inputs are known time functions or constants, if the initial values of the level variables are known, all other variables can be computed from them for that time. Then the new values of the level variables for the next point in time can be found from the "level" equation. STELLA II is a computer software which can do integrate calculation directly.
3. Description of China’s Socio-Economics Development Model

3.1 Overview

The demand for any transportation service is affected by a variety of factors which can be classified in two categories: socio-economic and transportation. The socio-economic factors consist of a wide range of considerations which determine the disposition and means of travel. Among the most important of the socio-economic factors are population, gross national product, income, and the composition of the labor force. The transportation factors include the various attributes of the transportation service which interact with socio-economic factors, to further enhance or depress the total volume of travel demand. The principal transportation factors are price or user cost, travel time, convenience, reliability and safety. The objective of the China’s Socio-economic Development Model (CSEDM) is to identify and quantify through Systems Dynamics simulation how these socio-economic factors affect the financial viability of the transportation system in China.

CSEDM is formulated based on the principles of Systems Dynamics. Figure 3.1 shows a sample causal diagram of CSEDM generated with STELLA II. CSEDM is structured to accommodate three development orientations: (1) resource development, (2) regional development and (3) sectional development. Resource components include natural resources, land resources, water resources, and human resources (manpower). Regional development is organized on the basis of rural and urban in CSEMD. Economic elements represented in the model include agriculture, manufacturing, business, infrastructure and government. Obviously, the three orientations overlap. they are also tied together by two quantities most responsible for material growth: (1) population including the effects of all economic and environmental factors that influence human birth, death, and immigration rates, and (2) capital including the mean of producing industrial and agriculture outputs. For the purpose of this thesis, CSEDM is organized and divided into the following
sectors: industrial, agriculture, social, infrastructure, population, and potential air demand and air subsidy sectors.

Figure 3.1 Causal Diagram of the China’s Socio-economic Development Model
The national economy is regarded as a create organization which within a plan period has a readily definable product. The most comprehensive measure of this product is the gross national product (GNP). GNP is the values of all goods and services produced annually. For the purpose of national accounts analysis, GNP statistics are subdivided into nine major categories, based on the International standard Industrial Classification (ISIC). The nine major categories are listed in Table 3.1.

**Table 3.1 International Standard Industrial Classification**

<table>
<thead>
<tr>
<th>Code</th>
<th>Classification and Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agriculture, hunting, forestry and fishing</td>
</tr>
<tr>
<td>2</td>
<td>Mining and quarrying</td>
</tr>
<tr>
<td>3</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>4</td>
<td>Electricity, gas and water</td>
</tr>
<tr>
<td>5</td>
<td>Construction</td>
</tr>
<tr>
<td>6</td>
<td>Wholesale and retail trade, restaurants and hotels</td>
</tr>
<tr>
<td>7</td>
<td>Transport, storage and communication</td>
</tr>
<tr>
<td>8</td>
<td>Financing, insurance, real-estate and business services</td>
</tr>
<tr>
<td>9</td>
<td>Community, social and personal services</td>
</tr>
</tbody>
</table>

In the CSEDM, the agriculture sector is comprised of agriculture, hunting, forestry and fishing. In the industrial sector of the CSEDM is included mining, quarrying, construction, wholesale and retail trade, restaurants and hotels, manufacturing, financing, insurance, real estate, and business services. The infrastructure sector of CSEDM consists of electricity, gas and water, transport, storage and communication. The social sector refers to community, social, and personal services.
3.2 Industry Sector

The causal diagram of the industry sector appears in Figure 3.2

![Causal Diagram of the Industry Sector](image)

**Figure 3.2 Causal Diagram of the Industry Sector**

Chinese industry has been affected greatly by political changes. Since the end of the Cultural Revolution industrial fluctuations have clearly been reduced. At the start of the economic reform from 1977-1978 the industrial growth rate was over 10%, but by 1981 this had declined to almost zero. The industrial growth rate rose to 20% in 1985, when industry worked at full capacity, but from 1986 to 1987 it dropped when the government employed a tight monetary policy. Nevertheless, it still exceeded 10%. It will be developed according to this growth rate or a little bit less than the growth rate in the future. The following paragraphs present a description of relevant model variables.
Industry Capital, IC

Industry capital (IC) is a stock (Level) variable in yuan (Chinese money unit). Each stock variable requires an initial value for the industry capital. The initial value has been assumed 476000E8 in 1995. It is dependent on new industry capital increase rate, industry capital investment and industry capital depreciation. The equation of the industry capital can be written as,

\[ iC(t) = IC(t - dt) + [NICIR(t) + ICI(t) - ICD(t)] * dt \]  \hspace{1cm} (3.1)

\[ INIT \ IC = 476000E8 \]  \hspace{1cm} (3.2)

where:

- IC - industry capital (yuan)
- INIT IC - initial value of industry capital in China in 1995 (yuan)
- NICIR - new industry capital increase rate (yuan/year)
- ICI - industry capital investment (yuan/year)
- ICD - industry capital depreciation (yuan/year)

Industry capital depreciation, ICD

Industry capital depreciation (ICD) is a rate variable in yuan per year and is assumed to depend on the industry capital and the lifetime of the industry capital in a year. The mathematically, ICD can be given by,

\[ ICD = IC/LIC \]  \hspace{1cm} (3.3)

where:

- ICD - industry capital depreciation (yuan/year)
- IC - industry capital (yuan)
- LIC - lifetime of industry capital (years)

The lifetime of the industry capital has been assumed to be 30 years in China.
**New industry capital increase rate, NICIR**

New industry capital increase rate (NICIR) is a rate variable in yuan per year. It is dependent on the gross national product, the fraction of GNP to the industry capital and industry capital increase multiplier. NICIR can be expressed mathematically;

\[
\text{NICIR} = \text{FGNPIC} \cdot \text{GNP} \cdot \text{ICIM} \tag{3.4}
\]

where:

- GNP - gross national product (yuan)
- FGNPIC - fraction of GNP to industry capital (dim)
- ICIM - industry capital increase multiplier (dim)

The fraction of GNP to the industry capital (FGNPIC) is a dimensionless constant expressing how much GNP input to industry capital and has been assumed to be 0.08 in China.

**Industry capital increase multiplier, ICIM**

Industry capital increase multiplier (ICIM) is a dimensionless auxiliary representing the increase in industry capital. The equation of industry capital increase multiplier is written as,

\[
\text{ICIM} = 1 - \text{FIOI} \tag{3.5}
\]

where:

- ICIM - industry capital increase multiplier (dim)
- FIOI - fraction of industry capital output to input (dim)
Industry product, IP

Industry product (IP) is an auxiliary variable in yuan per year. This is the value added by industry after deducting the value of input, such as materials and infrastructure. The industry product equation can be written as,

\[ IP = IO \times (1 - FIOI) \]  \hspace{1cm} (3.6)

where:
- IP - industry product (yuan/year)
- IO - industry output (yuan/year)
- FIOI - fraction of industry output to input (dim)

Industry output, IO

Industry output (IO) is an auxiliary variable in yuan per year. This variable defines the selling price. It depends on the amount of the industry capital and the efficiency of that capital as measured by the industry capital output ratio. The industry capital output equation can be written as,

\[ IO = IC / COR \]  \hspace{1cm} (3.7)

where:
- IO - industry output (yuan/year)
- IC - industry capital (yuan)
- COR - capital output ratio (years)

Capital output ratio, COR

Capital output ratio (COR) is an auxiliary variable in years, it is product of capital output ratio normal by capital output ratio multiplier (CORM). The equation can be written as,

\[ COR = CORN \times CORM \]  \hspace{1cm} (3.8)
where:

- COR - capital output ratio (years)
- CORN - capital output ratio normal (years)
- CORM - capital output ratio multiplier (dim)

The capital output ratio normal has been assumed to be 7.5 years.

**Capital output ratio multiplier, CORM**

Capital output ratio multiplier (CORM) is a dimensionless auxiliary variable which decreases with increasing technical upgrade investment. In this model is represented a by table function of the GNP to industry technical upgrade investment ratio.

**Fraction of the industry output to input, FIOI**

Fraction of the industry output to input (FIOI) is a dimensionless auxiliary variable. This fraction includes costs of infrastructure and materials. Mathematically, FIOI can be written as,

\[
FIOI = FIORM + FIOIFS
\]  

(3.9)

where:

- FIOI - fraction of the industry output to input (dim)
- FIORM - fraction of the industry output to raw materials (dim)
- FIOIFS - fraction of the industry output to infrastructure (dim)

The fraction of the industry output to the raw materials has been assumed to be 0.25 based on the study of the country.

**Fraction of the industry output to infrastructure, FIOIFS**

Fraction of the industry output to the infrastructure (FIOIFS) is a dimensionless auxiliary variable, defined as the product of the fraction of the industry output to infrastructure normal that has been assumed 0.06 by the fraction of the industry output to infrastructure multiplier.
Fraction of the industry output to infrastructure multiplier, FIOIFSM

Fraction of the industry output to infrastructure multiplier (FIOIFSM) is an auxiliary variable modeled as a table function of the ratio of the industry capital to the infrastructure capital. It decreases with increasing infrastructure investment, otherwise, increases.

Jobs in industry, JII

Jobs in industry (JII) is an auxiliary variable representing the number of jobs in industry.

The equation of the jobs in industry can be written as,

\[ JII = \frac{IC}{ICL} \]  

(3.10)

where:

- JII - jobs in industry (persons)
- IC - industry capital (yuan)
- ICL - industry capital per labor force (yuan/person)

ICL has been assumed as 25E4 yuan and is increased at a growth rate of 3.2%

Industry capital investment, ICI

Industry capital investment (ICI) is a rate variable in yuan per year. The amount reinvested in industry capital each year is the product of the industry product and the fraction of industry product invested. The equation of the industry capital investment can be written as,

\[ ICI = FIP_{I1}*IP \]  

(3.11)

where:

- ICI - industry capital investment (yuan/year)
- IP - industry product (yuan/year)
- FIP_{I1} - fraction of industry product investment (dim)
Fraction of industry product investment, FIPI

Fraction of industry product investment (FIPI) is a dimensionless constant dependent upon the fraction of industry product to labor and fraction of industry product to taxes. The fraction of industry product to taxes has been assumed to be 0.3.

Fraction of industry product to labor, FIPL

Faction industry product to labor (FIPL) is a dimensionless constant representing the amount which is paid for labor, it is dependent on the amount of wages and the amount paid for transportation subsidy. The equation of fraction of industry product to labor can be written as,

\[ \text{FIPL} = \text{FIPS} + \text{FIPW} \]  \hspace{1cm} (3.12)

where:
- FIPL - fraction of industry product to labor (dim)
- FIPS - fraction of industry product to transportation subsidy (dim)
- FIPW - fraction of industry product to wages (dim)

The fraction of industry product to transportation subsidy has been assumed to be 0.1. The fraction of industry product to wages has been assumed to be 0.2.

Worker earning non-agriculture, WENA

Worker earning non-agriculture (WENA) is an auxiliary variable (in yuan per person in a year). dependent on the industry product and the jobs in non-agriculture (see equation 3.13).

\[ \text{WENA} = \frac{\text{IP}}{\text{JNA}} \]  \hspace{1cm} (3.13)

where:
- WENA - worker earning non agriculture (yuan/person-year)
- JNA - jobs in non-agriculture (persons)
3.3 Agriculture Sector

The following causal diagram represents the agriculture sector of CSEDM

![Causal Diagram](image)

**Figure 3.3 Causal Diagram of the Agriculture Sector**

Agriculture is one of the most important sector in the initial stages of a nation’s economic development. China is a big agriculture country where the 70% of the population is estimated to be engaged directly in farming and other agricultural pursuits and other are involved in marketing, processing, or exporting agricultural products. China’s agricultural
output has growth rapidly since 1949 and agriculture has played several important roles in the nation’s economic development. By the end of 1970s the primary industry had achieved an annual growth rate of 1.9%. Between 1980 and 1990, this growth jumped to 6.5% per year.
The total of the cultivable land in China is $20E8$ mu (unit of mu is equivalent to 667 square meter) according to recent statistical data (people’s daily newspaper, 1996)

**Cultivable Land, CL**

Cultivable land(CL) is a level variable in (mu). The initial value has been assumed $20E8$ mu. CL is dependent on cultivable land rate of change. Mathematically CL is expressed as,

$$ \text{CL}(t) = \text{CL}(t - \text{dt}) + (- \text{CLR}(t) \times \text{dt}) \quad (3.14) $$

$$ \text{INIT CL} = 2E9 \quad (3.15) $$

where:

- CL - cultivable land in (mu)
- CLR - cultivable land rate of change (mu/year)

**Cultivable land rate of change, CLR**

Cultivable land rate of change is a rate variable in mu per year. It is dependent on urban land required and can be written as,

$$ \text{CLR} = \text{ULR} \quad (3.16) $$

where:

- CLR - cultivable land decrease rate (mu/year)
- ULR - urban land required (mu/year)
Urban land required, ULR

Urban land required (ULR) is an auxiliary variable in mu per year. It is dependent on the urban industry land required and urban population land required. The equation can be written as,

\[ ULR = UILR + UPLR \]  (3.17)

where:
- ULR - urban land required (mu/year)
- UILR - urban industry land required (mu/year)
- UPLR - urban population land required (mu/year)

Urban industry land required, UILR

Urban industry land required (UILR) is an auxiliary variable in mu per year. It is dependent on the land per industry capital and urban industry capital increment. The mathematically, UILR can be written as,

\[ UILR = LPC \times UICI \]  (3.18)

where:
- UILR - urban industry land required (mu/year)
- LPC - land per industry capital (mu/100 million yuan)
- UICI - urban industry capital increment (yuan)

The land required per 100 million yuan has been assumed to be 45 mu.

Urban industry capital increment value, UICI

Urban industry capital increment value (UICI) is an auxiliary variable in yuan per year. It is dependent on the industry capital, the infrastructure capital, the social capital and the initial value of them. The equation can be written as,
\[
UICI = (IC + IFS + SC) - (INIT IC + INIT IFS + INIT SC)
\]  
(3.19)

where:

- \(UICI\) - urban industry capital increment (yuan/year)
- \(IC\) - industry capital (yuan)
- \(IFS\) - infrastructure capital (yuan)
- \(SC\) - social capital (yuan)
- \(INIT IC\) - initial value of the industry capital (yuan)
- \(INIT IFS\) - initial value of the infrastructure capital (yuan)
- \(INIT SC\) - initial value of the social capital (yuan)

Initial values assumed for industry capital, infrastructure capital and social capital are 47600E8, 50575E8 and 43670E8 yuan, respectively.

**Urban population land required, UPLR**

Urban population land required (UPLR) is an auxiliary variable in mu per year. It is dependent on the land per urban population and the urban population increment. UPLR can be written mathematically as,

\[
UPLR = LPUP \times UPI
\]  
(3.20)

where:

- \(UPLR\) - urban population land required (mu/year)
- \(LPUP\) - land per urban population (mu/person)
- \(UPI\) - urban population increment value (persons/year)

The land per urban population has been assumed to be 0.15 mu.

**Urban population increment, UPI**

Urban population increment value (UPI) is an auxiliary variable in persons per year. It is dependent on the initial value of the urban population and the urban population itself. Mathematically, UPI can be written as,
UPI = UP - UPN \tag{3.21}

where:

UPI - urban population increment (persons/year)

UP - urban population (persons)

UPN - initial value of the urban population (persons)

Cultivable area, CA

The cultivable area (CA) is an auxiliary variable in mu. It is dependent on the cultivable land and the multiple cropping index. CA can be written mathematically as follow:

\[ CA = CL \times MCI \tag{3.22} \]

where:

CA - cultivable area (mu)

CL - cultivable land (mu)

MCI - multiple cropping index (dim)

Multiple cropping index, MCI

The multiple cropping index (MCI) is a dimensionless auxiliary variable. It is dependent on the multiple cropping index normal and the multiple cropping index multiplier. MCI can be written as,

\[ MCI = MCIN \times MCIM \tag{3.23} \]

where:

MCI - multiple cropping index (dim)

MCIN - multiple cropping index normal (dim)

MCIM - multiple cropping index multiplier (dim)

The multiple cropping index normal has been assumed to be 1.5.
The multiple cropping index multiplier, MCIM

The multiple cropping index multiplier (MCIM) is a dimensionless auxiliary variable. For modeling purposes it is expressed as a table function of the GNP to agriculture investment ratio.

**GNP to agriculture investment ratio, GNPAIR**

GNP to agriculture investment ratio (GNPAIR) is a dimensionless auxiliary variable. GNPAIR is the GNP to agriculture investment to the initial value of GNP to agriculture investment that has been assumed to be 300E8 yuan in 1995.

\[
\text{GNPAIR} = \frac{\text{GNPAI}}{\text{GNPAIN}} \quad (3.24)
\]

where:
- GNPAIR - GNP to agriculture investment ratio (dim)
- GNPAI - GNP to agriculture investment (yuan/year)
- GNPAIN - the initial value of GNP to agriculture investment (yuan)

**GNP to agriculture investment, GNPAI**

GNP to agriculture investment (GNPAI) is an auxiliary variable in yuan per year. It is dependent on GNP to agriculture investment increment that has been assumed to be 0.075. The equation can be written as,

\[
\text{GNPAI} = 300E8 \times (1+\text{GNPAII})^{\text{TIME-1995}} \quad (3.25)
\]

where:
- GNPAI - GNP to agriculture investment (yuan/year)
- GNPAII - GNP to agriculture investment increment (dim)
Worker earning in agriculture, WEA

The worker earning in agriculture (WEA) is an auxiliary variable in yuan per person in a year. It is dependent on the initial value of worker earning in agriculture, the ratio of the cultivable area to the initial value of cultivable area and the ratio of the agriculture diversity index to the initial value of agriculture diversity index. Mathematically, this can be written as,

\[
\text{WEA} = \text{WEAN} \times (\text{CA} / \text{CAN}) \times (\text{ADI} / \text{ADIN}) \tag{3.26}
\]

where:
- WEA - worker earning in agriculture (yuan/person-year)
- WEAN - initial value of worker earning in agriculture (yuan/person-year)
- CA - cultivable area (mu)
- CAN - initial value of cultivable area (mu)
- ADI - agriculture diversity index (dim)
- ADIN - initial value of agriculture diversity index (dim)

The initial value of worker earning in agriculture has been assumed 3310 yuan in 1995. The initial value of the cultivable area is an auxiliary constant and it’s mathematical expression is;

\[
\text{CAN} = \text{CLN} \times \text{MCIN} \tag{3.27}
\]

where:
- CAN - initial value of the cultivable area (mu)
- CLN - initial value of the cultivable land (mu)
- MCIN - initial value of the multiple cropping index (dim)

Agriculture diversity index, ADI

Agriculture diversity index (ADI) is a dimensionless auxiliary variable. It is modeled as a table function of time.
Agriculture diversity index normal, ADIN
Agriculture diversity index normal (ADIN) is an auxiliary constant which has been assumed to be 1 in 1995.

Relative earning in agriculture, REA
Relative earning in agriculture (REA) is a dimensionless auxiliary variable. It is dependent on the worker earning in agriculture and the worker earning non-agriculture. The equation of relative earning in agriculture is expressed by:

\[ \text{REA} = \frac{\text{WEA}}{\text{WENA}} \] (3.28)

where:

- REA - relative earning in agriculture (dim)
- WEA - worker earning in agriculture (yuan/person-year)
- WENA - worker earning non-agriculture (yuan/person-year)

Agriculture product, AP
Agriculture product (AP) is an auxiliary variable in yuan per year. It is dependent on the worker in agriculture and the rural labor force. AP is computed by,

\[ \text{AP} = \text{WEA} \times \text{RLF} \] (3.29)

where:

- AP - agriculture product (yuan/year)
- WEA - worker in agriculture (yuan/person-year)
- RLF - rural labor force (persons)

Rural labor force, RLF
Rural labor force (RLF) is an auxiliary variable dependent on the rural population and rural labor force participation. The equation for rural labor force can be written as,
\[ RLF = RP \times RLFP \]  \hspace{1cm} (3.30)

where:

- \( RLF \) - rural labor force (persons)
- \( RP \) - rural population (persons)
- \( RLFP \) - rural labor force participation (dim)

The rural labor force participation has been assumed to be 0.4 in China.

### 3.4 Social sector

The following causal diagram represents the social sector.

![Causal Diagram of the Social Sector](image)

**Figure 3.4 Causal Diagram of the Social Sector**

**Social capital, SC**

Social capital (SC) is a level variable in yuan. It is dependent on the social capital investment and the social capital depreciation. The equation for SC can be written as,

\[ SC(t) = SC(t - dt) + [SCI(t) - SCD(t)] \times dt \]  \hspace{1cm} (3.31)

\[ \text{INIT } SC = 43670E8 \]  \hspace{1cm} (3.32)
where:

SC - social capital (yuan)
SCI - social capital investment (yuan/year)
SCD - social capital depreciation (yuan/year)

The initial value of the social capital has been assumed 43670E8 yuan.

**Social capital investment, SCI**

Social capital investment (SCI) is a rate variable in yuan per year. It is dependent on the GNP and the fraction of GNP to the social capital. The equation of SCI is expressed by,

\[
SCI = FGNPSC \times GNP
\]  
(3.33)

where:

SCI - social capital investment (yuan/year)

FGNPSC - fraction of GNP to social capital (dim)

The fraction of GNP to social capital is assumed to be 0.035.

**Social capital depreciation, SCD**

Social capital depreciation (SCD) is a rate variable in yuan per year. It is dependent on the social capital and the lifetime of social capital. The equation of the SCD is expressed by,

\[
SCD = \frac{SC}{LSC}
\]  
(3.34)

where:

SCD - social capital depreciation (yuan/year)
SC - social capital (yuan)
LSC - lifetime of social capital (year)

The LSC has been assumed to be 50 years.
**Jobs in social capital, JSC**

Jobs in social capital (JSC) is an auxiliary variable dependent on the social capital and the social capital labor force. JSC is expressed by,

\[
JSC = \frac{SC}{SCL}
\]  \hspace{1cm} (3.35)

where:

- JSC - jobs in social capital (persons)
- SC - social capital (yuan)
- SCL - social capital labor force (yuan/person)

The initial value of SCL has been assumed to be 12E4 yuan, it is increased at a growth rate of 0.003 per year.

**Social capital per capita ratio, SCPCR**

Social capital per capita ratio (SCPCR) is a dimensionless auxiliary variable. SCPCR depends on the social capital, the total population, the initial value of the social capital and the initial value of the total population. The equation to estimate SCPCR is shown below.

\[
SCPCR = \frac{(SC/TP)}{(SCN/TPN)}
\]  \hspace{1cm} (3.36)

where:

- SCPCR - social capital per capita ratio (dim)
- SC - social capital (yuan)
- SCN - initial value of social capital (yuan)
- TP - total population (persons)
- TPN - initial value of total population (persons)

The initial value of the total population in China is 1.2112 billion by the end of 1995 (people’s daily, 1996).
3.5 Infrastructure Sector

Figure 3.5 shows the causal diagram of the infrastructure sector.

![Causal Diagram of the Infrastructure Sector](image)

**Figure 3.5 Causal Diagram of the Infrastructure Sector**

**Infrastructure capital, IFS**

Infrastructure (IFS) is a level variable (in yuan) dependent on the infrastructure capital investment and the infrastructure capital depreciation. The equation to estimate IFS can be written as,

\[
IFS(t) = IFS(t - dt) + [IFSI(t) - SIFSD(t)] * dt
\]  

(3.37)

\[
INIT IFS = 50575E8
\]  

(3.38)

where:

IFS - infrastructure capital (yuan)

IFSI - infrastructure capital investment(yuan/year)
IFSD  -  infrastructure capital depreciation (yuan/year)
The initial value of infrastructure capital has been assumed to be 50575E8 yuan in 1995.

Infrastructure capital investment, IFSI
Infrastructure capital investment (IFSI) is a rate variable (in yuan per year) dependent on the GNP and the fraction of GNP to infrastructure capital. Equation 3.39 estimates IFSI.

\[
IFSI = FGNPIFS \times GNP
\]  

(3.39)

where:

\[FGNPIFS\]  -  fraction of GNP to infrastructure capital (dim)
\[IFSI\]  -  infrastructure capital investment (yuan/year)

The fraction of GNP to infrastructure capital is assumed to be 0.06.

Infrastructure capital depreciation, IFSD
Infrastructure capital depreciation (IFSD) is a rate variable (in yuan per year) dependent on the infrastructure capital and the lifetime of infrastructure capital. Equation 3.40 estimates IFSD.

\[
IFSD = IFS / LIFS
\]  

(3.40)

where:

\[IFSD\]  -  infrastructure capital depreciation (yuan/year)
\[IFS\]  -  infrastructure capital (yuan)
\[LIFS\]  -  lifetime of infrastructure capital (years)
The LIFS has been assumed to be 40 years.
Jobs in infrastructure capital, JIFS
Jobs in infrastructure capital (JIFS) is an auxiliary variable (in persons) dependent on the infrastructure capital and the infrastructure capital per labor force. The equation for JIFS is expressed by,

\[ JIFS = \frac{IFS}{IFSL} \]  

(3.41)

where:
- JIFS - jobs in infrastructure capital (persons)
- IFS - infrastructure capital (yuan)
- IFSL - infrastructure capital per labor force (yuan/person)

The initial value of SCL has been assumed to be 25E4 yuan, and is increased at a growth rate of 0.04 per year.

Industry capital to infrastructure capital ratio, ICIFSR
Industry capital to infrastructure capital ratio (ICIFSR) is a dimensionless auxiliary variable dependent on the industry capital, the infrastructure capital, the initial value of industry capital and the initial value of the infrastructure capital. Equation 3.42 estimates ICIFSR.

\[ ICIFSR = \frac{IC}{IFS} \frac{ICN}{IFSN} \]  

(3.42)

where:
- ICIFSR - industry capital to infrastructure capital ratio (dim)
- IC - industry capital (yuan)
- ICN - initial value of industry capital (yuan)
- IFS - infrastructure capital (yuan)
- IFSN - initial value of infrastructure capital (yuan)
3.6 Population Sector

Figure 3.6 shows a causal diagram depicting the population sector. The total population is 1.2112 billion according to the census in 1995. China is the most populated country in the world which means that the adequate labor force market is provided in China but it also requires the economy to provide the jobs and materials necessary for an adequate standard of living.

Figure 3.6 Causal Diagram of the Population Sector
Urban Population, UP

Urban population (UP) is a level variable (in persons) dependent on the rural to urban migration rate and the net urban population growth. UP can be estimated according to equation 3.43.

\[ UP(t) = UP(t - dt) + [RUMR(t) + NUPG(t)] \times dt \]  \hspace{1cm} (3.43)

INIT UP = 3.5355E8  \hspace{1cm} (3.44)

where:

- UP - urban population (persons)
- RUMR - rural to urban migration rate (persons/year)
- NUPG - net urban population growths (persons/year)

The initial value of the urban population is 3.5355E8 persons in China by the end of 1995.

Rural to urban migration rate, RUMR

Rural to urban migration rate (RUMR) is a rate variable (in persons per year) dependent on the rural population and the rural to urban migration multiplier. Equation 3.45 is used to estimate RUMR.

\[ RUMR = RP \times RUMM \]  \hspace{1cm} (3.45)

where:

- RUMR - rural to urban migration rate (persons/year)
- RP - rural population (persons)
- RUMM - rural urban migration multiplier (dim)
Rural urban migration multiplier, RUMM

Rural urban migration multiplier (RUMM) is a dimensionless auxiliary variable. RUMM is modeled as a table function of relative earnings in agriculture.

Net urban population growth, NUPG

Net urban population growth (NUPG) is a rate variable (in persons per year) dependent on the urban birth and the urban death. Equation 3.46 estimates NUPG.

\[ \text{NUPG} = \text{UB} - \text{UD} \quad (3.46) \]

where:

- NUPG - net urban population growth (persons/year)
- UB - urban birth (persons/year)
- UD - urban death (persons/year)

Urban birth, UB

Urban birth (UB) is an auxiliary variable (in persons per year) dependent on the urban population and the urban fertility. Equation 3.47 estimates UB.

\[ \text{UB} = \text{UP} \times \text{UF} \quad (3.47) \]

where:

- UB - urban birth (persons/year)
- UP - urban population (persons)
- UF - urban fertility (fraction/year)

Urban fertility, UF

Urban fertility (UF) is an auxiliary variable (in fraction per year) dependent on the urban fertility normal and the one child policy in China. Mathematically, urban fertility can be estimated as follow:
\[ UF = UFN - OCP \] (3.48)

where:
- \( UF \) - urban fertility (fraction/year)
- \( UFN \) - urban fertility normal (fraction/year)
- \( OCP \) - one child policy in China (dim)

The urban fertility normal has been assumed to be 0.0148. The one child policy is modeled as a table function of time.

**Urban death, UD**

Urban death (UD) is an auxiliary variable (in persons per year) dependent on the urban population and the urban mortality. Mathematically, UD is estimated using equation 3.49.

\[ UD = UP \times UM \] (3.49)

where:
- \( UD \) - urban deaths (persons/year)
- \( UP \) - urban populations (persons)
- \( UM \) - urban mortality (fraction/year)

**Urban mortality, UM**

Urban mortality (UM) is an auxiliary variable dependent on the urban mortality normal and the urban mortality multiplier. Equation 3.50 is used to estimate urban mortality.

\[ UM = UMN \times UMM \] (3.50)

where:
- \( UM \) - urban mortality (fraction/year)
- \( UMN \) - urban mortality normal (fraction/year)
UMM - urban mortality multiplier (dim)

Urban mortality multiplier (UMM) is a dimensionless auxiliary variable modeled as a table function in term of social capital per capita ratio.

Urban mortality normal has been assumed to be 0.0065.

**Rural Population, RP**

Rural population (RP) is a level variable (in persons) dependent on the rural to urban migration rate and the net rural population growth. Mathematically, RP can be estimated according to equation 3.51.

\[
RP(t) = RP(t - dt) + [NRPG(t) - RUMR(t)] \times dt \tag{3.51}
\]

\[
INIT\ RP = 8.5766E8 \tag{3.52}
\]

where:

- \( RP \) - rural population (persons)
- \( RUMR \) - rural to urban migration rate (persons/year)
- \( NRPG \) - net urban population growth (persons/year)

The initial value of the rural population is 8.5766E8 people in China by the end of 1995.

**Net rural population growth, NRPG**

Net rural population growth (NRPG) is a rate variable (in persons per year) dependent on the rural birth and the rural death. NRPG can be estimated according to equation 3.53.

\[
NRPG = RB - RD \tag{3.53}
\]

where:

- \( NRPG \) - net rural population growth (persons/year)
- \( RB \) - rural births (persons/year)
- \( RD \) - rural deaths (persons/year)
Rural birth, RB

Rural birth (RB) is an auxiliary variable dependent on the rural population and the rural fertility. RB can be estimated according to equation 3.54.

\[ RB = RP \cdot RF \quad (3.54) \]

where:
- RB - rural birth (persons/year)
- RP - rural population (persons)
- RF - rural fertility (fraction/year)

Rural fertility, RF

Rural fertility (UF) is an auxiliary variable dependent on the rural fertility normal and the one child policy in China. Mathematically, RF is found as follow:

\[ RF = RFN - OCP \quad (3.55) \]

where:
- RF - rural fertility (fraction/year)
- RFN - rural fertility normal (fraction/year)
- OCP - one child policy in China (dim)

The rural fertility normal has been assumed to be 0.0205. The one child policy is modeled as a table function of time.

Rural death, RD

Rural death (RD) is an auxiliary variable (in persons per year) dependent on the rural population and the rural mortality. Mathematically RD can be estimated according to equation 3.56.

\[ RD = RP \cdot RM \quad (3.56) \]
where:

RD - rural death (persons/year)
RP - rural population (persons)
RM - rural mortality (fraction/year)

**Rural mortality, RM**

Rural mortality (RM) is an auxiliary variable dependent on the rural mortality normal and the rural mortality multiplier. RM can be estimated according to equation 3.57.

\[ RM = RMN \times RMM \]  \hspace{1cm} (3.57)

where:

RM - rural mortality (fraction/year)
RMN - rural mortality normal (fraction/year)
RMM - rural mortality multiplier (dim)

The rural mortality multiplier (RMM) is a dimensionless auxiliary variable modeled as a table function of the social capital per capita ratio. The rural mortality normal has been assumed to be 0.0095.

### 3.7 Air passenger and air subsidy sector

#### 3.7.1 Air Transportation Demand

Every day an extremely large number of trips are made and considerable amounts of merchandise are transported by air. The need for transportation arises from various activities. By monitoring the number of passengers flows on different routes during a day, week and month, certain patterns are noted that characterize the demand for air transportation services. In addition, air transportation developments in the past revealed certain dependencies between the demand for air transportation services and the socio-economic characteristics. Demand is greater in more developed regions on the one hand,
and air traffic accelerates the development of the regions it links, on the other. The noted dependencies between the demand for air transportation services and the socio-economic characteristics of the region are used in the air transportation planning process. This process entails the planning of airports and other transportation facilities, route networks and planning networks of airways.

Passenger demand intensity comprises the number of passenger in a unit of time. There is also a potential passenger demand intensity that includes the number of passenger in a unit of time that would like to travel. Real and potential passenger demand intensities most often differ due to numerous factors. It is important that we estimate the air transportation demand applied a model, since passenger traffic is crucially important to the dimensions given to certain facilities in a region.

3.7.2 The Supply of Air Transportation Services

The supply of air transportation services normally comprises a set of the following attributes: travel time, waiting time at an airport, transportation tariffs, ground costs, flight frequency, airline schedule, airplane types and cabin service.

Travel time includes the total time needed for a passenger to go from the center of the city of departure to the center of another city, waiting time and transfer time must also be added to flight time. Travel time is a factor that considerably affects the passenger’s decision to use a certain mode of transportation. Travel costs normally comprises the passenger’s total costs. This includes, in addition to the cost of the tickets, all other passenger outlays during trip. Flight frequency and airline schedule are extremely important attributes to the supply of the air transportation services. The quality of air transportation services certainly depends on flight frequency and the size of the aircraft providing transportation. The airline schedule, or the distribution of airplane departures, also has an essential effect on the quality of supply.
Comfort during the trip, i.e. cabin services, is evaluated by the polling the passengers. Airline carriers take surveys of the passengers from time to time thereby establishing the quality of cabin services. The supply of transportation services has an essential effect on air transportation demand. For example, by increasing flight frequency, better adjusting the airline schedule to passenger requests, reducing tariffs of some other promotional measure, air transportation demand can be increased to a certain extent. In the same vein, a decline in demand is often caused by an inadequate supply of air transportation facilities and poor air transportation services offered to passengers. Due to this dependence between transport demand and supply, many models that evaluate transportation demand have built in certain attributes of the supply of transportation services in both air transportation and on other competitive modes mode of transportation in a region.

3.7.3 Demand Estimation Models

The previous presentation underscored that demand for transportation in a region depends on both the socio-economic characteristics of the region and the characteristics of the transportation system. Models to estimate air transportation demand most often evaluate the number of potential passengers or the number of passenger kilometers that can be achieved, Forecasting transportation demand is certainly the most important step in transportation planning.

Several classifications of air transportation demand models have been proposed over the years. In certain cases transportation demand should be estimated independently of the other types of transportation. In other case transportation demand must be estimated by taking into consideration the characteristics of competitive transportation modes. depending on whether or not the model includes competitive modes of transportation, demand estimation models in air transportation can be divided into:

1) multimode models
2) estimated demand models that are independent of characteristics of alternative modes of transportation.
In long haul traffic, different modes of transportation are most often studied independently of each other since the longer the trip the smaller the number of alternative modes of transportation. The airplane is the predominant mode of transportation on many long-distance traffic routes. Travel time is much more important to long-distance passengers than the price of the ticket. Therefore, demand for air transportation on long haul routes should be estimate independently of other modes of transportation.

Multimode models are primarily used to estimate demand for air transportation on short-haul routes.

Another classification of air transportation demand models views the size of the market to be studied. Two models of air transportation demand suggested by Kanafani are: a) macroscopic models and b) microscopic models.

Microscopic models estimate air transportation demand between two cities, the passenger traffic at an airport, the number of passengers along a specific route when there are several different routes and the number of passengers on each class when there different tariffs on a route.

Macroscopic models are used to estimate the development level of air transportation in a certain country or region. These models are used to estimate the number of passengers, the number of airplane operations or the number of passenger kilometers. The number of passengers normally comprises the total number of passengers on commercial flights in a region during a certain period of time.

3.7.4 Estimated Demand for China's Air Transportation Using a Macroscopic Model

Macroscopic models to predict air transportation demand consider socio-economic characteristics as independent variables. The socio-economic characteristics that are most
often selected include: total population (TP), gross national product (GNP), capita income (CI), jobs in non-agriculture (JOBNA), urban population (UP), etc.

Macroscopic models make it possible to estimate the development level of air traffic in a specific country or region. In order to successfully calibrate macroscopic models, a good statistical database must be available. Macroscopic models where demand is a function of socio-economic characteristics can be written in the following general form:

\[
Y_t = a \prod_{i=1}^{m} S_{it}^{b_i}
\]  

(3.58)

where:

- \( m \) - the total number of socio-economic characteristic factors
- \( Y_t \) - the number of potential air passengers in year \( t \),
- \( S_{it} \) - the value of the \( i \)-th socio-economic characteristics in year \( t \),
- \( a, b_i \) - parameters to be estimated statistically.

By taking the natural logarithm of both sides of above equation we get the following:

\[
\ln Y_t = \ln a + \sum_{i=1}^{m} b_i \ln S_{it}
\]  

(3.59)

The parameters can be estimated using the multiple regression techniques. The following estimation equation has been derived for the air transportation demand in China.

\[
\ln Y_t = -36 + 0.97 \ln \text{GNP} + 11 \ln \text{TP} - 2.84 \ln \text{JOBNA}
\]  

(3.60)

where:

- \( Y_t \) - the number of potential air passengers in year \( t \),
- GNP - gross national product (yuan)
- TP - total population (persons)
JOBNA - jobs non-agriculture (persons)

Some socio-economic characteristics were not used, such as capita income, because they showed high correlation with other variables.

Following is the discussion of the correlation of this regression equation 3.60. Table 3.2 shows a analysis of variance for the multiple linear regression.

**Table 3.2 Analysis of Variance**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>3</td>
<td>9.0875</td>
<td>3.0292</td>
<td>1586.70</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td>0.0210</td>
<td>0.0018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>9.1085</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

One criterion that is commonly used to illustrate the adequacy of a fitted regression model is the coefficient of multiple determination:

\[ R^2 = \frac{SSR}{SST} \]  \hspace{1cm} (3.61)

where:

- \( R^2 \) - coefficient of multiple determination
- SSR - regression sum of squares
- SST - total sum of squares

This quantity merely indicates what proportion of the total variation in the response Y is explained by the fitted model. Often an experimenter will report \( R \times 100\% \) and interpret the result as percentage variation explained by the postulated model.

In the CSEDM, the value of \( R \) indicating the proportion of variation explained by the three independent variables GNP, TP and JNA is found to be:

\[ R^2 = \frac{9.0875}{9.1085} = 0.9976 \]  \hspace{1cm} (3.62)
Which means that 99.8% of the variation in percent air demand has been explained by the linear regression model.

The regression sum of squares can be used to give some indication concerning whether or not the model is an adequate explanation of the true situation. One can test the hypothesis $H_0$ that the regression is not significantly by merely forming ration:

$$f = \frac{SSR/k}{[SSE/(n-k-1)]}$$  \hspace{1cm} (3.63)

where:

- $f$ - forming the ratio
- $SSR$ - regression sum of squares
- $SSE$ - error sum of squares
- $k$, $n-f-1$ - degree of freedom

and rejecting $H_0$ at the $\alpha$-level of significance when $f > f_\alpha (k, n-k-1)$. For CSEDW we obtain:

$$f = \frac{(9.0875/3)/[0.0210/(15-3-1)]} = 1586.70$$  \hspace{1cm} (3.64)

This value of $F$ exceed that tabulated critical point 5.95 of the $F$-distribution for 3 and 12 degree of freedom at the $\alpha = 0.01$ level. So, this regression explained by the model is significant.

Referring to Figure 3.7, the following is the explanation of the causal diagram of air passenger and air subsidy sector.

**Total number of potential air passengers, TAP**

Total number of potential air passengers is an auxiliary variable in person per year. It is dependent on the total population, the gross national product, the non-agriculture jobs and a regression constant. The equation for TAP is written as,
\[ \ln Y_t = -36 + 0.97 \ln GNP + 11 \ln TP - 2.84 \ln JNA \]  \hspace{1cm} (3.65) \\

\[ Y_t = TAP = e^{-36 \times GNP^{0.97 \times TP^{11}} \times JNA^{-2.84}} \]  \hspace{1cm} (3.66) \\

where:

TAP - total number of air passenger (persons/year)  
GNP - gross national product (yuan/year)  
TP - total population (persons)  
JNA - non-agriculture jobs (persons) 

The constants before the socio-economic characteristics are the regression parameters.

![Diagram of potential air demand and air subsidy sector]

Figure 3.7 Causal Diagram of the Potential Air Demand and Air Subsidy Sector
Total population, TP

Total population (TP) is an auxiliary variable dependent on the urban population and the rural population. The equation for the total population can be written as,

\[
TP = RP + UP
\]  \hspace{1cm} (3.67)

where:
- TP - total population (persons)
- UP - urban population (Persons)
- RP - rural population (persons)

Non-agriculture Jobs, JNA

Non-agriculture Jobs (JNA) is an auxiliary variable dependent on the jobs in industry capital, jobs in social capital and jobs in infrastructure. Equation 3.68 estimates the number of non-agriculture jobs.

\[
JNA = JII + JIFS + JSC
\]  \hspace{1cm} (3.68)

where:
- JNA - non-agriculture jobs (persons)

Gross National Product, GNP

Gross national product (GNP) is an auxiliary variable (in yuan per year) dependent on the industrial product and the agriculture product. Equation 3.69 is used to estimate GNP.

\[
GNP = (IP + AP)/(1 + AROI)^{(TIME - 1995)}
\]  \hspace{1cm} (3.69)

where:
- GNP - gross national product (yuan/year)
IP - industrial product (yuan/year)
AP - agriculture product (yuan/year)
AROI - annual rate of inflation (fraction/year)

In this model, AROI has been assumed to be zero.

**Air transportation subsidy, ATS**

Air transportation subsidy (ATS) is an auxiliary variable (in yuan per year) dependent on the infrastructure capital and the faction of the infrastructure capital to the air transportation. Mathematically ATS can be estimates as,

\[ \text{ATS} = \text{IFS} \times \text{FIFSAT} \]  \hspace{1cm} (3.70)

where:

ATS - air transportation subsidy (yuan/year)
IFS - infrastructure capital (yuan/year)
FIFSAT - fraction of infrastructure capital to air transportation (fraction/year)

**Faction of infrastructure capital to the air transportation, FIFSAT**

Faction of infrastructure capital to the air transportation (FIFSAT) is an auxiliary variable (in fraction per year) dependent on the initial value of the faction of infrastructure to the air transportation which has been assumed to be 0.0016 in 1995 and the fraction of infrastructure to the air transportation multiplier modeled as a table function of the time at an annual growth rate of 17%.
4. Description China’s Air Transportation Development Model

4.1 Overview

China’s air transportation system development model (CATSDM) is also formulated based on the principles of the Systems Dynamics. The visual description displaying the cause and effect relationship between goal and policy variables is presented in the form of a causal diagram (shown in Figure 4.1) which has been generated with STELLA II computer software. As mentioned before, civil aviation consists of at least five interconnected groups of individuals and organizations with an interest in the industry: 1) Airlines, 2) Airports and providers of Air Traffic Control, 3) Equipment Manufacturers, 4) Consumers, and 5) Third Parties. We mainly focus on two groups: airlines and infrastructure. CATSDM is organized into the following sectors: Airline, Airport and Air traffic control sectors.
Figure 4.1 Causal Diagram of China’s Air Transportation System

Development Model
4.2 Airlines Sector

The causal diagram for the airlines sector is shown in Figure 4.2.

![Causal Diagram of the Airlines Sector](image)

**Figure 4.2 Causal Diagram of the Airlines Sector**

**Airline fleet, AF**

Aircraft used in airlines operations have capacities ranging from less than 20 to approximately 500 passengers. Airline fleet (AF) is a level variable divided into three categories including: heavy aircraft (with maximum take-off weight greater than 136,000 kg.), large aircraft (with maximum take-off weight between 27,200 to 136,000 kg.) and small aircraft (with maximum take-off weight is less than 27,200 kg.). Heavy aircraft accounts for 20%, 60% for the large and 20% for the small aircraft in China’s commercial airline fleet according to the data of China’s civil aviation statistical book. Each level variable required an initial value for the airline fleet. The initial value has been assumed to be 416 aircraft by the end of 1995. The airline fleet is dependent on the airline fleet increase rate and the airline fleet retirement rate. Mathematically, AF can be written as,

\[
AF(t) = AF(t - dt) + [AF\bar{R}(t) - AFRR(t)] \times dt \tag{4.1}
\]

\[
INIT \text{ } AF = 416 \tag{4.2}
\]
where:

$AF$ - airline fleet (aircraft)

$AFIR$ - airline fleet increase rate (aircraft/year)

$AFRR$ - airline fleet retirement rate (aircraft/year)

**Airline fleet retirement rate, AFRR**

Airline fleet retirement rate ($AFRR$) is a rate variable in aircraft per year. It depends on the airline fleet and the lifetime of the airline fleet. Equation 4.3 is used to estimate the airline fleet retirement rate.

$$AFRR = \frac{AF}{LAF} \quad (4.3)$$

where:

$AFRR$ - air fleet retirement rate (aircraft/year)

$AF$ - air fleet (aircraft)

$LAF$ - lifetime of air fleet (years)

The lifetime of the airline fleet has been assumed to be 20 years.

**Airline fleet increase rate, AFIR**

Airline fleet increase rate ($AFIR$) is a rate variable with units of aircraft per year. The airline fleet in China’s civil aviation system is increased according to the existing proportion of the heavy aircraft, large aircraft and small aircraft mentioned above. It is dependent on the ratio of air demand to airline capacity, the new aircraft budget, the costs of small, large and heavy aircraft. Mathematically, AFIR can be written as,

$$AFIR = \begin{cases} 0 & \text{if } DCR < 0.65 \\ (NAF) \times \frac{0.05}{CPSA} + \frac{0.55}{CPLA} + \frac{0.4}{CPHA} & \text{else} \end{cases} \quad (4.4)$$
where:

AFIR - airline fleet increase rate (aircraft/year)
DCR - ratio of air demand to airline fleet capacity (dim)
NAF - new aircraft funding (yuan/year)
CPS - costs per small aircraft (yuan/aircraft)
CPL - costs per large aircraft (yuan/aircraft)
CPH - costs per heavy aircraft (yuan/aircraft)

The numbers of 0.05, 0.55 and 0.4 are the proportion coefficient of the new aircraft budget, that is to purchase the small aircraft using 5% of the new aircraft budget, 55% for the large aircraft and 40% for the heavy aircraft.

The costs of small, large and heavy aircraft have been assumed to be 7E8, 3E8 and 10E7 yuan, respectively. The price of all categories aircraft is increased at growth rate of 15% (K3) every year. Equations to estimate aircraft costs are:

\[
\text{CPS} = 10E7*(1+K3)^{(\text{TIME}-1995)} \quad (4.5)
\]

\[
\text{CPL} = 3E8*(1+K3)^{(\text{TIME}-1995)} \quad (4.6)
\]

\[
\text{CPH} = 7E8*(1+K3)^{(\text{TIME}-1995)} \quad (4.7)
\]

The number of 0.65 is the typical load factor for airlines. The average load factor for most airlines in China is 0.65 according to statistical data. To model a decision making rule China’s civil aviation system will purchase new aircraft if the ratio of air demand to air fleet capacity is more than the load factor, otherwise, Airlines will maintain the existing air fleet.

The IF, THEN and ELSE are logical functions used in this context and explained in Appendix E.
**New aircraft budget, NAB**

New aircraft budget (NAB) is an auxiliary variable (in yuan per year) dependent on the airlines revenue to new aircraft budget, the total air subsidy to new aircraft budget and the loan funding. Mathematically, NAB can be written as,

\[
NAB = ARNAB + ASNAB + LOAN \tag{4.8}
\]

where:
- **NAB** - new aircraft budget (yuan/year)
- **ARNAB** - airlines revenue to new aircraft budget (yuan/year)
- **ASNAB** - total air subsidy to new aircraft budget (yuan/year)
- **LOAN** - loan funding (yuan/year)

**Total air subsidy to new aircraft budget, ASNAB**

Total air subsidy to new aircraft budget (ASNAB) is an auxiliary variable (in yuan per year) dependent on the fraction of total air subsidy to new aircraft budget and the total air subsidy. ASNAB is computed according to equation 4.9.

\[
ASNAB = FASNAB \times AS \tag{4.9}
\]

where:
- **ASNAB** - total air subsidy to new aircraft budget (yuan/year)
- **AS** - total air transportation subsidy (yuan/year)
- **FASNAB** - fraction of total air subsidy to new aircraft budget (fraction/year)

The fraction of total air subsidy to new aircraft budget has been assumed 0.25. The total air transportation subsidy is estimated by the China's socio-economic development model.
Airlines revenue to new aircraft budget, ARNAB

Airlines revenue to new aircraft budget (ARNAB) is an auxiliary variable (in yuan per year) dependent on the fraction of airlines revenue to new aircraft budget and the airlines revenue. Equation 4.10 estimates ARNAB

\[
\text{ARNAB} = \text{AR} \times \text{FARNAB} \quad (4.10)
\]

where:

- ARNAB - airlines revenue to new aircraft budget (yuan/year)
- AR - airlines revenue (yuan/year)
- FARNAB - fraction of airlines revenue to new aircraft budget (fraction/year)

The fraction of airlines revenue to new aircraft budget has been assumed to be 0.4.

Airline fleet capacity, AFCAPA

Airline fleet capacity (AFCAPA) is an auxiliary variable (in passengers per year) dependent on the airline fleet, the airline fleet utilization factor, the trips per aircraft a day, and the capacity of aircraft. Mathematically, AFCAPA is,

\[
\text{AFCAPA} = \text{AF} \times \text{AFUF} \times \text{TPAD} \times (0.2 \times \text{CHA} + 0.6 \times \text{CLA} + 0.2 \times \text{CSA}) \times 365 \quad (4.11)
\]

where:

- AFCAPA - Airline fleet capacity (passengers/year)
- AF - airline fleet (aircraft)
- AFUF - airline fleet utilization factor (dim)
- TPAD - trips per aircraft a day (dim)
- CSA - capacity of small aircraft (passengers/aircraft)
- CLA - capacity of large aircraft (passengers/aircraft)
- CHA - capacity of heavy aircraft (passengers/aircraft)

The numbers of 0.2, 0.6 and 0.2 are the proportion of the small, large and heavy aircraft in the airlines fleet, respectively.
Airlines fleet utilization factor has been assumed 0.96 according to China's civil aviation statistical data. In 1995, the average trips per aircraft a day was 3 operations, we assumed that the average trips per aircraft a day will reach 4 in the year 2010. So, the trips per aircraft a day modeled as a table function of time.

The airlines fleet capacity is expressed as the yearly capacity, so, the right of the equation is multiplied by 365 days.

**Operation and maintenance costs, OMC**

Operation and maintenance costs of the airlines (OMC) is an auxiliary variable (in yuan per year) dependent on the operations, the maintenance, and insurance costs. Equation 4.12 computes OMC.

\[
OMC = MC + OC + IC
\]  

(4.12)

where:

- **OMC** - operation and maintenance costs (yuan/year)
- **MC** - maintenance costs (yuan/year)
- **OC** - operation costs (yuan/year)
- **IC** - insurance costs (yuan/year)

**Operation cost, OC**

Operation costs (OC) is an auxiliary variable (in yuan per year) dependent on the air traffic control revenue from the airlines, the airport revenue (including the runways and terminals) from the airlines, fuel and salary costs. Equation 4.13 estimates OC.

\[
OC = ATCR + RWR + TNR + FC + SC
\]  

(4.13)

where:

- **OC** - operation costs (yuan/year)
- **ATCR** - air traffic control revenue (yuan/year)
RWR - runway revenue (yuan/year)
TNR - terminal revenue (yuan/year)
FC - fuel costs (yuan/year)
SC - salary costs (yuan/year)

Salary costs, SC
Salary costs (SC) is an auxiliary variable (in yuan per year) dependent on the total number of workers in the airlines and the salary per worker. Equation 4.14 computes SC.

\[ SC = TW \times SPW \] (4.14)

where:

- SC - salary costs (yuan/year)
- TW - total number of worker (persons)
- SPW - salary per worker (yuan/person-year)

In 1995, worker in the airlines earned about 15,000 yuan per year, in this model salary increment are assumed to be 10% (K2) (see equation 4.15).

\[ SPW = 15000 \times (1+K2)^{(\text{TIME}-1995)} \] (4.15)

The total number of workers in all airlines in 1995 was 100,000 persons, the growth rate of the airline workforce is assumed to be 5% (K1) per year (see equation 4.16).

\[ TW = 100000 \times (1+K1)^{(\text{TIME}-1995)} \] (4.16)

Fuel costs, FC
Fuel costs (FC) is an auxiliary variable (in yuan per year) dependent on the fuel price and the fuel consumption (equation 4.17).

\[ FC = FP \times FCON \] (4.17)
where:

\[ \text{FC} \text{ - fuel costs (yuan/year)} \]
\[ \text{FP} \text{ - fuel price (yuan/ton)} \]
\[ \text{FCON} \text{ - fuel consumption (tons)} \]

In 1995, fuel price in China was about 2,500 yuan per ton. In the model, the price is increased at an average growth rate of 20% (K6). The equation for fuel price is expressed by,

\[ \text{FP} = 2500(1+K6)^{(\text{TIME}-1995)} \]  \hspace{1cm} (4.18)

**Fuel consumption, FCON**

Fuel consumption (FCON) is an auxiliary variable (in tons per year) dependent on the size of the airline fleet and the fuel consumption of aircraft (equation 4.19).

\[ \text{FCON} = \text{AF}*(0.2*\text{FCONPHA}+0.6*\text{FCONPLA}+0.2*\text{FCONPSA}) \]  \hspace{1cm} (4.19)

where:

\[ \text{FCON} \text{ - fuel consumption (tons/year)} \]
\[ \text{AF} \text{ - airline fleet (aircraft)} \]
\[ \text{FCONPSA} \text{ - fuel consumption per small aircraft (tons/year)} \]
\[ \text{FCONPLA} \text{ - fuel consumption per large aircraft (tons/year)} \]
\[ \text{FCONPHA} \text{ - fuel consumption per heavy aircraft (tons/year)} \]

The fuel consumption for small aircraft is assumed to be 550 tons per year, 5,100 tons for large aircraft and 16,000 tons for heavy aircraft.

**Maintenance cost, MC**

Maintenance costs (MC) is an auxiliary variable (in yuan per year) dependent on the airline fleet and the maintenance costs for small, large and heavy aircraft. Mathematically, MC can be estimated as,
\[
MC = AF*(0.2*MCPHA+0.6*MCPLA+0.2*MCPSA) \quad (4.20)
\]

where:

- **MC** - maintenance costs (yuan/year)
- **AF** - air fleet (aircraft)
- **MCPSA** - maintenance costs of small aircraft (yuan/year)
- **MCPLA** - maintenance costs of large aircraft (yuan/year)
- **MCPHA** - maintenance costs of heavy aircraft (yuan/year)

In 1995, the maintenance costs of small, large and heavy aircraft have been assumed to be 15E4, 3E6 and 15E6 yuan, respectively. The maintenance costs for all aircraft categories are increased at an average growth rate of 15% (K3). Equations to estimate maintenance costs are:

\[
MCPSA = 15E4*(1+K3)^{(TIME-1995)} \quad (4.21)
\]
\[
MCPLA = 3E6*(1+K3)^{(TIME-1995)} \quad (4.22)
\]
\[
MCPHA = 15E6*(1+K3)^{(TIME-1995)} \quad (4.23)
\]

**Air demand, AD**

Air demand (AD) is a level variable (in passengers) dependent on the air demand rate of change. Mathematically, AD can be written as:

\[
AD(t) = AD(t - dt) + [DC(t) \ast dt] \quad (4.24)
\]

\[
INIT AD = 5117E4 \quad (4.25)
\]

where:

- **AD** - air demand (passengers)
- **DC** - air demand change (passengers/year)
Air demand change, CD

Air demand change (CD) is a rate variable (in passengers per year) dependent on the air passenger increment per year, the air transportation level of service multiplier and the air fare multiplier. Equation 4.26 can be estimated DC.

\[ DC = API \times (1 - ALOSM) \times (1 - FAREM) \]  \hspace{1cm} (4.26)

where:

- \( DC \) - air demand change (passengers/year)
- \( API \) - air passenger increment (passengers/year)
- \( ALOSM \) - air transportation level of service multiplier (dim)
- \( FAREM \) - air fare multiplier (dim)

Air transportation level of service multiplier, ALOSM

Air levels of service multiplier (ALOSM) is a dimensionless auxiliary variable dependent on the total delay on the air transportation system. ALOSM is modeled as a table function of the total delay on the air transportation system.

Total delay on the air transportation system, TDAT

Total delay on the air transportation system (TDAT) is an auxiliary variable (in hours aircraft) dependent on the delay in the air route, the delay on the runway and the delay in the terminal. The mathematical expression for TDAT is;

\[ TDAT = DAIRR + DRW + DTN \]  \hspace{1cm} (4.27)

where:

- \( TDATS \) - total delay on the air transportation system (hours-aircraft)
- \( DAIRR \) - delay in the air route (hours-aircraft)
- \( DRW \) - delay on the runway (hours-aircraft)
- \( DTN \) - delay in the terminal (hours-aircraft)
Air fare multiplier, AFAREM
Air fare multiplier (AFAREM) is a dimensionless auxiliary variable dependent on the elasticity coefficient of the air fare. AFAREM is modeled as a table function of the elasticity coefficient of the air fare.

Elasticity coefficient of air fare, ECAFARE
Elasticity coefficient of air fare (ECAFARE) is a dimensionless auxiliary variable dependent on the growth rate of the air fare and the growth rate of the per capita income. Mathematically, ECAFARE is found as follows:

\[ \text{ECAFARE}= \frac{\text{GRAFARE}}{\text{RPCI}} \quad (4.28) \]

where:
- ECAFARE - elasticity coefficient of air fare (dim)
- GRAFARE - growth rate of the air fare (fraction/year)
- RPCI - growth rate of the per capita income (fraction/year)

Growth rate of the air fare, GRAFARE
Growth rate of the air fare (GRAFARE) is an auxiliary variable (in fraction per year) dependent on the airline operation and maintenance deficit. Mathematically, the equation to estimate GRAFARE is shown below.

\[ \text{GRAFARE} = \text{IF} (\text{AOMD} < 0) \times \text{THEN} (10) \times \text{ELSE} (5) \quad (4.29) \]

where:
- GRAFARE - growth rate of the air fare (fraction/year)
- AOMD - airline operation and maintenance deficit (yuan/year)
Air fare, AFARE

Air fare (AF) is a level variable (in yuan) dependent on the air fare change and the initial value of the air fare. The initial value of the air fare is 818 yuan in 1995. Mathematically, AF can be estimated according to equation 4.30.

\[
\text{AFARE}(t) = \text{AFARE}(t - dt) + [\text{AFAREC}(t)] * dt \quad (4.30)
\]

\[
\text{INIT AFARE} = 818 \quad (4.31)
\]

where:
- AFARE - air fare (yuan)
- AFAREC - air fare change (yuan/year)

Air fare change, AFAREC

Air fare change (AFAREC) is a rate variable (in yuan per year) dependent on the air fare and the growth rate of the air fare. AFAREC can be expressed mathematically;

\[
\text{AFAREC} = \text{AFARE}*(\text{GRAFARE}/100) \quad (4.32)
\]

where:
- AFAREC - air fare change (yuan/year)
- AFARE - air fare (yuan)
- GRAFARE - growth rate of the air fare (fraction/year)

Airline operation and maintenance deficit, AOMD

Airlines operation and maintenance deficit (AOMD) is an auxiliary variable (in yuan per year) dependent on the airlines operation and maintenance budget and airlines operation and maintenance costs. The equation of the airlines operation and maintenance deficit can be written as,
AOMD = AOMB - AOMC \hfill (4.33)

where:

AOMD - airlines operation and maintenance deficit (yuan/year)
AOMB - airlines operation and maintenance budget (yuan/year)
AOMC - airlines operation and maintenance costs (yuan/year)

**Airlines operation and maintenance budget, AOMB**

Airlines operation and maintenance budget (AOMB) is an auxiliary variable (in yuan per year) dependent on the airlines revenue to operation and maintenance and the air subsidy to airlines operation and maintenance. Mathematically, AOMB can be written as,

\[ AOMB = AROM + ASOM \] \hfill (4.34)

where:

AOMB - airlines operation and maintenance budget (yuan/year)
AROM - airlines revenue to operation and maintenance (yuan/year)
ASOM - air subsidy to airlines operation and maintenance (yuan/year)

**Airlines revenue to operation and maintenance, AROM**

Airlines system revenue to operation and maintenance (AROM) is an auxiliary variable (in yuan per year) dependent on the airlines revenue and the fraction of airlines revenue to operation and maintenance. AROM can be written mathematically as follows:

\[ AROM = AR \times FAROM \] \hfill (4.35)

where:

AROM - airlines revenue to operation and maintenance (yuan/year)
AR - airlines revenue (yuan/year)
FAROM - fraction of airline revenue to operation and maintenance (fraction/year)
The fraction of airlines revenue to operation and maintenance has been assumed to be 0.6.

**Airlines revenue, AR**

Airlines revenue (AR) is an auxiliary variable (in yuan per year) dependent on the air demand and the air fare. AR can be written as,

\[ AR = AD \times AFARE \]  \hspace{1cm} (4.36)

where:

- **AR** - airlines revenue (yuan/year)
- **AD** - air demand (passengers)
- **AFARE** - air fare (yuan/passenger)

**Total Air subsidy to airlines operation and maintenance, TSUOM**

Total air subsidy to airlines operation and maintenance (TSUOM) is an auxiliary variable (in yuan per year) dependent on the total air subsidy and the fraction of total air subsidy to the airlines operation and maintenance. TSUOM is computed by,

\[ TSUOM = TSU \times FTSUOM \]  \hspace{1cm} (4.37)

where:

- **TSUOM** - total air subsidy to airlines operation and maintenance (yuan/year)
- **TSU** - total air subsidy (yuan/year)
- **FTSUOM** - fraction of total air subsidy to the airlines operation and maintenance (fraction/year)

The fraction of total air subsidy to the airlines operation and maintenance has been assumed to be 0.05.
4.3 Air Routes Sector

The total distance of 797 air routes of 1,420, 600 km (including repeat air routes) or 750,800 km (not including repeat air routes) by the end of 1995. All air routes are classified into three categories: 1) high-density traffic air routes (with traffic volume more than 4,000 operations per year), such as the airway between Beijing and Shanghai, 2) medium-density traffic air routes (with traffic volume between 1,000 and 4,000 operations per year), such as the airway between Guangzhou and Chengdu, and 3) low-density traffic air routes (with traffic volume less than 1,000 operations per year), such as the airway between Kuiming and Baishan. The following causal diagram represents the air routes sector.

Figure 4.3 Causal Diagram of the Air Route Sector

Air routes (AR) is a level variable (in kilometers). The high-density traffic air routes account for 10% of the total air routes distance, 40% for the medium-density traffic and 50% for the low-density traffic according to the data of China’s civil aviation statistical book (CAAC, 1995). Each level variable requires an initial value for the air routes. The initial value has been assumed to be 750,000 kilometers by the end of 1995. The air
routes are dependent on the air routes increase rate and the air routes retirement rate. Mathematically, AR is,

\[
AIRR(t) = AIRR(t - dt) + [ARIR(t) - ARRR(t)] \times dt
\]  
(4.38)

\[
INIT \, AIRR = 75E4
\]  
(4.39)

where:

- \(AIRR\) - air routes (kilometers)
- \(ARIR\) - air routes increase rate (kilometers/year)
- \(ARRR\) - air routes retirement rate (kilometers/year)

**Air routes retirement rate, ARRR**

Air routes retirement rate (ARRR) is a rate variable (in kilometers per year) dependent on the air routes and the lifetime of the air routes. Equation 4.40 is used to estimate the air routes retirement rate.

\[
ARRR = AIRR/LAR
\]  
(4.40)

where:

- \(ARRR\) - air routes retirement rate (kilometers/year)
- \(AIRR\) - air routes (kilometers)
- \(LAR\) - lifetime of air routes (years)

The average lifetime of air routes has been assumed to be 60 years.

**Air routes increase rate, ARIR**

Air routes increase rate (ARIR) is a rate variable expressed in unit of kilometers per year. The air routes in China’s civil aviation system are increased according to the existing proportion of the high-density traffic, medium-density traffic and low-density traffic
mentioned above. ARIR is dependent on the ratio of total flight to air routes capacity, the air routes budget and the costs unit air route. Mathematically, ARIR can be written as,

\[
ARIR = IF(TFARCR<0.60)\text{THEN}(0)\text{ELSE}(ARB/CUAR)
\]  

(4.41)

where:

- ARIR - air routes increase rate (kilometers/year)
- TFARCR - ratio of total flight to air route capacity (dim)
- ARB - air routes budget (yuan/year)
- CUAR - costs of unit air route (yuan/kilometer)

The costs of unit air route has been assumed to be 2E4 yuan and is increased at an average growth rate of 10% (K2) per year.

**Air route capacity, ARC**

Air routes capacity (ARC) is an auxiliary variable (in operations) dependent on the air routes, the capacity of the high-density traffic, medium-density traffic and low-density traffic air routes. The equation to estimate air routes capacity is,

\[
ARC = AIRR*(0.1*HDARC+0.5*LDARC+0.4*MDARC)*365
\]  

(4.42)

where:

- ARC - air routes capacity (operations/year)
- AIRR - air routes (kilometers)
- HDARC - the capacity of the high-density traffic air routes (operations/day)
- MDAREC - the capacity of the medium-density traffic air routes (operations/day)
- LDARC - the capacity of the low-density traffic air routes (operations/day)

Values of 0.1, 0.5 and 0.4 are assumed to be the proportions of the air routes assigned to high-density, medium-density and low-density traffic air routes, respectively.
The capacity of the high-density traffic air routes, HDARC

The capacity of the high-density traffic air routes (HDARC) is an auxiliary variable (in operations per day) dependent on the high-density traffic air routes capacity per hour, the high-density traffic air routes layers, the high-density traffic air routes peak period and high-density traffic maximum air route distance. Mathematically, HDARC can be written as,

$$HDARC = HL*HDPP*HRC/HMRD$$  \hspace{1cm} (4.43)

where:

- HDARC - high-density traffic air routes capacity (operations/day)
- HL - high-density air routes layers (dim)
- HDPP - high-density traffic air routes peak period (hours)
- HRC - high-density traffic air routes capacity (operations/hour)
- HMRD - high-density traffic maximum air routes distance (kilometers)

High-density traffic maximum air routes distance (HMRD) is an auxiliary constant (in kilometers), and has been assumed to be 1,600 kilometers.

High-density traffic air routes peak period (HDPP) is an auxiliary constant (in hours). It has been assumed to be 12 hours.

High-density air routes layers (HL) is a constant, which is assumed to be 2.

High-density traffic air route capacity per hour, HRCPH

High-density traffic air routes capacity per hour (HRCPH) is an auxiliary variable (in operations per hour) dependent on the high-density traffic air routes headway between two successive airplanes. HRCPH is the reciprocal of the high-density traffic air routes headway between two successive airplanes.
High-density traffic air routes headway between two successive airplanes, HRHW
High-density traffic air routes headway between two successive airplanes (HRHW) is an auxiliary variable (in minutes). HRHW is model as a table function of the air routes technical upgrade investment index.

Air routes technical upgrade investment index, ARTUII
Air routes technical upgrade investment index (ARTUII) is a dimensionless auxiliary variable dependent on air routes technical upgrade investment normal and the air routes technical upgrade investment multiplier. ARTUII is the product of them. The air routes technical upgrade investment normal is assumed to be 1 in 1995.

Air routes technical upgrade investment multiplier, ARTUIM
Air routes technical upgrade investment multiplier (ARTUIM) is a dimensionless auxiliary variable. ARTUIM is modeled as a table function of the air routes technical upgrade investment ratio.

Air routes technical upgrade investment ratio, ARTUIR
Air routes technical upgrade investment ratio (ARTUIR) is a dimensionless auxiliary variable dependent on air routes technical upgrade investment and the initial value of the air routes technical upgrade investment. The initial value of the air routes technical upgrade investment is assumed to be 10E8 yuan in 1995. The air routes technical upgrade investment is increased at an average growth rate of 10% (K2) from the initial value of 1995.

The capacity of the medium-density traffic air routes, MDARC
The capacity of the medium-density traffic air routes (MDARC) is an auxiliary variable (in operations per day) dependent on the medium-density traffic air routes capacity per hour, the medium-density traffic air routes layers, the medium-density traffic air routes peak period and medium-density traffic maximum air routes distance. Mathematically, MDARC can be written as,
MDARC = ML*MDPP*MRC/MMRD  \hspace{1cm} (4.44)

where:

- **MDARC** - medium-density traffic air routes capacity (operations/day)
- **ML** - medium-density air routes layers (dim)
- **MDPP** - medium-density traffic air routes peak period (hours)
- **MRC** - medium-density traffic air routes capacity (operations/hour)
- **MMRD** - medium-density traffic maximum air routes distance (kilometers)

Medium-density traffic maximum air routes distance (MRC) is an auxiliary constant (in kilometers), and has been assumed to be 1,500 kilometers.

Medium-density traffic air routes peak period (MDPP) is an auxiliary constant (in hours). MDDP has been assumed to be 7 hours.

Medium-density air routes layers (MDDR) is a constant, which is assumed to be 2.

**Medium-density traffic air routes capacity per hour, MRCPH**

Medium-density traffic air routes capacity per hour (MRCPH) is an auxiliary variable (in operations per hour) dependent on the medium-density traffic air routes headway between two successive airplanes. MRCPH is the reciprocal of the medium-density traffic air routes headway between two successive airplanes.

**Medium-density traffic air route headway between two successive airplanes, MRHW**

Medium-density traffic air routes headway between two successive airplanes (MRHW) is an auxiliary variable (in minutes). MRHW is modeled as a table function of the air routes technical upgrade investment index.
The capacity of the low-density traffic air routes LDARC

The capacity of the low-density traffic air routes (LDARC) is an auxiliary variable (in operations per day) dependent on the low-density traffic air routes capacity per hour, the low-density traffic air routes layers, the low-density traffic air routes peak period and low-density traffic maximum air routes distance. Mathematically, LDARC can be written as,

\[ LDARC = \frac{LDDR \times LDPP \times LRC}{LMRD} \quad (4.45) \]

where:

- LDARC - low-density traffic air routes capacity (operations/day)
- LL - low-density air routes layers (dim)
- LDPP - low-density traffic air routes peak period (hours)
- LRC - low-density traffic air routes capacity (operations/hour)
- LMRD - low-density traffic maximum air routes distance (kilometers)

Low-density traffic maximum air routes distance (LRC) is an auxiliary constant (in kilometers), LRC has been assumed to be 1,100 kilometers.

Low-density traffic air routes peak period (LDPP) is an auxiliary constant (in hours). LDPP has been assumed to be 5 hours.

Low-density air routes layers (LL) is a constant, LL is assumed to be 2.

**Low-density traffic air routes capacity per hour, LRC**

Low-density traffic air routes capacity per hour (LHRCPH) is an auxiliary variable (in operations per hour) dependent on the low-density traffic air routes headway between two successive airplanes. LRCPH is the reciprocal of the low-density traffic air routes headway between two successive airplanes.
Low-density traffic air route headway between two successive airplanes, LRHW
Low-density traffic air routes headway between two successive airplanes (LRHW) is an auxiliary variable (in minutes). LRHW is modeled as a table function of the air routes technical upgrade index.

Air route fee, ARF
Air route fee (ARF) is a level variable (in yuan) dependent on the air route fee change. The initial value of the air route fee is 500 yuan in 1995. Mathematically, ARF can be written as,

\[ ARF(t) = ARF(t - dt) + [ARFC(t)] * dt \]  
\[ \text{INIT ARF} = 500 \]  

where:

AFF - air route fee (yuan)
ARFC - air route fee change (yuan/year)

Air route fee change, ARFC
Air route fee change (ARFC) is a rate variable (in yuan per year) dependent on the initial value of air route fee in 1995 and the air route fee increment. Equation 4.48 is used to compute the air route fee change.

\[ \text{ARFC} = \text{ARF} \times \text{ARFI} \]  

where:

ARFC - air route fee change (yuan/year)
ARF - air route fee (yuan)
ARFI - air route fee increment (fraction/year)

The air route fee increment has been assumed to be 10% per year.
Air traffic control revenue, ATCR

Air traffic control revenue (ATCR) is an auxiliary variable (in yuan) dependent on the total flights and the air route fee. Equation 4.49 is used to estimate the air traffic control revenue.

\[
\text{ATCR} = \text{TF} \times \text{ARF} \tag{4.49}
\]

where:

- ATCR - air traffic control revenue (yuan/year)
- TF - total flight (operations)
- ARF - air route fee (yuan/operation)

Air routes budget, ARB

Air routes budget (ARB) is a auxiliary variable (in yuan). The air routes budget mainly comes from the air traffic revenue, the total air subsidy and is used to the air route technical upgrade investment, the operation and maintenance of air route and construction new air route. The equation for the air route budget can be written as,

\[
\text{ARB} = (\text{TSUAR} + \text{ATCRAR}) - (\text{OMCAR} + \text{ARTUI}) \tag{4.50}
\]

where:

- ARB - air route budget (yuan/year)
- TSUAR - total air subsidy to the air routes budget (yuan/year)
- ATCRAR - air traffic control revenue to the air routes budget (yuan/year)
- OMCAR - operation and maintenance costs of the air routes (yuan/year)
- ARTUI - air routes technical upgrade investment (yuan/year)

Total flights, TF

Total flights (TF) is an auxiliary variable (in operations). The amount of the total flights equals the total times at the terminals of all aircraft.
Delay in air routes, DAIRR

Delay in air routes (DAIRR) is an auxiliary variable (in hours aircraft). DAIRR is estimated by the stochastic queue theory. First, we calculate the average utilization per airway, then the following formula is used to calculate the average waiting time per flight in the queue.

\[ w = \frac{\rho^2}{(1-\rho) \lambda} \]  \hspace{1cm} (4.51)

Where:
- \( w \) - the average waiting time per flight in the queue
- \( \rho \) - the average utilization per airway
- \( \lambda \) - the demand of flight per airway a day

Final, we calculate the total delay in all air routes in a year. The equation of the total delay in all air route is expressed by:

\[ DAIRR = \frac{((\text{TFARCR} \times \text{TFARCR}) / ((1-\text{TFARCR}) \times (\text{TF} / (\text{AIRR} / 1300 / 365)))) \times \text{TF}} \]  \hspace{1cm} (4.52)

where:
- DAIRR - delay in the air route (hours-aircraft)
- TFARCR - total flight to air route capacity ratio (dim)
- AIRR - air route (kilometers)
- TF - total flight (operations)

The average distance per air route is assumed to be 1,300 km. The same method of estimating the delay on the runway and in the terminal is used in the airports sector.

Operation and maintenance costs of air routes, OMCAR

Operation and maintenance costs of air routes (OMCAR) is an auxiliary variable (in yuan per year) dependent on the air routes and the costs per kilometer air route. Equation 4.53 estimates OMCAR.
OMCAR = AIRR*CPAR \hspace{1cm} (4.53)

where:

OMCAR - operation and maintenance costs of air routes (yuan/year)
AIRR - air routes (kilometers)
CPAR - costs per air route (yuan/kilometer)

4.4 Airports Sector

Airports sector is another key sector of CATSDM. The purpose of the airports sector is to modeling the airports facilities. We mainly consider the following parts: runways and terminals. There are 139 runways and 138 terminals in China by the end of 1995. Due to imbalance distribution of air traffic in China, so, all airports are divided into three categories: 1) high-density traffic airports (with traffic volume more than 36,500 operations per year), such as the Beijing and Shanghai airports, 2) medium-density traffic airports (with traffic volume between 1,000 and 36,500 operations per year), such as Kuimeng airport, 3) low-density traffic airports (with traffic volume less than 1,000 operations per year), such a Baishan airport. The following Figure 4.4 is the causal diagram of the airports sector.

The following is the definitions of the key variables in the airports sector.

Runways, RW
Runways (RW) is a level variable (in numbers). The high-density traffic runways account for 10% of the total number of runway, 40% for the medium-density traffic runways and 50% for the low-density traffic runways according to the data of China’s civil aviation statistical book (CAAC, 1995). Each level variable required an initial value for the runways. The initial value has been assumed to be 139 by the end of 1995.
Figure 4.4 Causal Diagram of the Airports

The runways is dependent on the runways increase rate and the runways retirement rate. Mathematically, RW can be written as,

\[ RW(t) = RW(t - dt) + [RWIR(t) - RWRR(t)] \times dt \]  \hspace{1cm} (4.54)

\[ \text{INIT } RW = 139 \]  \hspace{1cm} (4.55)

where:

- \( RW \) - runways (numbers)
- \( RWIR \) - runways increase rate (numbers/year)
- \( RWRR \) - runways retirement rate (numbers/year)
**Runways retirement rate, RWRR**

Runways retirement rate (RWRR) is a rate variable (in numbers per year) dependent on the runways and lifetime of runway. Equation 4.56 is used to estimate the runways retirement rate.

\[
RWRR = \frac{RW}{LRW}
\]  

(4.56)

where:

- **RWRR** - runways retirement rate (numbers/year)
- **RW** - runways (numbers)
- **LRW** - lifetime of runways (years)

The average lifetime of runways has been assumed to be 60 years.

**Runways increase rate, RWIR**

Runways increase rate (RWIR) is a rate variable (in numbers per year). Runways in China’s civil aviation system is increased according to the existing proportion of the high-density traffic, medium-density traffic and low-density traffic mentioned above. RWIR is dependent on the ratio of total times of landing and take-off to runways capacity, the airports budget to runways and costs of unit runway. Equation 4.57 is used to compute the runways increase rate.

\[
RWIR = \begin{cases} 
\text{IF(TTLTRWCR<0.60)THEN(0)ELSE(APBRW/CURW)} \end{cases}
\]  

(4.57)

where:

- **TTLTRWCR** - ratio of total times of landing and take-off to runways capacity (dim)
- **APBRW** - airports budget to runways (yuan/year)
- **CURW** - costs of unit runways (yuan/runway)

The costs of unit runway has been assumed to be 5E8 yuan and is increased at an annual average growth rate of 10%.
Runways capacity, RWC

Runways capacity (RWC) is an auxiliary variable (in operations) dependent on the capacity of the high-density traffic, the medium-density traffic and the low-density traffic runways. Mathematically, RWC can be written as,

\[ RWC = RW*(0.1*HRWC+0.5*MRWC+0.4*LRWC)*365 \quad (4.58) \]

where:

- RWC - runways capacity (operations/year)
- HRWC - the capacity of the high-density traffic runways (operations/day)
- MRWC - the capacity of the medium-density traffic runways (operations/day)
- LRWC - the capacity of the low-density traffic runways (operations/day)

The numbers of 0.1, 0.5 and 0.4 are the proportion of the high-density traffic, medium-density traffic and low-density traffic runways in all runways, respectively.

The capacity of the high-density traffic runways, HRWC

The capacity of the high-density traffic runways (HRWC) is an auxiliary variable (in operations per day) dependent on the high-density traffic runways capacity per hour (HRWCPH), the high-density traffic runways peak period. Equation 4.59 estimates HRWC.

\[ HRWC = HRWCPH*HRWDPP \quad (4.59) \]

where:

- HRWC - high-density traffic runways capacity (operations/day)
- HRWDPP - high-density traffic runways peak period (hours)
- HRWCPH - high-density traffic runways capacity per hour (operations/hour)

High-density traffic runways peak periods (HRWDPP) is an auxiliary constant (in hours). HRWDPP has been assumed to be 12 hours.
High-density traffic runway capacity per hour, HRWCPH
High-density traffic runways capacity per hours (HRWCPH) is an auxiliary variable (in operations per hour) dependent on the high-density traffic runways headway between the two airplanes. HRWCPH is the reciprocal of the high-density traffic runways headway between the two airplanes.

High-density traffic runways headway between the two airplanes, HRWHW
High-density traffic runways headway between the two airplanes (HRWHW) is an auxiliary variable (in minutes). HRWHW is modeled as a table function of the runways technical upgrade investment index.

Runways technical upgrade investment index, RWTUII
Runways technical upgrade investment index (RWTUII) is a dimensionless auxiliary variable dependent on runways technical upgrade investment normal and the runways technical upgrade investment multiplier. RWTUI is the product of them. The runways technical upgrade normal has been assumed to be 1 in 1995.

Runways technical upgrade investment multiplier, RWTUIM
Runways technical upgrade investment multiplier (RWTUIM) is a dimensionless auxiliary variable. RWTUIM is modeled as a table function of the runways technical upgrade investment ratio.

Runways technical upgrade investment ratio, RWTUIR
Runways technical upgrade investment ratio (RWTUIR) is a dimensionless auxiliary variable dependent on runways technical upgrade investment and the initial value of the runways technical upgrade investment. RWTUIR is computed according to equation 4.60.

\[
\text{RWTUIR} = \frac{\text{RWTUI}}{\text{RWTUIM}}
\]  
(4.60)
where:

\[ \text{RWTUIR} - \text{runways technical upgrade investment ratio (dim)} \]
\[ \text{RWTUI} - \text{runways technical upgrade investment (yuan/year)} \]
\[ \text{RWTUIN} - \text{initial value of runways technical upgrade investment (yuan/year)} \]

The initial value of the runways technical upgrade investment is assumed to be 15E8 in 1995. The runways technical upgrade investment is increased at an average growth rate of 10% from the initial value of 1995.

**The capacity of the medium-density traffic runways, MRWC**

The capacity of the medium-density traffic runways (MRWC) is an auxiliary variable (in operations per day) dependent on the medium-density traffic runways capacity per hour (MRWCPH), the medium-density traffic runways peak period. Equation 4.61 computes MRWC.

\[ \text{MRWC} = \text{MRWCPH} \times \text{MRWDPP} \]  \hspace{1cm} (4.61)

where:

\[ \text{MRWC} - \text{medium-density traffic runways capacity (operations/day)} \]
\[ \text{MRWDPP} - \text{medium-density traffic runways peak period (hours)} \]
\[ \text{MRWCPH} - \text{medium-density traffic runways capacity (operations/hour)} \]

Medium-density traffic runways peak periods (MRWDPP) is an auxiliary variable (in hours). MRWDPP has been assumed to be 7 hours.

**Medium-density traffic runways capacity per hour, MRWCPH**

Medium-density traffic runways capacity per hour (MRWCPH) is an auxiliary variable (in operations per hour) dependent on the medium-density traffic runways headway between the two airplanes. MRWCPH is the reciprocal of the medium-density traffic runways headway between the two airplanes.
Medium-density traffic runways headway between the two airplanes, MRWHW

Medium-density traffic runways headway between the two airplanes (MRWHW) is an auxiliary variable (in minutes). MRWHW is modeled as a table function of the runways technical upgrade investment index.

The capacity of the low-density traffic runways, LRWC

The capacity of the low-density traffic runways (LRWC) is an auxiliary variable (in operations per day) dependent on the low-density traffic runways capacity per hour (LRWCPH), the low-density traffic runways peak period. Mathematically, LRWC can be written as,

\[ LRWC = LRWCPH \times LRWDPP \] (4.62)

where:

- LRWC - low-density traffic runways capacity (operations/day)
- LRWDPP - low-density traffic runways peak period (hours)
- LRWCPH - low-density traffic runways capacity (operations/hour)

Low-density traffic runways peak period (HRWDPP) is an auxiliary variable (in hours). HRWDPP has been assumed to be 5 hours.

Low-density traffic runways capacity, LRWCPH

Low-density traffic runways capacity (LRWCPH) is an auxiliary variable (in operations per hour) dependent on the low-density traffic runways headway between the two airplanes. LRWCPH is the reciprocal of the low-density traffic runways headway between the two airplanes.
Low-density traffic runways headway between the two airplanes, LRWHW
Low-density traffic runways headway between the two airplanes (LRWHW) is an auxiliary variable (in minutes). LRWHW is modeled as a table function of the runways technical upgrade investment index.

Terminals, TN
Terminals (TN) is a level variable (in numbers). The high-density traffic terminals account for 10% of the total number of terminal, 40% for the medium-density traffic and 50% for the low-density traffic according to the data of China’s civil aviation statistic book (CAAC, 1995). Each level variable required an initial value for the terminals. The initial value has been assumed 138 by the end of 1995. TN is dependent on the terminals increase rate and the terminals retirement rate. Mathematically, TN can be written as,

\[ TN(t) = TN(t - dt) + [TNIR(t) - TNRR(t)] \times dt \]  \hspace{1cm} (4.63)

\[ INIT \ TN = 138 \] \hspace{1cm} (4.64)

where:
- TN  - terminals (numbers)
- TNIR  - terminals increase rate (numbers/year)
- TNRR  - terminals retirement rate (numbers/year)

Terminals retirement rate, TNRR
Terminals retirement rate (TNRR) is a rate variable (in numbers per year) dependent on the terminals and the lifetime of terminals. Equation 4.65 estimates TNRR.

\[ TNRR = \frac{TN}{LTN} \] \hspace{1cm} (4.65)

where:
- TNRR  - terminals retirement rate (numbers/year)
- TN  - terminals (numbers)
LTN - lifetime of terminals (years)
The average lifetime of the terminal has been assumed to be 60 years.

Terminal increase rate, TNIR
Terminals increase rate (TNIR) is a rate variable (in numbers per year). Terminals in China’s civil aviation system is increased according to the existing proportion of the high-density traffic, medium-density traffic and low-density traffic mentioned above. TN is dependent on the ratio of total times at terminals to terminal gates capacity, the airports budget to terminals and costs of unit terminal. Equation 4.66 computes TNIR.

\[\text{TNIR} = \text{IF(}\text{TTTNTNGCR}<0.60)\text{THEN}(0)\text{ELSE}(\text{APBTN}/\text{CUTN})\] \hspace{1cm} (4.66)

where:
\begin{align*}
\text{TNIR} &\quad \text{terminals increase rate (numbers/year)} \\
\text{TTTNTNGCR} &\quad \text{ratio of total times at terminals to terminal gates capacity (dim)} \\
\text{APBTN} &\quad \text{airports budget to terminals (yuan/year)} \\
\text{CURW} &\quad \text{costs of unit terminal (yuan/terminal)}
\end{align*}
The costs of unit terminal has been assumed to be 5E8 yuan and is increased at annual average growth rate of 10% (K2).

Terminal gates capacity, TNGC
The basis of gates capacity analysis is that the gates time demanded by aircraft should be less than or equal to the gates time available for them. Two analytical models have been developed for determining the capacity of gates at an airport. One model assumes that all aircraft can use all the gates available at an airport. The other model assumes that aircraft of a certain size or airline can use only gates specifically designed for these aircraft and airline. This is called a restricted gate use strategy. Both models are described, and most situations encountered in practice may be approached through one of the two models.
When there are no restrictions on the use of gates, i.e., all aircraft can use all the gates, the capacity of the gates Cg can be derived as,
Gate time supplied $\geq$ gate time demanded \hspace{1cm} (4.67)

$U_kN_k \geq E(T_g)C_g$ \hspace{1cm} (4.68)

where:

$U_k$ - gate utilization factor, or percentage of time in 1 hour
that gate of type $k$ may be used by aircraft of type $I$

$N_k$ - number of type $k$ gates available to aircraft of type $I$

$E(T_g)$ - expected value of gate occupancy time demanded by
aircraft which can be use gate type $k$

$C_g$ - capacity of type $k$ gates, aircraft per hour

The expected value of the gate occupancy time $E(T_g)$ is,

$E(T_g) = \sum m_i T_{gi}$ \hspace{1cm} (4.69)

where:

$m_i$ - percentage of type $i$ aircraft in fleet mix using gates at airport

$T_{gi}$ - gate occupancy time required for type $i$ aircraft at airport

For restricted gate use, the mix of gates and the mix of aircraft using the airport may not
be the same. Therefore, it is necessary to find the capacity of each type of gate and then to
determine the overall capacity of the airport based upon gate capabilities as the minimum
capacity gate capacity of any type gate. mathematically, this becomes,

$C_g = \min(C_{gk})$ \hspace{1cm} (4.70)
Terminal gates capacity, TNGC

Terminal gates capacity (TNGC) is an auxiliary variable (in operations) dependent on the capacity of the high-density traffic, the medium-density traffic and the low-density traffic terminals. Mathematically, TNGC is,

\[
\text{TNG} = \begin{cases} 
\text{IF}(\text{TIME} < 2000) \text{THEN}(\text{TN} \times (0.1 \times \text{HTNGC} + 0.4 \times \text{MTNGC} + 0.5 \times \text{LTNGC}) \times 365) \text{ELSE} \\
\text{IF}(\text{TIME} < 2005) \text{THEN}(\text{TN} \times (0.2 \times \text{HTNGC} + 0.5 \times \text{MTNGC} + 0.3 \times \text{LTNGC}) \times 365) \text{ELSE}(\text{TN} \times (0.3 \times \text{HTNGC} + 0.5 \times \text{MTNGC} + 0.2 \times \text{LTNGC}) \times 365) 
\end{cases}
\]

(4.71)

where:

- TNGC - terminal gates capacity (operations/year)
- HTNGC - the capacity of the high-density traffic terminal gates (operations/day)
- MTNGC - the capacity of the medium-density traffic terminal gates (operations/day)
- LTNGC - the capacity of the low-density traffic terminal gates (operations/day)

The capacity of the high-density traffic terminal gates, HTNGC

We assume that a high-density traffic terminal has 15 gates available for aircraft. These gates are restricted in the types of aircraft which can be accommodated. 40% of these gates can accommodate heavy aircraft, 60% of these gates for large aircraft and 100% of these gates for small aircraft.

The aircraft mix at the high-density traffic terminal in the peak hour consists of 30% heavy aircraft, 50% large aircraft and 20% small aircraft.

Heavy aircraft requires a gate occupancy time of 150 min, large requires 120 min, and small aircraft requires 75 min.

The capacity of the high-density traffic terminal gates (HTNGC) is an auxiliary variable (in operations per day) dependent on the high-density traffic terminal gates capacity per
hour (HTNGC), the high-density traffic terminals peak period. We use the equations of (4.68), (4.69) and (4.70) and get the following the equation of the capacity of high-density traffic terminal gates:

\[
\text{HTNGC}=\text{MIN} (\text{HTNDPP} \times 15 \times 0.4 \times 60 / 0.3 \times 150, \\
\text{HTNDPP} \times 15 \times 0.6 \times 60 / (0.3 \times 150 + 0.5 \times 120), \\
\text{HTNDPP} \times 15 \times 1 \times 60 / (0.3 \times 150 + 0.5 \times 120 + 0.2 \times 75))
\] (4.72)

where:

HTNGC - capacity of high-density traffic terminal gates (operations/day)
HTNDPP - high-density traffic terminals peak period (hours)

High-density traffic terminals peak period (HTNDPP) is an auxiliary constant (in hours). HTNDPP has been assumed to be 12 hours.

The capacity of the medium-density traffic terminal gates, MTNGC

We assume that a medium-density traffic terminal has 8 gates available for aircraft. These gates are restricted in the types of aircraft which can be accommodated. 10% of these gates can accommodate heavy aircraft, 40% of these gates for large aircraft and 100% of these gates for small aircraft.
The aircraft mix at the high-density traffic terminal in the peak hour consists of 10% heavy aircraft, 50% large aircraft and 40% small aircraft.
Heavy aircraft requires a gate occupancy time of 150 min, large requires 120 min, and small aircraft requires 75 min.
The capacity of the medium-density traffic terminal gates (MTNGC) is an auxiliary variable (in operations per day) dependent on the medium-density traffic terminal gates capacity per hour (MTNGC), the medium-density traffic terminals peak period. We use the equations of (4.68), (4.69) and (4.70) and get the following the equation of the capacity of medium-density traffic terminal gates.
\[ \begin{align*}
\text{MTNG} &= \text{MIN}(\text{MTNDPP} \times 8 \times 0.1 \times 60 / 0.1 \times 150, \\
&\quad \text{MTNDPP} \times 8 \times 0.4 \times 60 / (0.1 \times 150 + 0.5 \times 120), \\
&\quad \text{MTNDPP} \times 8 \times 1 \times 60 / (0.1 \times 150 + 0.5 \times 120 + 0.4 \times 75)) \\
\end{align*} \] (4.73)

where:

- \( \text{MTNGC} \) - capacity of medium-density traffic terminal gates (operations/day)
- \( \text{MTNDPP} \) - medium-density traffic terminals peak period (hours)

Medium-density traffic terminals peak period (MTNDPP) is an auxiliary constant (in hours). MTNDPP has been assumed to be 7 hours.

**The capacity of the low-density traffic terminal gates, LTNGC**

We assume that a low-density traffic terminal has 4 gates available for aircraft. These gates are restricted in the types of aircraft which can be accommodated. 20% of these gates can accommodate large aircraft and 100% of these gates for small aircraft.

The aircraft mix at the high-density traffic terminal in the peak hour consists of 40% large aircraft, and 60% small aircraft.

Large aircraft requires a gate occupancy time of 120 min, and small aircraft requires 75 min.

The capacity of the low-density traffic terminal gates (LTNGC) is an auxiliary variable (in operations per day) dependent on the low-density traffic terminal gates capacity per hour (LTNGC), the low-density traffic terminals peak period. We use the equations of (4.68), (4.69) and (4.70) and get the following the equation of the capacity of low-density traffic terminal gates.

\[ \begin{align*}
\text{LTNGC} &= \text{MIN}(\text{LTNDPP} \times 4 \times 0.2 \times 60 / 0.4 \times 120, \\
&\quad \text{LTNDPP} \times 4 \times 1 \times 60 / (0.4 \times 120 + 0.6 \times 75)) \\
\end{align*} \] (4.74)

where:

- \( \text{LTNGC} \) - capacity of low-density traffic terminal gates (operations/day)
- \( \text{LTNDPP} \) - low-density traffic terminals peak period (hours)
Low-density traffic terminals peak period (LTNDPP) is an auxiliary constant (in hours). LTNDPP has been assumed to be 5 hours.

**Airports budget, APB**

Airports budget (APB) is a auxiliary variable (in yuan per year). The airports budget mainly comes from the runways revenue, terminals revenue, the air subsidy and the local government funding and is used to the runways technical upgrade investment, the operation and maintenance of runways and terminals and construction new runways and terminals. The equation of the airports budget can be written as,

\[
APB = (RWRAP+TNRAP+SAP+LGF)-(RWTUI+OMCTN+OMCRW)
\]  

(4.75)

where:

- **APB** - airports budget (yuan/year)
- **RWRAP** - runways revenue to airports (yuan/year)
- **TNRAP** - terminals revenue to airports (yuan/year)
- **SAP** - air subsidy to airports (yuan/year)
- **LGF** - local government funding (yuan/year)
- **RWTUI** - runways technical upgrade investment (yuan/year)
- **OMCTN** - operation and maintenance costs of terminals (yuan/year)
- **OMCRW** - operation and maintenance costs of runways (yuan/year)

**Local government funding, LGF**

Local government funding (LGF) is a main funding resource of constructing new airports, the initial value of local government funding has been assumed to be 60E8 yuan in 1995, and at a growth rate of 20% (K6). Equation 4.76 estimates LGF.

\[
LGF = 60E8*(1+K6)^{(TIME-1995)}
\]  

(4.76)
Runways fee, RWF

Runways fee (RWF) is a level variable (in yuan) dependent on the runways fee change. The initial value of the runways fee is 500 yuan in 1995. Mathematically, RWF is,

\[ RWF(t) = RWF(t - dt) + [RWFC(t)] \times dt \quad (4.77) \]

\[ \text{INIT} \; RWF = 500 \quad (4.78) \]

where:
- RWF - runways fee (yuan)
- RWFC - runways fee change (yuan/year)

Runways fee change, RWFC

Runways fee change (RWFC) is a rate variable (in yuan per year) dependent on the initial value of runways fee in 1995 and the runways fee increment. Equation 4.79 computes RWFC.

\[ RWFC = RWF \times RWFI \quad (4.79) \]

where:
- RWF - runways fee (yuan)
- RWFC - runways fee change (yuan/year)
- RWFI - runways fee increment (dim)

The runways fee increment has been assumed to be 10% per year.

Runways revenue, RWR

Runways revenue (RWRR) is an auxiliary variable (in yuan per year) dependent on the total operations on the runways and the runways fee. RWR can be estimated according to equation 4.80.
$$RWR = TTLT \times RWF$$  \hfill (4.80)

where:
- **RWR** - runways revenue (yuan/year)
- **TTLT** - total times of landing and take-off (operations/year)
- **RWF** - runways fee (yuan/operation)

**Total terminals revenue, TTNR**

Total terminals revenue is divided into two parts: terminals revenue from the aircraft and passengers. The equation of the total terminals revenue can be written as,

$$TTNR = TNRPAX + TNRA$$  \hfill (4.81)

where:
- **TTNR** - terminals revenue (yuan/year)
- **TNRPAX** - terminals revenue from passengers (yuan/year)
- **TNRA** - terminals revenue from aircraft (yuan/year)

**Terminals revenue from passengers, TNRPAX**

Terminals revenue from passengers (TNRPAX) is an auxiliary variable (in yuan per year) dependent on the air demand and the passengers fee in the terminals. Mathematically, TNRPAX can be estimated as,

$$TNRPAX = AD \times PAXFTN$$  \hfill (4.82)

where:
- **TNRPAX** - terminals revenue from the passengers (yuan/year)
- **AD** - air demand (persons)
- **PAXFTN** - passengers fee in the terminals (yuan/person)
Passengers fee in the terminals, PAXFTN
Passengers fee in the terminals (PAXFTN) is a level variable (in yuan) dependent on the passengers fee in the terminals change. The initial of value of the passengers fee in the terminals is 50 yuan in 1995. Equation 4.83 estimates the passengers fee in the terminals.

\[
PAXFTN(t) = PAXFTN(t - dt) + [PAXFC(t)]* dt
\]

\[
INIT PAXFTN = 50
\]

where:

- PAXFTN - passengers fee in the terminals (yuan)
- PAXFC - passengers fee change (yuan/year)

Passengers fee change in the terminals, PAXFC
Passengers fee change in the terminals (PAXFC) is a rate variable (in yuan per year) dependent on the passengers fee in the terminals and the passengers fee increment. Mathematically, PAXFC can be written as,

\[
PAXFC = PAXFTN*PAXFI
\]

where:

- PAXFC - passengers fee change (yuan/year)
- PAXFTN - passengers fee in the terminals (yuan)
- PAXFI - passengers fee increment (dim)

The passengers fee increment (PAXFI) has been assumed to be 10% per year.

Terminals revenue from aircraft, TNRA
Terminals revenue from aircraft (TNRA) is an auxiliary variable (in yuan per year) dependent on the total times at terminals of aircraft and the aircraft fee in the terminals. Equation 4.86 estimates TNRA.
TNRA = AFTN*TTTN \tag{4.86}

where:

TNRA - terminals revenue from the aircraft (yuan/year)
TTTN - total times at terminals (operations)
AFTN - aircraft fee in the terminals (yuan/operation)

Aircraft fee at terminals, AFTN

Aircraft fee at terminals (AFTN) is a level variable (in yuan per year) dependent on the aircraft fee change. The initial of value of the aircraft fee is 500 yuan in 1995. Equation 4.87 is used to estimate AFTN.

\[
AFTN(t) = AFTN(t - dt) + [AFC(t)] * dt \tag{4.87}
\]

INIT AFTN = 500 \tag{4.88}

where:

AFTN - aircraft fee at the terminals (yuan)
AFC - aircraft fee change (yuan/year)

Aircraft fee change, AFC

Aircraft fee change (AFC) is a rate variable (in yuan per year) dependent on the aircraft fee and the aircraft fee increment. Equation 4.89 computes AFC.

\[
AFC = AFTN*AFI \tag{4.89}
\]

where:

AFC - aircraft fee change (yuan/year)
AFTN - aircraft fee at the terminals (yuan)
AFI - aircraft fee increment (dim)
The aircraft fee increment has been assumed to be 10% per year.

**Total times at terminal, TTTN**

Total times at terminal (TTTN) is an auxiliary variable (in operations) dependent on the airlines fleet, the airlines fleet utilization factor, the trips per aircraft a day, and the foreign flights. Mathematically, TTTN can be written as,

\[
TTTN = AF \times AFUF \times TPAD \times 365 + FF
\]  

(4.90)

where:

- **TTTN** - total times at terminals (operations)
- **AF** - airlines fleet (aircraft)
- **AFUF** - airlines fleet utilization factor (dim)
- **TPAD** - trips per aircraft a day (operations/aircraft-day)
- **FF** - foreign flights (operations)

**Foreign flights, FF**

Foreign flights (FF) is a level variable (in operations) dependent on the foreign flights change. The initial of value of the foreign flights is 71599 operations in 1995. The equation for the foreign flights can be written as,

\[
FF(t) = FF(t - dt) + [FFC(t)] \times dt
\]

(4.91)

\[
INIT \ FF = 71599
\]

(4.92)

where:

- **FF** - foreign flights (operations)
- **FFC** - foreign flights change (operations/year)
Foreign flights change, FFC

Foreign flights change (FFC) is a rate variable (in operations per year) dependent on the foreign flights and the foreign flights increment. Equation 4.93 computes FFC.

\[ FFC = FF \times FFI \]  \hspace{2cm} (4.93)

where:

- FFC - foreign flights change (operations/year)
- FF - foreign flights (operations)
- FFI - foreign flights increment (dim)

The foreign flights increment (FFI) has been assumed to be 10% per year.

Total air subsidy to airports budget, TSUAP

Total air subsidy to airports budget (TSUAP) is an auxiliary variable (in yuan per year) dependent on the total air subsidy and the fraction of the total air subsidy to airports budget. Equation 4.94 estimates TSUAP.

\[ TSUAP = FTSUAP \times TSU \]  \hspace{2cm} (4.94)

where:

- TSUAP - total air subsidy to airports budget (yuan/year)
- FTSUAP - fraction of the total air subsidy to airports budget (dim)
- TSU - total air subsidy (yuan/year)

The fraction of the total air subsidy to airports budget has been assumed to be 0.5.

Airports budget to runways, APBRW

Airports budget to runways (APBRW) is an auxiliary variable (in yuan per year) dependent on the fraction of the airports budget to runways and the airports budget. The equation for the airports budget to runways can be written as,
APBRW = APB * FAPBRW \hspace{1cm} (4.95)

where:

- APBRW - airports budget to runways (yuan/year)
- APB - airports budget (yuan/year)
- FAPBRW - fraction of the airports budget to runways (dim)

The fraction of the airports budget to runways has been assumed to be 0.45

**Airports budget to terminals, APBTN**

Airports budget to terminals (APBTN) is an auxiliary variable (in yuan per year) dependent on the fraction of the airports budget to terminals and the airports budget. APBTN is computed according to equation 4.96.

APBTN = APB * FAPBTN \hspace{1cm} (4.96)

where:

- APBTN - airports budget to terminals (yuan/year)
- APB - airports budget (yuan/year)
- FAPBTN - fraction of airports budget to terminals (dim)

The fraction of the airports budget to terminals has been assumed to be 0.55

**Operation and maintenance costs of runways, OMCRW**

Operation and maintenance costs of runways (OMCRW) is an auxiliary variable (in yuan per year) dependent on the runways and the costs per runway. OMCRW is computes by,

OMCRW = RW * CPRW \hspace{1cm} (4.97)

where:

- OMCRW - operation and maintenance costs of runways (yuan/year)
- RW - runways (numbers)
- CPRW - costs per runway (yuan/runway)
Operation and maintenance costs of terminals, OMCTN

Operation and maintenance costs of terminals (OMCTN) is an auxiliary variable (in yuan per year) dependent on the terminal and the costs per terminal. OMCTN is estimated by,

\[ OMCTN = TN \times CPTN \]  \hspace{1cm} (4.98)

where:

OMCTN - operation and maintenance costs of terminals (yuan/year)

TN - terminals (numbers)

CPTN - costs per terminal (yuan/terminal)
5. Results and policy analysis

5.1 Baseline results

5.1.1 CSEDMM output results

Baseline results of CSEDMM are shown in Table 5.1, Figure 5.1 and Figure 5.2. This results illustrate the dynamic behavior of the system from 1995 to 2010.

<table>
<thead>
<tr>
<th>Year</th>
<th>Gross national product (yuan)</th>
<th>Total population (persons)</th>
<th>Jobs in non-agriculture (persons)</th>
<th>Air demand(^1) (100 million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>5,773,299,521,159</td>
<td>1,211,210,000</td>
<td>247,021,666</td>
<td>0.61</td>
</tr>
<tr>
<td>1996</td>
<td>6,387,358,617,313</td>
<td>1,230,859,415</td>
<td>247,973,813</td>
<td>0.79</td>
</tr>
<tr>
<td>1997</td>
<td>7,064,458,718,701</td>
<td>1,250,245,793</td>
<td>249,651,822</td>
<td>1.02</td>
</tr>
<tr>
<td>1998</td>
<td>7,821,216,904,666</td>
<td>1,269,346,891</td>
<td>252,149,251</td>
<td>1.29</td>
</tr>
<tr>
<td>1999</td>
<td>8,586,987,751,855</td>
<td>1,288,140,456</td>
<td>255,591,195</td>
<td>1.60</td>
</tr>
<tr>
<td>2000</td>
<td>9,320,180,617,749</td>
<td>1,306,604,280</td>
<td>259,889,537</td>
<td>1.93</td>
</tr>
<tr>
<td>2001</td>
<td>10,118,626,690,166</td>
<td>1,324,716,268</td>
<td>264,855,589</td>
<td>2.30</td>
</tr>
<tr>
<td>2002</td>
<td>10,961,004,630,192</td>
<td>1,342,454,497</td>
<td>270,577,994</td>
<td>2.71</td>
</tr>
<tr>
<td>2003</td>
<td>11,881,843,109,174</td>
<td>1,359,797,229</td>
<td>277,078,226</td>
<td>3.16</td>
</tr>
<tr>
<td>2004</td>
<td>12,860,040,114,004</td>
<td>1,376,722,962</td>
<td>284,457,302</td>
<td>3.62</td>
</tr>
<tr>
<td>2005</td>
<td>13,932,088,687,728</td>
<td>1,393,210,471</td>
<td>292,750,246</td>
<td>4.12</td>
</tr>
<tr>
<td>2006</td>
<td>14,884,506,003,043</td>
<td>1,409,238,858</td>
<td>302,068,783</td>
<td>4.55</td>
</tr>
<tr>
<td>2007</td>
<td>15,972,879,270,910</td>
<td>1,424,787,596</td>
<td>312,287,475</td>
<td>5.00</td>
</tr>
<tr>
<td>2008</td>
<td>17,212,587,867,006</td>
<td>1,439,836,495</td>
<td>323,585,846</td>
<td>5.46</td>
</tr>
<tr>
<td>2009</td>
<td>18,502,490,032,698</td>
<td>1,454,365,824</td>
<td>336,145,811</td>
<td>5.87</td>
</tr>
<tr>
<td>Final</td>
<td>19,747,826,044,197</td>
<td>1,468,356,347</td>
<td>349,909,855</td>
<td>6.20</td>
</tr>
</tbody>
</table>

Notes: 1 Air demand is the potential air demand.
Figure 5.1 Growth of Gross National Product

Figure 5.2 Growth of Total Population (TP), Jobs in Non-agriculture (JNA) and Potential Air Demand (AD)

In Table 5.1, the air demand is the potential air demand which is only the function of the socio-economic characteristics, without considering effects of the air transportation
system characteristics. As shown in Table 5.1, the potential air demand could reach 193 million passengers by the year 2000 and 620 million for the year 2010.

5.1.2 CATSDM output results

Table 5.2 and Figure 5.3 show baseline results of the CATSDM according to existing investment levels as well as the growth rate of all the variables on the air transportation system. CATSDM factors air transportation system characteristics in the estimation of the air transportation demand. The characteristics of the air transportation system normally comprises the set of following attributes: travel time, waiting time at an airport, transportation tariffs, ground costs, flight frequency, airline schedule, airplane type and cabin service. As explained before, in the CATSDM, we mainly consider the following two key factors: travel time and travel costs.

Travel time most often comprises of the total time needed for a passenger to go from the center of the city of departure to the center of another city, waiting time and transfer time must also be added to flight time. Travel time is an important factor that considerably affects the passenger’s decision to use a certain mode of transportation. Travel time by air is the shortest in the alternative modes of transport. People like to travel by air, As they perceive a clear travel time advantage over other modes. In the CATSDM, the total delay on the air transportation system of China is considered as a factor that directly affects air demand. Delays in the air routes, terminals and on the runways are estimated in the model.

The second factor affecting air demand is travel costs. Travel costs normally comprise the passenger’s total costs. This includes, in addition to the cost of the tickets, all other passenger outlays during trip. Generally, the travel costs on an air transportation system are more expensive than that of other modes of transportation. Time savings in the air transportation system can sometimes be offset by transportation costs. In developing
countries, such as China, the income per person is lower, and the travel costs are a very important factor in the model split process.

<table>
<thead>
<tr>
<th>Year</th>
<th>Air demand (persons)</th>
<th>Number of aircraft</th>
<th>Number of runways</th>
<th>Number of terminals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>51,170,000</td>
<td>416</td>
<td>139</td>
<td>138</td>
</tr>
<tr>
<td>1996</td>
<td>64,020,596</td>
<td>547</td>
<td>150</td>
<td>153</td>
</tr>
<tr>
<td>1997</td>
<td>78,825,661</td>
<td>679</td>
<td>163</td>
<td>170</td>
</tr>
<tr>
<td>1998</td>
<td>95,776,092</td>
<td>811</td>
<td>178</td>
<td>189</td>
</tr>
<tr>
<td>1999</td>
<td>114,787,053</td>
<td>944</td>
<td>194</td>
<td>210</td>
</tr>
<tr>
<td>2000</td>
<td>135,459,751</td>
<td>1,077</td>
<td>212</td>
<td>234</td>
</tr>
<tr>
<td>2001</td>
<td>161,932,547</td>
<td>1,210</td>
<td>232</td>
<td>259</td>
</tr>
<tr>
<td>2002</td>
<td>184,757,797</td>
<td>1,344</td>
<td>254</td>
<td>287</td>
</tr>
<tr>
<td>2003</td>
<td>211,803,145</td>
<td>1,475</td>
<td>277</td>
<td>317</td>
</tr>
<tr>
<td>2004</td>
<td>239,085,159</td>
<td>1,604</td>
<td>303</td>
<td>350</td>
</tr>
<tr>
<td>2005</td>
<td>267,655,539</td>
<td>1,730</td>
<td>331</td>
<td>386</td>
</tr>
<tr>
<td>2006</td>
<td>301,741,199</td>
<td>1,857</td>
<td>361</td>
<td>425</td>
</tr>
<tr>
<td>2007</td>
<td>336,884,749</td>
<td>1,987</td>
<td>394</td>
<td>466</td>
</tr>
<tr>
<td>2008</td>
<td>373,099,594</td>
<td>2,118</td>
<td>429</td>
<td>511</td>
</tr>
<tr>
<td>2009</td>
<td>410,933,426</td>
<td>2,251</td>
<td>467</td>
<td>560</td>
</tr>
<tr>
<td>Final</td>
<td>449,327,626</td>
<td>2,385</td>
<td>508</td>
<td>612</td>
</tr>
</tbody>
</table>
Figure 5.3 Growth of Airline Fleet (AF), Runway (RW) and Terminal (TN)

Figure 5.4 Comparison of Actual and Potential Air Demand

As shown in Table 5.2, the air transportation system in China can accommodate about 135.5 million air passengers by the year 2000, 449.3 million air passengers for the year
2010 after the air demand is calibrated by the air transportation system delay and the air fare. At the same time, in order to meet the air demand, the airlines fleet, the runways and the terminals will reach values of 1078, 213 and 234, respectively in the year 2000 and 2385, 509 and 612 in the year 2010.

Figure 5.4 shows the comparison between actual and potential air demand.

### 5.2 Policy Analysis

Several probable scenarios that a decision maker would face while doing policy analysis are developed in order to demonstrate the versatility and the capabilities of the CATSDM. The baseline scenarios developed for the CSEDM and CATSDM used existing representative conditions. Several input parameters are varied from the baseline scenarios to test the sensitivity of the model. The scenarios have the following components:

1. **Scenario-I**   Air fare parameter
2. **Scenario-II**  Air fuel parameter
3. **Scenario-III** Air transportation system investment parameter
4. **Scenario-IV**  Aircraft utilization
5. **Scenario-V**   Total delay parameter

#### 5.2.1 Scenario-I   Air fare parameter

The first scenario deals with the air fare parameter which is increased to at an average growth rate of 10%, 15% and 20% from the baseline average growth rate of 7.5% per year. From Table 5.2, the air passengers will reach 449.3 million which is an 8.8 fold in air passengers of the baseline year (1995) if air fare is increased at a average growth rate of 7.5% by the year 2010. As expected the air transportation demand is decreased with the increasing of the air fare. The air transportation demand decreases to 417.2 million, 389.7 and 324.9 million if the air fares are increased at an average growth rate of 10%, 15% and 20%, respectively, by the year 2010. This represents an 8.2, 7.6 and 6.3 fold over the air travelers of the baseline year, respectively. For example, more than 125
million air passengers will not choose the air transportation system mode due to expensive air fare by the year 2010 when the air fare is increased at the growth rate of 20%. The results are shown in Table 5.3. However, the airlines revenue will not decrease with declining air demand, as air fare will be higher per passenger. The results are shown in Table 5.4,

It is considerable for the airlines benefit to increase the air fare, but the social benefit will be negative.

<table>
<thead>
<tr>
<th>Year</th>
<th>Air demand (persons) (GR(^1) = 10%)</th>
<th>Air demand (persons) (GR = 15%)</th>
<th>Air demand (persons) (GR = 20%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>51,170,000</td>
<td>51,170,000</td>
<td>51,170,000</td>
</tr>
<tr>
<td>1996</td>
<td>63,495,645</td>
<td>63,227,812</td>
<td>62,874,274</td>
</tr>
<tr>
<td>1997</td>
<td>77,693,039</td>
<td>77,079,939</td>
<td>75,718,220</td>
</tr>
<tr>
<td>1998</td>
<td>93,891,254</td>
<td>92,828,137</td>
<td>90,340,959</td>
</tr>
<tr>
<td>1999</td>
<td>114,680,975</td>
<td>113,400,100</td>
<td>109,684,914</td>
</tr>
<tr>
<td>2001</td>
<td>161,323,601</td>
<td>160,805,013</td>
<td>148,042,545</td>
</tr>
<tr>
<td>2002</td>
<td>184,711,302</td>
<td>182,230,491</td>
<td>163,882,738</td>
</tr>
<tr>
<td>2003</td>
<td>211,774,209</td>
<td>205,104,817</td>
<td>184,629,335</td>
</tr>
<tr>
<td>2004</td>
<td>236,300,130</td>
<td>222,533,388</td>
<td>204,139,811</td>
</tr>
<tr>
<td>2005</td>
<td>264,822,124</td>
<td>241,568,171</td>
<td>218,232,565</td>
</tr>
<tr>
<td>2006</td>
<td>297,530,641</td>
<td>274,235,000</td>
<td>244,289,796</td>
</tr>
<tr>
<td>2007</td>
<td>330,513,422</td>
<td>301,194,667</td>
<td>257,996,471</td>
</tr>
<tr>
<td>2008</td>
<td>362,942,935</td>
<td>322,207,782</td>
<td>278,168,806</td>
</tr>
<tr>
<td>2009</td>
<td>391,867,508</td>
<td>356,963,697</td>
<td>300,645,770</td>
</tr>
<tr>
<td>Final</td>
<td>417,125,200</td>
<td>389,697,618</td>
<td>324,919,375</td>
</tr>
</tbody>
</table>

Notes: 1 GR - growth rate of the air fare
Table 5.4 Airline Revenue from Air Passengers (millions)

<table>
<thead>
<tr>
<th>Year</th>
<th>Airline revenue (yuan) GR(^1) = 10%</th>
<th>Airline revenue (yuan) GR = 15%</th>
<th>Airline revenue (yuan) GR = 20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>41,857</td>
<td>41,857</td>
<td>41,857</td>
</tr>
<tr>
<td>1996</td>
<td>54,987</td>
<td>57,133</td>
<td>59,478</td>
</tr>
<tr>
<td>1997</td>
<td>71,088</td>
<td>76,899</td>
<td>83,385</td>
</tr>
<tr>
<td>1998</td>
<td>90,693</td>
<td>102,224</td>
<td>115,485</td>
</tr>
<tr>
<td>1999</td>
<td>114,130</td>
<td>137,705</td>
<td>162,240</td>
</tr>
<tr>
<td>2000</td>
<td>141,419</td>
<td>181,493</td>
<td>222,600</td>
</tr>
<tr>
<td>2001</td>
<td>177,510</td>
<td>239,576</td>
<td>304,256</td>
</tr>
<tr>
<td>2002</td>
<td>212,657</td>
<td>300,815</td>
<td>396,514</td>
</tr>
<tr>
<td>2003</td>
<td>255,976</td>
<td>378,350</td>
<td>513,229</td>
</tr>
<tr>
<td>2004</td>
<td>303,395</td>
<td>467,348</td>
<td>640,367</td>
</tr>
<tr>
<td>2005</td>
<td>373,616</td>
<td>561,868</td>
<td>799,413</td>
</tr>
<tr>
<td>2006</td>
<td>463,315</td>
<td>694,391</td>
<td>1,043,644</td>
</tr>
<tr>
<td>2007</td>
<td>569,005</td>
<td>848,505</td>
<td>1,318,179</td>
</tr>
<tr>
<td>2008</td>
<td>693,190</td>
<td>1,024,935</td>
<td>1,621,665</td>
</tr>
<tr>
<td>2009</td>
<td>839,830</td>
<td>1,217,279</td>
<td>2,066,079</td>
</tr>
<tr>
<td>Final</td>
<td>1,010,127</td>
<td>1,425,312</td>
<td>2,593,872</td>
</tr>
</tbody>
</table>

Notes: 1 GR - growth rate of the air fare

5.2.2 Scenario-II Air fuel parameter

Generally, labor and fuel are the two biggest costs contributors in the operation of an airline. China is a country of ‘high employment’ and ‘low income’. So, the fuel costs represent the biggest cost for China’s airlines in fact. It represents over one-third of total operating costs. Despite great improvement in fuel efficiency, the modern airline still consumes fuel liberally, the fuel costs remain a severe challenge to the airlines. It directly
affects the benefit and development of the airlines. Table 5.5 and Figure 5.5 show that the air demand are impacted by the change of the price of air fuel. The first column shows that the growth rate of the price of air fuel is decreased to 10% according to the growth rate of 20% of existing price of air fuel. In the year 2010, the air demand could increase by 10 million due to a 3 fold reduction in the airlines operating cost when the price of air fuel is increased at a growth rate of 10% (instead of 20% baseline). The results are shown in Table 5.6 and Figure 5.6.

<table>
<thead>
<tr>
<th>Year</th>
<th>Air demand (persons) GRP = 10%</th>
<th>Air demand (persons) GRP = 20%</th>
<th>Air demand (persons) GRP = 30%</th>
<th>Air demand (persons) GRP = 40%</th>
<th>Air demand (persons) GRP = 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>51,170,000</td>
<td>51,170,000</td>
<td>51,170,000</td>
<td>51,170,000</td>
<td>51,170,000</td>
</tr>
<tr>
<td>1996</td>
<td>64,020,596</td>
<td>64,020,596</td>
<td>64,020,596</td>
<td>64,020,596</td>
<td>64,020,596</td>
</tr>
<tr>
<td>1997</td>
<td>78,825,661</td>
<td>78,825,661</td>
<td>78,825,661</td>
<td>78,825,661</td>
<td>78,825,661</td>
</tr>
<tr>
<td>1998</td>
<td>95,776,092</td>
<td>95,776,092</td>
<td>95,776,092</td>
<td>95,776,092</td>
<td>95,776,092</td>
</tr>
<tr>
<td>1999</td>
<td>114,787,053</td>
<td>114,787,053</td>
<td>114,787,053</td>
<td>114,787,053</td>
<td>114,007,950</td>
</tr>
<tr>
<td>2001</td>
<td>161,932,547</td>
<td>161,932,547</td>
<td>160,832,787</td>
<td>159,981,375</td>
<td>159,134,284</td>
</tr>
<tr>
<td>2002</td>
<td>184,757,797</td>
<td>184,757,797</td>
<td>182,710,599</td>
<td>181,801,944</td>
<td>180,843,111</td>
</tr>
<tr>
<td>2003</td>
<td>211,803,145</td>
<td>211,803,145</td>
<td>208,522,185</td>
<td>207,395,444</td>
<td>205,941,568</td>
</tr>
<tr>
<td>2004</td>
<td>239,085,159</td>
<td>239,085,159</td>
<td>233,613,848</td>
<td>230,307,289</td>
<td>225,968,789</td>
</tr>
<tr>
<td>2005</td>
<td>268,894,996</td>
<td>267,655,539</td>
<td>257,916,041</td>
<td>251,587,216</td>
<td>246,253,426</td>
</tr>
<tr>
<td>2006</td>
<td>304,456,765</td>
<td>301,741,199</td>
<td>291,440,634</td>
<td>284,847,229</td>
<td>279,084,219</td>
</tr>
<tr>
<td>2007</td>
<td>341,212,239</td>
<td>336,884,749</td>
<td>325,843,382</td>
<td>318,979,608</td>
<td>312,820,092</td>
</tr>
<tr>
<td>2008</td>
<td>379,194,701</td>
<td>373,099,594</td>
<td>361,150,572</td>
<td>354,000,607</td>
<td>347,419,349</td>
</tr>
<tr>
<td>2009</td>
<td>419,033,226</td>
<td>410,933,426</td>
<td>397,900,417</td>
<td>390,436,746</td>
<td>383,321,210</td>
</tr>
<tr>
<td>Final</td>
<td>459,675,353</td>
<td>449,327,626</td>
<td>435,069,958</td>
<td>427,159,824</td>
<td>419,443,767</td>
</tr>
</tbody>
</table>

Notes: 1 GRP - growth rate of the price of air fuel.

In Figure 5.5, the curves labeled 1, 2, 3, 4, and 5 represent the changes of the air demand with time when the growth rates of the price of air fuel are 10%, 20%, 30%, 40% and 50%, respectively.
Figure 5.5 Air Demand Change with the Changing of the Price of Air Fuel

Table 5.6 The Operation Costs of Airline with the Change of the Price of Air Fuel (millions)

<table>
<thead>
<tr>
<th>Year</th>
<th>Operation costs (yuan) GRP(^1) = 10%</th>
<th>Operation costs (yuan) GRP = 20%</th>
<th>Operation costs (yuan) GRP = 30%</th>
<th>Operation costs (yuan) GRP = 40%</th>
<th>Operation costs (yuan) GRP = 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>9,387</td>
<td>9,387</td>
<td>9,387</td>
<td>9,387</td>
<td>9,387</td>
</tr>
<tr>
<td>1996</td>
<td>13,221</td>
<td>14,092</td>
<td>14,964</td>
<td>15,835</td>
<td>29,005</td>
</tr>
<tr>
<td>1998</td>
<td>23,108</td>
<td>28,739</td>
<td>34,301</td>
<td>41,371</td>
<td>49,526</td>
</tr>
<tr>
<td>1999</td>
<td>29,400</td>
<td>38,568</td>
<td>50,338</td>
<td>65,162</td>
<td>83,526</td>
</tr>
<tr>
<td>2000</td>
<td>36,772</td>
<td>51,837</td>
<td>72,853</td>
<td>101,434</td>
<td>139,839</td>
</tr>
<tr>
<td>2001</td>
<td>45,374</td>
<td>68,781</td>
<td>104,262</td>
<td>156,772</td>
<td>232,596</td>
</tr>
<tr>
<td>2002</td>
<td>55,457</td>
<td>90,443</td>
<td>148,437</td>
<td>241,230</td>
<td>385,255</td>
</tr>
<tr>
<td>2003</td>
<td>67,115</td>
<td>117,774</td>
<td>209,932</td>
<td>368,541</td>
<td>633,945</td>
</tr>
<tr>
<td>2004</td>
<td>80,623</td>
<td>152,217</td>
<td>295,453</td>
<td>561,245</td>
<td>1,037,715</td>
</tr>
<tr>
<td>2005</td>
<td>96,213</td>
<td>195,377</td>
<td>413,717</td>
<td>849,145</td>
<td>1,686,904</td>
</tr>
<tr>
<td>2006</td>
<td>114,206</td>
<td>249,853</td>
<td>576,407</td>
<td>1,277,256</td>
<td>2,725,027</td>
</tr>
<tr>
<td>2007</td>
<td>135,042</td>
<td>318,677</td>
<td>800,887</td>
<td>1,916,195</td>
<td>4,389,848</td>
</tr>
<tr>
<td>2008</td>
<td>159,136</td>
<td>405,382</td>
<td>1,109,582</td>
<td>2,866,472</td>
<td>7,050,153</td>
</tr>
<tr>
<td>2009</td>
<td>186,988</td>
<td>514,328</td>
<td>1,532,728</td>
<td>4,275,056</td>
<td>11,286,305</td>
</tr>
<tr>
<td>Final</td>
<td>219,204</td>
<td>650,927</td>
<td>2,111,173</td>
<td>6,356,811</td>
<td>18,010,325</td>
</tr>
</tbody>
</table>

Notes: 1 GRP - growth rate of the air fuel price.
Figure 5.6 Curves of Operation Costs of the Airlines

The air passengers will decline by 14 million, 22 million and 30 million, respectively, if the price of fuel is increased 10%, 20% and 30% from the baseline growth rate of 20%, respectively, by the year 2010. The reason is that the operation costs of airlines are extremely sensitive to fuel price. Results are shown in Table 5.6 and Figure 5.2.

In Figure 5.6, the curves labeled 1, 2, 3, 4, and 5 represent the change of the operation costs of the airlines with time when the growth rates of the price of air fuel are 10%, 20%, 30%, 40% and 50%, respectively.

5.2.3 Scenario-III Air transportation system investment parameter

In China, the airports and airlines were owned and operated by the central government a few years ago. Today, local governments and private enterprises have invested in this field, because the development of an air transportation system is viewed to enhance regional development. In order to study the effects of CATSDM when the capital investment devoted to the air transportation system is increased 130% of the existing
capital investment. Table 5.7 shows the simulation results of China's air transportation system in the future in China under this new initiative.

<table>
<thead>
<tr>
<th>Year</th>
<th>Air demand (persons)</th>
<th>Number of aircraft</th>
<th>Number of runway</th>
<th>Number of terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>51,170,000</td>
<td>416</td>
<td>139</td>
<td>138</td>
</tr>
<tr>
<td>1996</td>
<td>64,020,596</td>
<td>550</td>
<td>154</td>
<td>158</td>
</tr>
<tr>
<td>1997</td>
<td>78,950,033</td>
<td>719</td>
<td>172</td>
<td>181</td>
</tr>
<tr>
<td>1998</td>
<td>97,524,311</td>
<td>889</td>
<td>191</td>
<td>205</td>
</tr>
<tr>
<td>1999</td>
<td>119,134,466</td>
<td>1001</td>
<td>212</td>
<td>232</td>
</tr>
<tr>
<td>2000</td>
<td>142,177,393</td>
<td>1,138</td>
<td>236</td>
<td>262</td>
</tr>
<tr>
<td>2001</td>
<td>170,448,350</td>
<td>1,228</td>
<td>261</td>
<td>295</td>
</tr>
<tr>
<td>2002</td>
<td>194,833,003</td>
<td>1,397</td>
<td>289</td>
<td>331</td>
</tr>
<tr>
<td>2003</td>
<td>223,581,371</td>
<td>1,562</td>
<td>320</td>
<td>370</td>
</tr>
<tr>
<td>2004</td>
<td>252,485,034</td>
<td>1,724</td>
<td>353</td>
<td>412</td>
</tr>
<tr>
<td>2005</td>
<td>282,613,781</td>
<td>1,882</td>
<td>389</td>
<td>458</td>
</tr>
<tr>
<td>2006</td>
<td>317,515,607</td>
<td>2,040</td>
<td>428</td>
<td>507</td>
</tr>
<tr>
<td>2007</td>
<td>353,336,918</td>
<td>2,198</td>
<td>470</td>
<td>560</td>
</tr>
<tr>
<td>2008</td>
<td>390,145,088</td>
<td>2,357</td>
<td>515</td>
<td>618</td>
</tr>
<tr>
<td>2009</td>
<td>428,537,104</td>
<td>2,516</td>
<td>564</td>
<td>680</td>
</tr>
<tr>
<td>Final</td>
<td>467,466,859</td>
<td>2,674</td>
<td>617</td>
<td>747</td>
</tr>
</tbody>
</table>

From Table 5.7, we can see that the air transportation demand will increase by 18 million by the year 2010. Other facilities of the air transportation system such as airlines fleet, runways and terminals will increase accordingly (see Table 5.8)
Table 5.8 Characteristics of the Air Transportation System According to the Existing Capital Investment

<table>
<thead>
<tr>
<th>Year</th>
<th>Air demand (person)</th>
<th>Number of aircraft</th>
<th>Number of runway</th>
<th>Number of terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>51,170,000</td>
<td>416</td>
<td>139</td>
<td>138</td>
</tr>
<tr>
<td>1996</td>
<td>64,020,596</td>
<td>547</td>
<td>150</td>
<td>153</td>
</tr>
<tr>
<td>1997</td>
<td>78,825,661</td>
<td>679</td>
<td>163</td>
<td>170</td>
</tr>
<tr>
<td>1998</td>
<td>95,776,092</td>
<td>811</td>
<td>178</td>
<td>189</td>
</tr>
<tr>
<td>1999</td>
<td>114,787,053</td>
<td>944</td>
<td>194</td>
<td>210</td>
</tr>
<tr>
<td>2000</td>
<td>135,459,751</td>
<td>1,077</td>
<td>212</td>
<td>234</td>
</tr>
<tr>
<td>2001</td>
<td>161,932,547</td>
<td>1,210</td>
<td>232</td>
<td>259</td>
</tr>
<tr>
<td>2002</td>
<td>184,757,797</td>
<td>1,344</td>
<td>254</td>
<td>287</td>
</tr>
<tr>
<td>2003</td>
<td>211,803,145</td>
<td>1,475</td>
<td>277</td>
<td>317</td>
</tr>
<tr>
<td>2004</td>
<td>239,085,159</td>
<td>1,604</td>
<td>303</td>
<td>350</td>
</tr>
<tr>
<td>2005</td>
<td>267,655,539</td>
<td>1,730</td>
<td>331</td>
<td>386</td>
</tr>
<tr>
<td>2006</td>
<td>301,741,199</td>
<td>1,857</td>
<td>361</td>
<td>425</td>
</tr>
<tr>
<td>2007</td>
<td>336,884,749</td>
<td>1,987</td>
<td>394</td>
<td>466</td>
</tr>
<tr>
<td>2008</td>
<td>373,099,594</td>
<td>2,118</td>
<td>429</td>
<td>511</td>
</tr>
<tr>
<td>2009</td>
<td>410,933,426</td>
<td>2,251</td>
<td>467</td>
<td>560</td>
</tr>
<tr>
<td>Final</td>
<td>449,327,626</td>
<td>2,385</td>
<td>508</td>
<td>612</td>
</tr>
</tbody>
</table>

If the capital investment of the air transportation system is limited, for example, the capital investment that central and local governments in China and other countries can provide is about 70% of the existing capital investment, a reduction in air transportation demand will result (see Table 5.9). About 126.38 million air passengers will be transported by the air transportation system in China in the year 2000. This amount of air passengers represents a small reduction compared with the baseline results. The main
reason for this phenomenon is that a fast growth of the air demand is not easy to be
controlled in the short term. China’s air transportation system may decrease the levels of
service to transport them. The airlines fleet, runways and terminals will decline to 996
airplanes, 186 runways and 20! terminals by the year 2000.

According to this scenario. By the year 2010, the number of air passengers transported
could be 419.6 million, the airlines fleet, runways and terminals would be 2203, 384 and
456, respectively. The air passengers, airlines fleet, runways and terminals would sharply
decrease.

<table>
<thead>
<tr>
<th>Year</th>
<th>Air demand (persons)</th>
<th>Number of aircraft</th>
<th>Number of runway</th>
<th>Number of terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>51,170,000</td>
<td>416</td>
<td>139</td>
<td>138</td>
</tr>
<tr>
<td>1996</td>
<td>64,020,596</td>
<td>547</td>
<td>146</td>
<td>148</td>
</tr>
<tr>
<td>1997</td>
<td>78,669,692</td>
<td>679</td>
<td>154</td>
<td>159</td>
</tr>
<tr>
<td>1998</td>
<td>95,085,464</td>
<td>811</td>
<td>164</td>
<td>172</td>
</tr>
<tr>
<td>1999</td>
<td>112,302,298</td>
<td>923</td>
<td>174</td>
<td>186</td>
</tr>
<tr>
<td>2000</td>
<td>126,384,981</td>
<td>996</td>
<td>186</td>
<td>201</td>
</tr>
<tr>
<td>2001</td>
<td>154,682,002</td>
<td>1,032</td>
<td>199</td>
<td>218</td>
</tr>
<tr>
<td>2002</td>
<td>178,582,288</td>
<td>1,171</td>
<td>213</td>
<td>237</td>
</tr>
<tr>
<td>2003</td>
<td>206,127,095</td>
<td>1,308</td>
<td>229</td>
<td>257</td>
</tr>
<tr>
<td>2004</td>
<td>228,257,496</td>
<td>1,443</td>
<td>246</td>
<td>280</td>
</tr>
<tr>
<td>2005</td>
<td>249,422,134</td>
<td>1,572</td>
<td>265</td>
<td>304</td>
</tr>
<tr>
<td>2006</td>
<td>282,252,179</td>
<td>1,696</td>
<td>285</td>
<td>330</td>
</tr>
<tr>
<td>2007</td>
<td>315,807,223</td>
<td>1,821</td>
<td>307</td>
<td>358</td>
</tr>
<tr>
<td>2008</td>
<td>350,028,157</td>
<td>1,948</td>
<td>330</td>
<td>388</td>
</tr>
<tr>
<td>2009</td>
<td>385,327,968</td>
<td>2,075</td>
<td>356</td>
<td>421</td>
</tr>
<tr>
<td>Final</td>
<td>419,578,302</td>
<td>2,203</td>
<td>384</td>
<td>457</td>
</tr>
</tbody>
</table>
5.2.4 Scenario-IV  Aircraft utilization

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of aircraft (TPAD$^{1} = 3$)</th>
<th>Number of aircraft (TPAD = 3.5)</th>
<th>Number of aircraft (TPAD = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>416</td>
<td>416</td>
<td>416</td>
</tr>
<tr>
<td>1996</td>
<td>547</td>
<td>395</td>
<td>395</td>
</tr>
<tr>
<td>1997</td>
<td>679</td>
<td>534</td>
<td>533</td>
</tr>
<tr>
<td>1998</td>
<td>811</td>
<td>674</td>
<td>506</td>
</tr>
<tr>
<td>1999</td>
<td>945</td>
<td>815</td>
<td>653</td>
</tr>
<tr>
<td>2000</td>
<td>1,079</td>
<td>956</td>
<td>802</td>
</tr>
<tr>
<td>2001</td>
<td>1,214</td>
<td>1,098</td>
<td>952</td>
</tr>
<tr>
<td>2002</td>
<td>1,350</td>
<td>1,241</td>
<td>1,103</td>
</tr>
<tr>
<td>2003</td>
<td>1,485</td>
<td>1,381</td>
<td>1,251</td>
</tr>
<tr>
<td>2004</td>
<td>1,618</td>
<td>1,519</td>
<td>1,396</td>
</tr>
<tr>
<td>2005</td>
<td>1,750</td>
<td>1,654</td>
<td>1,538</td>
</tr>
<tr>
<td>2006</td>
<td>1,879</td>
<td>1,786</td>
<td>1,675</td>
</tr>
<tr>
<td>2007</td>
<td>2,011</td>
<td>1,921</td>
<td>1,810</td>
</tr>
<tr>
<td>2008</td>
<td>2,145</td>
<td>2,057</td>
<td>1,945</td>
</tr>
<tr>
<td>2009</td>
<td>2,282</td>
<td>2,194</td>
<td>2,081</td>
</tr>
<tr>
<td>Final</td>
<td>2,419</td>
<td>2,331</td>
<td>2,217</td>
</tr>
</tbody>
</table>

Notes: 1 TPAD - the trips per aircraft a day

In this scenario we consider the size of airlines fleet as it is affected by the aircraft utilization factor expressed as average trips per aircraft per day. Under current conditions an aircraft trip takes 2 hours in China (CAAC, 1995). According to CAAC statistics the average number of trips per day is 3 thus resulting six block hours of utilization. The results shown in Table 5.10 and Figure 5.7 illustrate the effect of aircraft utilization in the
aircraft fleet in China. The airlines fleet will be decrease about 100 airplanes when the number of trips per aircraft increase by 0.5 trips per day. This is beneficial to the airlines.

![Graph showing aircraft fleet size vs. TPAD](image)

**Figure 5.7 Aircraft Fleet Size Vs TPAD**

5.2.5 Scenario-V Total delay parameter

The final scenario analyzed is with regard to the total delay on the air transportation system. The effectiveness of a transportation system is commonly measured in terms of its ability to efficiently process the transported unit. Since the system performance is dependent upon the individual components of that system, it is usually necessary to evaluate these components to determine overall system capabilities. In case where use of the system requires the sequential utilization of a group of processors, the overall efficiency of the system is usually limited by the characteristics of the least efficient component.

In air transportation, particular attention is given to the movement of aircraft, passengers, ground access vehicles, and cargo through both the airport and the aviation system. The experienced air traveler has grown accustomed to delay flights, overbooking, missed
connections, ground congestion, parking shortages, and long lines in the terminal building during peak travel periods. For many air transportation trips, the relative advantage of the speed characteristics of aircraft is considerably diminished by ground access, terminal system, and airside delays.

In a more general sense, the unprecedented growth in the demand for air transportation services over the past 20 years has, in many situations, outpaced the ability to provide facilities to adequately accommodate this growth. To a greater extent, elements of the air transport system are being stressed beyond their design capabilities, resulting in significant service deterioration at major airports in China. The air transportation system will lose some passengers due to the service deterioration that is caused by delay on the air transportation system. At the same time, by estimating the magnitude of delays often is more important for the justification and establishment of requirements of airfield improvements than the determination of capacity.

The total delay of China’s air transportation system in China is comprised of the delay in air routes, delay on the runways and delay in the terminals.

![Figure 5.8 Air Demand Vs Total Delay](image)
<table>
<thead>
<tr>
<th>Year</th>
<th>Air demand (persons) (TD⁰ = 60²)</th>
<th>Air demand (persons) (TD = 80)</th>
<th>Air demand (persons) (TD = 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>51,170,000</td>
<td>51,170,000</td>
<td>51,170,000</td>
</tr>
<tr>
<td>1996</td>
<td>64,020,596</td>
<td>64,020,596</td>
<td>64,020,596</td>
</tr>
<tr>
<td>1997</td>
<td>78,825,661</td>
<td>78,703,261</td>
<td>78,648,951</td>
</tr>
<tr>
<td>1998</td>
<td>95,776,092</td>
<td>95,170,404</td>
<td>94,931,220</td>
</tr>
<tr>
<td>1999</td>
<td>114,787,053</td>
<td>112,754,056</td>
<td>108,635,668</td>
</tr>
<tr>
<td>2000</td>
<td>135,459,751</td>
<td>126,836,739</td>
<td>122,718,351</td>
</tr>
<tr>
<td>2001</td>
<td>161,932,547</td>
<td>150,604,971</td>
<td>144,168,168</td>
</tr>
<tr>
<td>2002</td>
<td>184,757,797</td>
<td>173,804,461</td>
<td>168,365,695</td>
</tr>
<tr>
<td>2003</td>
<td>211,803,145</td>
<td>197,773,729</td>
<td>196,437,925</td>
</tr>
<tr>
<td>2004</td>
<td>239,085,159</td>
<td>223,977,116</td>
<td>217,030,872</td>
</tr>
<tr>
<td>2005</td>
<td>267,655,539</td>
<td>248,062,632</td>
<td>237,315,510</td>
</tr>
<tr>
<td>2006</td>
<td>301,741,199</td>
<td>281,451,878</td>
<td>261,194,572</td>
</tr>
<tr>
<td>2007</td>
<td>336,884,749</td>
<td>315,557,890</td>
<td>284,363,144</td>
</tr>
<tr>
<td>2008</td>
<td>373,099,594</td>
<td>350,413,437</td>
<td>308,138,225</td>
</tr>
<tr>
<td>2009</td>
<td>410,933,426</td>
<td>386,409,540</td>
<td>332,961,862</td>
</tr>
<tr>
<td>Final</td>
<td>449,327,626</td>
<td>422,483,696</td>
<td>358,219,554</td>
</tr>
</tbody>
</table>

Notes:  
1. TD - the total delay on the air transportation system  
2. The unit of the total delay is 10,000 hours

According to the existing delay level, the air transportation system in China will have a total annual delay of 600,000 hours by the year 2010. If we assume that the annual delay is increased to 800,000 hours and 1,000,000 hours because of the inadequate in the
investment of technical upgrade on air traffic control and construction and improvement of the airports by the year 2010. The results simulated are given in the Figure 5.8 and Table 5.11. As shown in Figure 5.8 and Table 5.11, the air passengers will be decreased by 27 million when the annual delay reach 800,000 hours, more than 91 million air passengers will not choose the air transportation system when the annual delay is 1,000,000 hours in the year 2010.
6. Conclusions and Recommendations

6.1 Conclusions

The application of Systems Dynamics for the development of China's Socio-economic and Air Transportation System has proven to be very effective. The models are found to be highly flexible so as to meet the needs of the policy analyst. The STELLA II computer software is problem oriented rather than computer oriented, therefore, the STELLA II is easy to develop Systems Dynamics models. These models also overcome the drawback that often is existed in most economic analysis models by its simplicity. So, decision makers could exercise policies at various points in time and quantify results immediately.

The purpose of CSEDM and CATSDM is not merely attempting to understand the dynamics of a complex process. The goal is to reach conclusions that may be translated to policies and strategies for guiding its future development and to serve as a living laboratory where policies can be tried before implementing them into the real system. Benefits of such a System Dynamics model are clear if one realizes the costly enterprise of developing air transportation system infrastructure without synergistically looking at the regional economies tied to it.

In CSEDM and CATSDM, the entire air transportation system is examined relative to the geographic, economic, industrial, and growth characteristics of a region to determine the air transportation system needs in a region. A wide range of economic, social, market, and operational factors affect aviation. Therefore, to properly assess the impact of predicted changes in the other sectors of society upon aviation demand and to investigate the effect of alternative assumptions on aviation, it is often desirable to use mathematical techniques to study the correlation between dependent and independent variables. The models that relate measures of aviation activity to economic and social factors are extremely valuable techniques in forecasting the future.
6.2 Recommendations

We can see that the market of the potential air passengers could be very large in the future. However, the rapid growth of the air passengers over the last decade years also has revealed weaknesses in the air transportation system in China. In order to remedy this new situation, the strengthening of China’s air transportation system becomes a veritable necessity. We give the following a few of recommendations based on the results of the two models to China’s air transportation system:

1. During the period of poor financial performance, CAAC should use the capital of investment correctly to three key components which are airline, air traffic control and airport on air transportation system so that they are achieved a balance and coordination between them. If so, the total delay on the air transportation system will be decreased further, the more air passengers will be captured.

2. The control of costs, such as , in order to increase the capacity of the air fleet, China’s airlines should try to enhance the utilization of aircraft, except purchasing new aircraft. Its economic benefit is very considerable.

3. The level of air fares is important for both the airlines and the air passengers. China is the country with very low incomes, almost all income is used to provide the necessities of life. Little remains for expenditure on luxury items such as air travel, no matter how desirable they may seem. The airlines will lose a lot of the potential air passengers if the level of air fares is too high for people to afford. On the other hand, the main resource of the airlines revenue comes from the revenue of the air fares. It is disastrous for the airlines if the level of the air fares is too low. So, the level of the air fares will be crucial.
References

1. Donald R. Drew “Systems Dynamics Modeling and Application” study notes, Virginia Tech
7. CAAC statistical yearbooks, from 1952 to 1995
8. “People’s Daily Newspaper” in China
   United nations Publication
13. Shephen Shaw “Airline Marketing and Management” the bath Press, Awn. 1985
16. David Sawers “Competition in the Air” Published by the Institute of Economic Affairs, 1987


21. Antonio A. Trani "Supplementary Documents for Airport Planning and Design" 1995

22. Forrester, Jay W. "Industrial Dynamics" the M. I. T. Press, Cambridge, Massachusetts, 1961


## Appendices


<table>
<thead>
<tr>
<th>Year</th>
<th>Gross National Product (yuan) (100 million)</th>
<th>Total population (persons) (100 million)</th>
<th>Urban Population (persons) (100 million)</th>
<th>Total Jobs Non-agriculture (persons) (100 million)</th>
<th>Per Capita Income (yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>3,588</td>
<td>9.58</td>
<td>1.20</td>
<td>1.18</td>
<td>375</td>
</tr>
<tr>
<td>1979</td>
<td>3,998</td>
<td>9.71</td>
<td>1.29</td>
<td>1.24</td>
<td>412</td>
</tr>
<tr>
<td>1980</td>
<td>4,470</td>
<td>9.83</td>
<td>1.34</td>
<td>1.32</td>
<td>455</td>
</tr>
<tr>
<td>1981</td>
<td>4,775</td>
<td>9.96</td>
<td>1.38</td>
<td>1.39</td>
<td>479</td>
</tr>
<tr>
<td>1982</td>
<td>5,128</td>
<td>10.15</td>
<td>1.51</td>
<td>1.43</td>
<td>505</td>
</tr>
<tr>
<td>1983</td>
<td>5,787</td>
<td>10.24</td>
<td>1.66</td>
<td>1.51</td>
<td>565</td>
</tr>
<tr>
<td>1984</td>
<td>6,928</td>
<td>10.35</td>
<td>1.79</td>
<td>1.68</td>
<td>669</td>
</tr>
<tr>
<td>1985</td>
<td>8,527</td>
<td>10.45</td>
<td>1.92</td>
<td>1.73</td>
<td>816</td>
</tr>
<tr>
<td>1986</td>
<td>9,688</td>
<td>10.57</td>
<td>2.01</td>
<td>1.82</td>
<td>917</td>
</tr>
<tr>
<td>1987</td>
<td>11,307</td>
<td>10.81</td>
<td>2.14</td>
<td>1.96</td>
<td>1,046</td>
</tr>
<tr>
<td>1988</td>
<td>14,074</td>
<td>10.96</td>
<td>2.33</td>
<td>2.03</td>
<td>1,284</td>
</tr>
<tr>
<td>1989</td>
<td>15,998</td>
<td>11.27</td>
<td>2.46</td>
<td>2.01</td>
<td>1,419</td>
</tr>
<tr>
<td>1990</td>
<td>17,681</td>
<td>11.43</td>
<td>2.52</td>
<td>2.16</td>
<td>1,547</td>
</tr>
<tr>
<td>1991</td>
<td>20,188</td>
<td>11.58</td>
<td>2.68</td>
<td>2.18</td>
<td>1,743</td>
</tr>
<tr>
<td>1992</td>
<td>24,362</td>
<td>11.70</td>
<td>2.77</td>
<td>2.20</td>
<td>2,082</td>
</tr>
<tr>
<td>1993</td>
<td>31,380</td>
<td>11.85</td>
<td>2.99</td>
<td>2.25</td>
<td>2,648</td>
</tr>
<tr>
<td>1994</td>
<td>43,800</td>
<td>11.98</td>
<td>3.13</td>
<td>2.36</td>
<td>3,656</td>
</tr>
<tr>
<td>1995</td>
<td>57,733</td>
<td>12.11</td>
<td>3.35</td>
<td>2.47</td>
<td>4,767</td>
</tr>
</tbody>
</table>
### Appendix B: Characteristics of the Air Transportation System in China 1978-1995

<table>
<thead>
<tr>
<th>Year</th>
<th>Enplaned passengers (million)</th>
<th>Flight (thousands)</th>
<th>Number of aircraft¹</th>
<th>Number of airports</th>
<th>Air fare (yuan)</th>
<th>Load factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>2.31</td>
<td>46.78</td>
<td>32</td>
<td>34</td>
<td>108</td>
<td>66.4</td>
</tr>
<tr>
<td>1979</td>
<td>2.98</td>
<td>57.70</td>
<td>32</td>
<td>39</td>
<td>117</td>
<td>64.0</td>
</tr>
<tr>
<td>1980</td>
<td>3.43</td>
<td>60.68</td>
<td>35</td>
<td>48</td>
<td>126</td>
<td>63.0</td>
</tr>
<tr>
<td>1981</td>
<td>4.01</td>
<td>62.91</td>
<td>41</td>
<td>52</td>
<td>140</td>
<td>63.1</td>
</tr>
<tr>
<td>1982</td>
<td>4.45</td>
<td>67.43</td>
<td>42</td>
<td>57</td>
<td>156</td>
<td>64.4</td>
</tr>
<tr>
<td>1983</td>
<td>3.91</td>
<td>58.77</td>
<td>49</td>
<td>65</td>
<td>210</td>
<td>66.4</td>
</tr>
<tr>
<td>1984</td>
<td>5.54</td>
<td>69.88</td>
<td>59</td>
<td>73</td>
<td>235</td>
<td>66.8</td>
</tr>
<tr>
<td>1985</td>
<td>7.47</td>
<td>85.03</td>
<td>63</td>
<td>83</td>
<td>248</td>
<td>68.2</td>
</tr>
<tr>
<td>1986</td>
<td>9.96</td>
<td>102.91</td>
<td>83</td>
<td>84</td>
<td>259</td>
<td>64.5</td>
</tr>
<tr>
<td>1987</td>
<td>13.10</td>
<td>130.55</td>
<td>104</td>
<td>93</td>
<td>280</td>
<td>66.1</td>
</tr>
<tr>
<td>1988</td>
<td>14.42</td>
<td>139.30</td>
<td>106</td>
<td>98</td>
<td>338</td>
<td>67.2</td>
</tr>
<tr>
<td>1989</td>
<td>12.83</td>
<td>136.27</td>
<td>114</td>
<td>101</td>
<td>418</td>
<td>59.5</td>
</tr>
<tr>
<td>1990</td>
<td>16.60</td>
<td>167.19</td>
<td>120</td>
<td>110</td>
<td>468</td>
<td>58.9</td>
</tr>
<tr>
<td>1991</td>
<td>21.78</td>
<td>204.90</td>
<td>139</td>
<td>113</td>
<td>489</td>
<td>63.8</td>
</tr>
<tr>
<td>1992</td>
<td>28.86</td>
<td>236.98</td>
<td>198</td>
<td>119</td>
<td>521</td>
<td>64.2</td>
</tr>
<tr>
<td>1993</td>
<td>33.83</td>
<td>287.23</td>
<td>280</td>
<td>127</td>
<td>577</td>
<td>58.4</td>
</tr>
<tr>
<td>1994</td>
<td>40.39</td>
<td>356.80</td>
<td>316</td>
<td>131</td>
<td>757</td>
<td>56.8</td>
</tr>
<tr>
<td>1995</td>
<td>51.17</td>
<td>437.79</td>
<td>336</td>
<td>138</td>
<td>818</td>
<td>63.5</td>
</tr>
</tbody>
</table>

Notes: ¹ The number of aircraft is only included the large and heavy aircraft.
## Appendix C: Main Commercial Airlines in China

<table>
<thead>
<tr>
<th>Name of Airline</th>
<th>Location</th>
<th>Aircraft used</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Air China</td>
<td>Beijing City</td>
<td>Boeing series</td>
<td>CG³</td>
</tr>
<tr>
<td>2 China east airline</td>
<td>Shanghai City</td>
<td>MD &amp; Airbus series</td>
<td>CG</td>
</tr>
<tr>
<td>3 China south airline</td>
<td>Guangzhou City</td>
<td>Boeing series</td>
<td>CG</td>
</tr>
<tr>
<td>4 China southwest airline</td>
<td>Chengdu City</td>
<td>Boeing &amp; TU¹ series</td>
<td>CG</td>
</tr>
<tr>
<td>5 China north airline</td>
<td>Shenyang City</td>
<td>MD &amp; Airbus series</td>
<td>CG</td>
</tr>
<tr>
<td>6 China northwest airline</td>
<td>Xian City</td>
<td>Airbus &amp; TU series</td>
<td>CG</td>
</tr>
<tr>
<td>7 China general airline</td>
<td>Taiyuan City</td>
<td>Yak¹ series</td>
<td>CG</td>
</tr>
<tr>
<td>8 Xinjiang airline</td>
<td>Urumqi City</td>
<td>Boeing &amp; TU series</td>
<td>CG</td>
</tr>
<tr>
<td>9 Yunnan airline</td>
<td>Kunming City</td>
<td>Boeing series</td>
<td>CG</td>
</tr>
<tr>
<td>10 Great wall airline</td>
<td>Chongqing City</td>
<td>TU series</td>
<td>CG</td>
</tr>
<tr>
<td>11 Xiamen airline</td>
<td>Xiamen City</td>
<td>Boeing series</td>
<td>LG⁴</td>
</tr>
<tr>
<td>12 Shanghai airline</td>
<td>Shanghai City</td>
<td>Boeing series</td>
<td>LG</td>
</tr>
<tr>
<td>13 Sichuan airline</td>
<td>Chengdu City</td>
<td>TU &amp; Airbus series</td>
<td>LG</td>
</tr>
<tr>
<td>14 China united airline</td>
<td>Beijing City</td>
<td>TU series</td>
<td>LG</td>
</tr>
<tr>
<td>15 Shenzhen airline</td>
<td>Shenzhen City</td>
<td>Boeing &amp; MD series</td>
<td>LG</td>
</tr>
<tr>
<td>16 Hainan airline</td>
<td>Haikou City</td>
<td>Boeing series</td>
<td>LG</td>
</tr>
<tr>
<td>17 Xihua airline</td>
<td>Tianjing City</td>
<td>Boeing series</td>
<td>LG</td>
</tr>
<tr>
<td>18 Wuhai airline</td>
<td>Wuhai City</td>
<td>Boeing &amp; Y-7² series</td>
<td>LG</td>
</tr>
<tr>
<td>19 Zhongyuan airline</td>
<td>Zhengzhou City</td>
<td>Y-7 series</td>
<td>LG</td>
</tr>
<tr>
<td>20 Guizhou airline</td>
<td>Guiyang City</td>
<td>Y-7 series</td>
<td>LG</td>
</tr>
<tr>
<td>21 Shandong airline</td>
<td>Jinan City</td>
<td>Boeing series</td>
<td>LG</td>
</tr>
<tr>
<td>22 Shanxi airline</td>
<td>Taiyuan City</td>
<td>Y-7 series</td>
<td>LG</td>
</tr>
<tr>
<td>23 Fujian airline</td>
<td>Fuzhou City</td>
<td>Y-7 series</td>
<td>LG</td>
</tr>
<tr>
<td>24 Nanjing airline</td>
<td>Nanjing City</td>
<td>Y-7 series</td>
<td>LG</td>
</tr>
<tr>
<td>25 Changan airline</td>
<td>Xian City</td>
<td>Y-7 series</td>
<td>LG</td>
</tr>
</tbody>
</table>

Notes:
1. Aircraft was made in Russian
2. Aircraft was made in China
3. Central Government
4. Local Government
Appendix D: Distribution of Air Routes in China

国内航线  Domestic Routes

国际航线  International Routes

地区航线  Regional Routes
Appendix E: Brief Description of STELLA-II

STELLA II is an acronym for “System Think, Experimental Learning Laboratory, with Animation”. The STELLA II software is designed to help people build understanding of dynamic systems and processes.

E.1 Systems Dynamics Variables

E.1.1 Level or Stock or State Variables

![Figure E.1 Level Variable](image)

Level or Stock or State Variables (Shown in Figure E.1) represent accumulations in a system. They collect whatever flows into and out of them, such as aircraft, number of runways, population etc.. The default stock type above is the Reservoir. Reservoirs act as a pool of water, or as an undifferentiated pile of “stuff”. A Reservoir passively accumulates its inflows, minus its outflows. Any units which flow into a Reservoir will lose their individual identity. Reservoir mix together all units into an undifferentiated mass as they accumulate.

E.1.2 Rate or Flow Variables

The job of Rate or Flow Variables (shown in Figure E.2) is to fill and drain accumulations. The unfilled arrow head on the flow pipe indicates the direction of the
flow. It presents how the Level or Stock or State Variables change over time, such as aircraft production rate, population growth rate etc..

![Rate or Flow Variables](image)

**Figure E.2 Rate Variable**

E.1.3 Auxiliary or Converters variables

The converter variables (shown in Figure E.3) serves a utilitarian role in the software. It holds values for constants, defines external input to the model, calculates algebraic relationships, and serves as the repository for graphical function. In general, it converts input into output, hence, the name “converter”

![Auxiliary or Converter](image)

**Figure E.3 Converter Variable**

E.1.4 Connectors

![Converter Variable](image)

**Figure E.4 Converter Variable**
As its name suggests, the job of the connector (shown in Figure E.4) is to connect model elements.

E.2 Logical Functions

STELLA II software supports logical function similar in nature to those available in higher level languages such as FORTRAN and PASCAL. The following are some logical functions IF, THEN, ELSE< AND, OR, and NOT which are used to create expressions, and they give value based upon whether the resulting expressions are TRUE or FALSE.

For example:

\[ AFIR = IF \ (DCR<0.70) \ THEN \ (0) \ ELSE \ ((NAB)*(0.05/CPS+0.55/CPL+0.4/CPI)) \]

This statement sets AFIR (airline fleet increase rate) at 0 - the “off” position - when DCR (air demand to capacity of airline fleet ratio) is less than 0.70. The statement sets AFIR at \((NAB)*(0.05/CPS+0.55/CPL+0.4/CPI))\) - the “on” position - otherwise.

E.3 Mathematical Functions

EXP: The EXP function gives “e” raised to the power of expression. Expression can be variable or constant.

LOGN: The LOGN function calculates the natural logarithm of expression. Expression can be variable or constant.

MAX: The MAX function gives the maximum value among the expressions contained within parentheses.

MIN: The MIN function gives the minimum value among the expressions contained within parentheses.
E.4 Table (Graphical) Function

You can define the converter as a graphical function. Graphical functions may also be defined from within a flow dialog. A graphical function is a sketch of a relationship between some input (which itself can be an algebraic relationship defined from the required input list and/or Bultins list) and an output.

1.5 Special Functions

DT: It is the time increment for calculations in a STELLA II model

TIME: It is the current time within a STELLA II simulation. Time is often used as an argument to logical function, trigonometric function, and graphical functions.
Appendix F: Causal Diagram of China’s Socio-economic Development Model
Appendix G: CSED Model Equations (STELLA II Language)

******************************** Stock(Level) and Flow(Rate) variables ********************************

\[ IC(t) = IC(t - dt) + (NICIR + ICI - ICD) \times dt \]

IC = The industry capital (yuan)

INIT IC = 476000E8

INIT IC = The initial value of the industry capital (yuan)

INFLOWS:

NICIR = FGNPIC*GNP*ICIM

NICIR = The new industry capital increase rate (yuan/year)

ICI = FIP1*IP

ICI = The industry capital investment (yuan/year)

OUTFLOWS:

ICD = IC/LIC

ICD = The industry capital depreciation (yuan/year)

IFS(t) = IFS(t - dt) + (IFSI - IFSD) \times dt

IFS = The infrastructure capital (yuan)

INIT IFS = 50575E8

INIT IFS = The initial value of the infrastructure capital (yuan)

INFLOWS:

IFSI = FGNPIFS*GNP

IFSI = The infrastructure capital increase rate (yuan/year)

OUTFLOWS:

IFSD = IFS/LIFS

IFSD = The infrastructure capital depreciation (yuan/year)

LCL(t) = LCL(t - dt) + (- LCLD) \times dt

LCL = The land cultivated (mu)

INIT LCL = 2E9
INIT LCL = The initial value of the land cultivated (mu)

OUTFLOWS:

LCLD = ULR

LCLD = The land cultivated decrease rate (mu/year)

RP(t) = RP(t - dt) + (NRPG - RUMR) * dt

RP = The rural population (persons)

INIT RP = 8.5766E8

INIT RP = The initial value of the rural population (persons)

INFLOWS:

NRPG = RB-RD

NRPG = The net rural population growth (persons/year)

OUTFLOWS:

RUMR = RP*RUMM/100

RUMR = The rural to urban migration rate (persons/year)

SC(t) = SC(t - dt) + (SCI - SCD) * dt

SC = The social capital (yuan)

INIT SC = 43670E8

INIT SC = The initial value of the social capital (yuan)

INFLOWS:

SCI = GNP*FGNPSC

SCI = The social capital increase rate (yuan/year)

OUTFLOWS:

SCD = SC/LSCD

SCD = The social capital depreciation rate (yuan/year)

UP(t) = UP(t - dt) + (RUMR + NUPG) * dt

UP = urban population (persons)

INIT UP = 3.5355E8

INIT UP = The initial value of the urban population (persons)

INFLOWS:

RUMR = RP*RUMM/100
RUMR = The rural to urban migration rate (persons/year)
NUPG = UB-UD
NUPG = The net urban population growth (persons/year)

 ************************** Converters(Auxiliary) variables and Constants **************************

ADIN = 1
ADIN = The initial value of the agriculture diversity index (dim)
AP = WEA*RLF
AP = The agriculture product (yuan/year)
AROI = 0
AROI = The annual rate of inflation (fraction/year)
ATS = IFS*FIFSAT
ATS = The air transportation subsidy (yuan/year)
CA = LCL*MCI
CA = The Crop area (mu)
CAN = CLN*MCIN
CAN = The initial value of the crop area (mu)
COR = CORM*CORN
COR = The capital output ratio (years)
CORN = 7.5
CORN = The initial value of the capital output ratio (years)
FGNPIC = 0.08
FGNPIC = The fraction of GNP to the industry capital (dim)
FGNPIFS = 0.06
FGNPIFS = The fraction of GNP to the infrastructure capital (dim)
FGNPSC = 0.035
FGNPSC = The fraction of GNP to the social capital (dim)
FIIFSAT = FIIFSATM*FIIFSATN
FIIFSAT = The fraction of the infrastructure to air transportation system (dim)
FIFSATN = 0.0016
FIFSATN = The initial value of fraction of the infrastructure to air transportation system (dim)
FIOI = FIFORM+FIOIFS
FIOI = The fraction of the industry output to input (dim)
FIOIFS = FIOIFSM*FIOIFSN
FIOIFS = The fraction of the industry output to infrastructure (dim)
FIOIFSN = 0.06
FIOIFS = The initial value of fraction of the industry output to infrastructure (dim)
FIFORM = 0.2
FIFORM = The fraction of the industry output to raw material (dim)
FIPI = FIPL+FIPT
FIPI = The fraction of industry product to investment (dim)
FIPL = FIPS+FIPW
FIPL = The fraction of industry product to labor (dim)
FIPS = 0.1
FIPS = The fraction of industry product to transportation subsidy (dim)
FIPT = 0.3
FIPT = The fraction of industry product to taxes (dim)
FIPW = 0.2
FIPW = The fraction of industry product to wages (dim)
GNP = (AP+IP)/(1+AROI)^((TIME-1995)
GNP = The gross national product (yuan/year)
GNPA = 300E8*(1+GNPAI)^((TIME-1995)
GNPAI = The GNP to agriculture investment (yuan/year)
GNPAI I = 0.075
GNPAI I= The GNP to agriculture investment increment (dim)
GNPAIN = 300E8
GNPAIN = The initial value of GNP to agriculture investment (yuan/year)
GNPAR = GNPA/GNPAIN
GNPAR = The GNP to agriculture investment ratio (dim)

GNPITUI = 3000E8*(1+GNPITUI)^TIME-1995

GNPITUI = The GNP to industry technical upgrade investment (yuan/year)

GNPITUIII = 0.1

GNPITUIII = The GNP to industry technical upgrade investment increment (dim)

GNPITUIR = GNPITU/NGNPITUI

GNPITUIR = The GNP to industry technical upgrade investment ratio (dim)

ICIM = 1-FIOI

ICIM = The industry capital increase multiplier (dim)

ICL = 25E4*(1+ICLI)^TIME-1995

ICL = The industry capital per labor force (yuan/labor force)

ICLI = 0.032

ICLI = The industry capital per labor force increment (dim)

ICN = 476000E8

ICN(INIT IC) = The initial value of the industry capital (yuan)

IC_IFS_R = (IC/IFS)/(ICN/IFSN)

IC_IFS_R = The industry capital to infrastructure capital ration (dim)

IFSCL = 25E4*(1+IFSCLI)^TIME-1995

IFSCL = The infrastructure capital per labor force (yuan/labor force)

IFSCLI = 0.04

IFSCLI = The infrastructure capital per labor force increment (dim)

IFSN = 50575E8

IFSN(INIT IFS) = The initial value of the infrastructure capital (yuan)

IO = IC/COR

IO = The industry output (yuan/year)

IP = IO*(1-FIOI)

IP = The industry product (yuan/year)

JIFS = IFS/IFSCL

JIFS = The jobs in the infrastructure (persons)

JII = IC/ICL
JII = The jobs in industry (persons)
JNA = JSC+JII+JIFS
JNA = The jobs non agriculture (persons)
JSC = SC/SCL
JSC = The jobs on social (persons)
LCLN = 2E9
LCLN(INIT LCL) = The initial value of the land cultivated (mu)
LFNA = UP*LFP
LFNA = The labor force non agriculture (persons)
LIC = 30
LIC = The lifetime of the industry capital (years)
LIFS = 40
LIFS = The lifetime of the infrastructure (years)
LPC = 45
LPC = The land per urban industry capital (mu/100 million yuan)
LPUP = 0.15
LPUP = The land per urban population (mu/person)
LSC = 50
LSC = The lifetime of social capital (years)
MCI = MCIN*MCIM
MCI = The multiple cropping index (dim)
MCIN = 1.5
MCIN = The initial value of the multiple cropping index (dim)
NGNPITUI = 3000E8
NGNPITUI = The initial value of the GNP to industry technical upgrade investment (Yuan)
NPAT = EXP(PAT)
NPAT = The number of passenger on air transportation system (100 million persons)
PAT =  -36+0.97*LOGN(GNP/100000000)
+11*LOGN(TP/100000000)-2.84*LOGN(JNA/100000000)
PAT = The power value of the passenger on air transportation system
PCI = GNP/TP
PCI = The per capita income (yuan/person)
RB = RF*RP
RB = The rural population birth (persons/year)
RD = RP*RM/1000
RD = The rural population deaths (persons/year)
REA = WEA/WENA
REA = The relative earning in agriculture (dim)
RF = RFN-OCP
RF = The rural population fertility (fraction/year)
RFN = 0.0205
RFN = The rural population fertility normal (fraction/year)
RLF = RP*RLPF
RLF = The rural labor force (persons)
RLPF = 0.4
RLPF = The rural labor participation factor (dim)
RM = RMM*RMN
RM = The rural population mortality (fraction/year)
RMN = 0.0095
RM = The rural population mortality aormal (fraction/year)
SCL = 12E4*(1+SCLI)^TIME-1995
SCL = The social capital per labor force (yuan/labor force)
SCLI = 0.003
SCLI = The social capital increment per labor force (dim)
SCN = 43670E8
SCN(INIT SC) = The initial value of the social capital (yuan)
SCPCR = (SC/TP)/(SCN/TPN)
SCPCR = The social capital per capita ratio (dim)
TP = RP+UP
TP = The total population (persons)
TPN = 12.1121E8
TPN = The initial value of the total population (persons)
UB = UP*UF
UB = The urban births (persons/year)
UCI = (IC+IFS+SC)-(476000E8+50575E8+43670E8)
UCI = The urban capital increment value (yuan)
UCLR = LPC*UCI
UCLR = The urban capital land required (mu/year)
UD = UP*UM/1000
UD = The urban deaths (persons/year)
UF = UFN-OCP
UF = The urban fertility (fraction/year)
UFN = 0.0148
UFN = The urban fertility normal (fraction/year)
UL = 9E7+ ULR
UL = The urban land (mu/year)
ULPF = 0.78
ULPF = The urban labor participation factor (dim)
ULR = UILR+UPLR
ULR = The urban land required (mu/year)
UM = UMM*UMN
UM = The urban population mortality (fraction/year)
UMN = 0.0065
UMN = The urban population mortality normal (fraction/year)
UNEMNA = (LFNA-JNA)/LFNA
UNEMNA = The unemployment non-agriculture (dim)
UPI = UP-3.5355*100000000
UPI = The urban population increment value (persons)
UPLR = LPUP*UPI
UPLR = The urban population land required (mu/year)
WEA = WEAN*(CA/CAN)*(ADI/ADIN)
WEA = The worker earning in agriculture (yuan/worker-year)
WEAN = 3310
WEAN = The initial value of the worker earning in agriculture (yuan/worker-year)
WENA = (IP/JNA)
WENA = The worker earning non-agriculture (yuan/worker-year)

****************************** Graphical (Table) function ******************************

ADI = GRAPHTIME
ADI = Agriculture diversity index (dim)
CORM = GRAPHTIME
COR = The capital output ratio multiplier (dim)
(1.00, 1.00), (1.40, 0.86), (1.80, 0.8), (2.20, 0.75), (2.60, 0.71), (3.00, 0.68), (3.40, 0.65), (3.80, 0.63), (4.20, 0.62), (4.60, 0.61), (5.00, 0.6)
FIFSATM = GRAPHTIME
FIFSAT = The infrastructure to air transportation system multiplier (dim)
FIOIFS = GRAPHTIME
FIOIFS = The industry output to infrastructure multiplier (dim)
(0.00, 1.00), (0.1, 1.01), (0.2, 1.02), (0.3, 1.03), (0.4, 1.04), (0.5, 1.05), (0.6, 1.06), (0.7, 1.08), (0.8, 1.10), (0.9, 1.14), (1, 1.20)
MCIM = GRAPHTIME
MCI = The multiple cropping index multiplier (dim)
(1.00, 1.00), (1.40, 1.05), (1.80, 1.10), (2.20, 1.15), (2.60, 1.20), (3.00, 1.25), (3.40, 1.30),
(3.80, 1.35), (4.20, 1.40), (4.60, 1.45), (5.00, 1.50)

OCPF = GRAPH(TIME)

OCPF = The one child per couple factor (dim)
(1995, 0.001), (1997, 0.002), (1999, 0.003), (2001, 0.004), (2004, 0.005), (2006, 0.006),
(2008, 0.007), (2010, 0.008)

RMM = GRAPH(SCPCR)

RMM = The rural population mortality multiplier (dim)
(1.00, 1.00), (1.10, 0.99), (1.20, 0.98), (1.30, 0.97), (1.40, 0.96), (1.50, 0.95), (1.60, 0.94),
(1.70, 0.93), (1.80, 0.92), (1.90, 0.91), (2.00, 0.9)

RUMM = GRAPH(REA)

RUMM = The rural to urban migration multiplier (dim)
(0.00, 2.00), (0.1, 1.60), (0.2, 1.40), (0.3, 1.30), (0.4, 1.20), (0.5, 1.10), (0.6, 1.00), (0.7,
0.95), (0.8, 0.9), (0.9, 0.85), (1, 0.8)

UMM = GRAPH(SCPCR)

UMM = The urban population mortality multiplier (dim)
(1.00, 1.00), (1.10, 0.98), (1.20, 0.96), (1.30, 0.94), (1.40, 0.92), (1.50, 0.9), (1.60, 0.89),
(1.70, 0.88), (1.80, 0.87), (1.90, 0.86), (2.00, 0.85)
Appendix H: Causal Diagram of China’s Air Transportation System Development Model
Appendix I: CATSDM Model Equations (STELLA II Language)

********************* Stock(Level) and Flow(Rate) variables *********************

AD(t) = AD(t - dt) + (ADC) * dt
AD = The air demand (persons)
INIT AD = 5117E4
INIT AD = The initial value of the air demand Persons)

INFLows:
ADC = API*(1-ALOSM)*(1-FAREEEM)
ADC = The air demand change (persons/year)
AF(t) = AF(t - dt) + (FIR - FRR) * dt
AF = The air fleet (number of aircraft)
INIT AF = 416
INIT AF = The initial value of the air fleet (number of aircraft)

INFLows:
AFIR = IF(DCR<0.70)THEN(0)ELSE
(NAB)*(0.05/CPS+0.55/CPL+0.4/CH)
AFIR = The air fleet increase rate (aircraft/year)

OUTFLows:
FRR = AF/LF
FRR = The air fleet retirement rate (aircraft/year)
AFARE(t) = AFARE(t - dt) + (AFAREC) * dt
AFARE = The air fare (yuan)
INIT AFARE = 600
INIT AFARE = The initial value of the air fare (yuan)

INFLows:
AFAREC = AFARE*(AFAREI/100)
AFAREC = The air fare change (yuan/year)
AFTN(t) = AFTN(t - dt) + (AFC) * dt
AFTN = The aircraft fee at terminal (yuan)

INIT AFTN = 500

INIT AFTN = The initial value of the aircraft fee at terminal (yuan)

INFLOWS:

AFC = AFTN*AFI

AFC = The aircraft fee change at terminal (yuan/year)

AIRR(t) = AIRR(t - dt) + (ARIR - ARRR) * dt

AIRR = The air route (kilometers)

INIT AIRR = 75E4

INIT AIRR = The initial value of the air route (kilometers)

INFLOWS:

ARIR = IF(FRCR<0.5)THEN(0)ELSE(ARB/CUR)

ARIR = The air route increase rate (kilometers/year)

OUTFLOWS:

ARRR = AIRR/LAR

ARRR = The air route retirement rate (kilometers/year)

FF(t) = FF(t - dt) + (FFC) * dt

FF = The foreign flight (operations)

INIT FF = 71599

INIT FF = The initial value of the foreign flight (operations)

INFLOWS:

FFC = FF*FFI

FFC = The foreign flight change (operations/year)

PAXFTN(t) = PAXFTN(t - dt) + (PAXFC) * dt

PAXFTN = The passenger fee through terminal (yuan)

INIT PAXFTN = 50

INIT PAXFTN = The initial value of the passenger fee through terminal (yuan)

INFLOWS:

PAXFC = PAXFTN*PAXFI

PAXFC = The passenger fee change through terminal (yuan/year)
ARF(t) = RF(t - dt) + (ARFC) * dt

ARF = The air route fee (yuan)

INIT ARF = 500

INIT ARF = The initial value of the air route fee (yuan)

INFLOWS:

ARFC = ARF*ARFI

ARFC = The air route fee change (yuan/year)

RW(t) = RW(t - dt) + (RWIR - RWRR) * dt

RW = The runway (number of runway)

INIT RW = 139

INIT RW = The initial value of the runway (number of runway)

INFLOWS:

RWIR = IF(FCR<0.5)THEN(0)ELSE(APBRW/CURW)

RWIR = The runway increase rate (runways/year)

OUTFLOWS:

RWRR = RW/LRW

RWRR = The runway retirement rate (runways/year)

RWF(t) = RWF(t - dt) + (RWFC) * dt

RWF = The runway fee per take-off or landing (yuan/operation)

INIT RWF = 800

INIT RWF = The initial value of the runway fee per take-off or landing (yuan/operation)

INFLOWS:

RWFC = RWF*RWFI

RWFC = The runway fee change (yuan/year)

TN(t) = TN(t - dt) + (TNIR - TNR) * dt

TN = The terminal (number of terminal)

INIT TN = 138

INIT TN = The initial value of the terminal (number of terminal)

INFLOWS:

TNIR = IF(TTTNTNGCR<0.5)THEN(0)ELSE(APBTN/CUTN)
TNIR = The terminal increase rate (terminal/year)

OUTFLOWS:
TNRR = TN/LTN
TNRR = The terminal retirement rate (number/year)

************************** Converters (Auxiliary) variables and Constants **************************

AFAREEC = AFAREI/PCIGR
AFAREEC = The air fare elasticity coefficient (dim)
AFAREI = IF(AOMD<0) THEN(10) ELSE(5)
AFAREI = The air fare increment (dim)
AFI = 0.05
AFI = The aircraft fee increment at terminal (dim)
AFUF = 0.96
AFUF = The aircraft utilization factor (dim)
AOMB = AROM+TSUOM
AOMB = The airlines operation and maintenance budget (yuan/year)
AOMD = AOMB-OMC
AOMD = The airlines operation and maintenance deficit (yuan/year)
APB = (RWRAP+TNRAP+TSUAP)-(RWTUI+OMCTN+OMCRW)
APB = The airport budget (yuan/year)
APBRW = APB*FAPBRW
APBRW = The airport budget to runway (yuan/year)
APBTN = APB*FAPBTN
APBTN = The airport budget to terminal (yuan/year)
AR = AD*AFARE
AR = The airlines revenue (yuan/year)
ARB = (TSUAR+ATCRAR)-OMCAR
ARB = The air route budget (yuan/year)
ARC = AIRR*(0.1*HDARC+0.5*LDARC+0.4*MDARC)*365
ARC = The air route capacity (operations/year)
ARFI = 0.05
ARFI = The air route fee increment (dim)
ARNA = AR*FARNA
ARNA = The airlines revenue to new aircraft budget (yuan/year)
AROM = AR*FAROM
AROM = The airlines revenue to operation and maintenance budget (yuan/year)
ARTUI = 10E8*(1+K2)^{(TIME-1995)}
ARTUI = The air route technical upgrade investment (yuan/year)
ARTUII = ARTUIM*ARTUIN
ARTUII = The air route technical upgrade investment index (dim)
ARTUIN = 1
ARTUIN = The air route technical upgrade investment normal (dim)
ARTUIR = ARTUI/NARTUI
ARTUIR = The air route technical upgrade investment ratio (dim)
ATCR = RF*TTTN
ATCR = The air traffic control revenue (yuan/year)
ATCRAR = ATCR*FATCRAR
ATCRAR = The air traffic control revenue to air route budget (yuan/year)
CH = 300
CH = The capacity of the heavy aircraft (person/aircraft)
CL = 150
CL = The capacity of the large aircraft (person/aircraft)
CPH = 7E8*(1+K3)^{(TIME-1995)}
CPH = The cost per heavy aircraft (yuan/aircraft)
CPL = 3E8*(1+K3)^{(TIME-1995)}
CPL = The cost per large aircraft (yuan/aircraft)
CPAR = 1000*(1+K2)^{(TIME-1995)}
CPAR = The maintenance cost of air route per kilometer (yuan/kilometer)
CPRW = 0.05E8
CPRW = the maintenance cost per runway (yuan/runway)
CPS = 1E8*(1+K3)^(TIME-1995)
CPS = The cost per small aircraft (yuan/aircraft)
CPTN = 5E5
CPTN = The maintenance cost per terminal (yuan/terminal)
CS = 50
CS = The capacity of the small aircraft (person/aircraft)
CUAR = 20000*(1+K2)^(TIME-1995)
CUAR = The construction cost of air route per kilometer (yuan/kilometer)
CURW = 5E8*(1+K2)^(TIME-1995)
CURW = The construction cost unit runway (yuan/airway)
CUTN = 5E8*(1+K2)^(TIME-1995)
CUTN = The construction cost unit terminal (yuan/terminal)
DAIRR = ((FRCR*FRCR)/((1-TFARCR)*(TTTN/(AIRR/1300)/365)))*TTTN
DAIRR = The total of the air route delay (hours)
DCR = AD/FCAPA
DCR = The air demand to the capacity of airlines ratio (dim)
DRW = (FCR*FCR)/((1-FCR)*(TTLT/(365*RW)))*TTLT
DRW = The total of runway delay (hours)
DTN = (TTTNTNGCR*TTTNTNGCR)/
    ((1-TTTNTNGCR)*((TTTN/(365*TN))))*TTTN
DTN = The total of terminal delay (hours)
FAPBRW = 0.45
FAPBRW = The fraction of airport budget to runway budget (dim)
FAPBTN = 0.55
FAPBTN = The fraction of airport budget to terminal budget (dim)
FARNA = 0.4
FARNA = The fraction of airlines revenue to new aircraft budget (dim)
FAROM = 0.6
FAROM = The fraction of airlines revenue to operation and maintenance budget (dim)

FATCRAR = 0.8

FATCRAR = The fraction of air traffic control revenue to air route budget (dim)

FC = FCON*FP

FC = The fuel cost (yuan/year)

FCAPA = AF*AFUF*TPAD*(0.2*CH+0.6*CL+0.2*CS)*365

FCAPA = The air fleet capacity (person/year)

FCON = AF*(0.2*FCONPH+0.6*FCONPL+0.2*FCONPS)

FCON = The fuel consumption (tons/year)

FCONPH = 16000

FCONPH = The fuel consumption per heavy aircraft (tons/aircraft-year)

FCONPL = 5100

FCONPL = The fuel consumption per large aircraft (tons/aircraft-year)

FCONPS = 550

FCONPH = The fuel consumption per small aircraft (tons/aircraft-year)

FFI = 0.1

FFI = The foreign flight increment (dim)

FP = 2500*(1+K6)^(TIME-1995)

FP = The fuel price (yuan/ton)

FRWRAP = 0.9

FRWRAP = The fraction of runway revenue to airport budget (dim)

FTSUAP = 0.5

FTSUAP = The fraction of total air subsidy to airport budget (dim)

FTSUAR = 0.2

FTSUAR = The fraction of total air subsidy to air route budget (dim)

FTSUNA = 0.25

FTSUNA = The fraction of total air subsidy to new aircraft budget (dim)

FTSUOM = 0.05

FTSUOM = The fraction of total air subsidy to operation and maintenance budget (dim)

FTNRAP = 0.8
FTNRAP = The fraction of terminal revenue to airport budget (dim)

HDARC = HL*HDPP*HRC/HMRD

HDARC = The high-density traffic air route capacity (operations/kilometer-day)

HL = 2

HL = The high-density traffic layers (dim)

HDPP = 12

HDPP = The high-density traffic during peak period (hours)

HMRD = 1600

HMRD = The high-density traffic maximum air route distance (kilometers)

HARCPH = (1/HRHW)*60

HARCPH = The high-density traffic air route capacity per hour

(operations/kilometer-hour)

HRWC = HRWCPH*HRWDPP

HRWC = The high-density traffic runway capacity

(operations of landing and take-off/day)

HRWCPH = (1/HRWHW)*60

HRWCPH = The high-density traffic runway capacity

(operations of landing and take-off/hour)

HRWDPP = 12

HRWDPP = The high-density traffic runway during peak period (hour)

HTNDPP = 12

HTNDPP = The high-density traffic terminal during peak period (hour)

HTNGC=MIN(HTNDPP*15*0.4*60/0.3*150, 
HTNDPP*15*0.6*60/(0.3*150+0.5*120), 
HTNDPP*15*1*60/(0.3*150+0.5*120+0.2*75))

HTNGC = The high-density traffic terminal gates capacity (operations/day)

IC = AF*ICPA

IC = The insurance cost (yuan/year)

ICPA = 15E5*(1+K6)^(TIME-1995)

ICPA = The insurance cost per aircraft (yuan/aircraft)
K1 = 0.05
K2 = 0.1
K3 = 0.15
K4 = 0.165
K5 = 0.18
K6 = 0.2

K1, K2, K3, K4, K5 and K6 = The growth factor of air transportation variables

LAR = 60

LAR = The lifetime of air route (years)

LDARC = LRC*LL*LDPP/LMRD

LDARC = The low-density traffic air route capacity
  (operations/kilometer-day)

LL = 2

LL = The low-density traffic air route layers (dim)

LDPP = 5

LDDP = The low-density traffic during peak period (hours)

LF = 20

LF = The lifetime of air fleet (years)

LGF = 60E8*(1+K6)^(TIME-1995)

LGF = The local government airport construction funding(yuan/year)

LMRD = 1100

LMRD = The low-density traffic maximum air route distance (kilometers)

LOAN = 260E8*(1+K1)^(TIME-1995)

LOAN = The loan funding of new aircraft (yuan/year)

LARCPH = (1/LRHW)*60

LARCPH = The low-density traffic air route capacity per hour
  (operations/kilometer-hour)

LRWC = LRWC*LRWDP

LRWC = The low-density traffic runway capacity
  (operations of landing and take-off/day)
LRWCPH = (1/LRWHW)*60
LRWCPH = The low-density traffic runway capacity
    (operations of landing and take-off/hour)
LRWDPP = 5
LRWDPP = The low-density traffic runway during peak period (hours)
LTN = 60
LTN = The lifetime of terminal (years)
LTNDPP = 5
LTNDPP = The low-density traffic terminal during peak period (hours)
LTNGC = MIN(LTNDPP*4*0.2*60/0.6*120, LTNDPP*4*1*60/(0.4*120+0.6*75))
LTNGC = The low-density traffic terminal gates capacity (operations/day)
LRW = 50
LRW = The lifetime of runway (years)
MC = AF*(0.2*MCPH+0.6*MCPL+0.2*MCPS)
MC = The maintenance cost of aircraft (yuan/year)
MCPH = 1500E4*(1+K3)^(TIME-1995)
MCPH = The maintenance cost per heavy aircraft (yuan/aircraft)
MCPL = 300E4*(1+K3)^(TIME-1995)
MCPL = The maintenance cost per large aircraft (yuan/aircraft)
MCPS = 15E4*(1+K3)^(TIME-1995)
MCPS = The maintenance cost per small aircraft (yuan/aircraft)
MDARC = MRC*ML*MDPP/MMRD
MDARC = The medium-density traffic air route capacity
    (operations/kilometer-day)
ML = 2
ML = The medium-density traffic air route layers (dim)
MDPP = 7
MDPP = The medium-density traffic during peak period (hours)
MMRD = 1500
MMRD = The medium-density traffic maximum air route distance (kilometers)
MARCPH = (1/MRWHW)*60
MARCPH = The medium-density traffic air route capacity per hour
(operations/kilometer-hour)

MRWC = MRWCPH*MRWDPP
MRWC = The medium-density traffic runway capacity
(operations of landing and take-off/day)

MRWCPH = (1/MRWHW)*60
MRWCPH = The medium-density traffic runway capacity
(operations of landing and take-off/hour)

MRWDPP = 7
MRWDPP = The medium-density traffic runway during peak period (hours)

MTNDPP = 7
MTNDPP = The medium-density traffic terminal during peak period (hours)

MTNGC = MIN(MTNDPP*8*0.1*60/0.1*150,MTNDPP*8*0.4*60/(0.1*150+0.5*120),
          MTNDPP*8*1*60/(0.1*150+0.5*120+0.4*75))
MTNGC = The medium-density traffic terminal gates capacity
(operations/day)

NAB = ARNA+TSUNA+LOAN
NAB = The new aircraft budget (yuan/year)
NAFARE = 600
NAFARE = The initial value of the air fare (yuan/person)
NARTUI = 10E8
NARTUI = The initial value of the air route technical upgrade investment (yuan/year)
NRWTUI = 15E8
NRWTUI = The initial value of the runway technical upgrade investment (yuan)
OC = FC+SC+ATCR+RWR+TNRA
OC = The operation cost of airlines (yuan/year)
OMC = MC+OC+IC
OMC = The operation and maintenance cost of airlines (yuan/year)
OMCAR = AIRR*CPAR
OMCAR = The operation and maintenance cost of air route (yuan/year)

OMCRW = RW*CPRW

OMCRW = The operation and maintenance cost of runway (yuan/year)

OMCTN = TN*CPTN

OMCTN = The operation and maintenance cost of terminal (yuan/year)

PAXFI = 0.05

PAXFI = The passenger fee increment in terminal (dim)

RWC = RW*(0.1*HRWC+0.4*LRWC+0.5*MRWC)*365

RWC = The runway capacity (operations of landing and take-off)

RWFI = 0.05

RWFI = The runway fee increment (dim)

RWR = RWF*TTLT

RWR = The runway revenue (yuan/year)

RWRAP = FRWRAP*RWR

RWRAP = The runway revenue to airport (yuan/year)

RWTUI = 15E8*(1+K4)*(TIME-1995)

RWTUI = The runway technical upgrade investment (yuan/year)

RWTUII = RWTUIM*RWTUIN

RWTUII = The runway technical upgrade investment index (dim)

RWTUIN = 1

RWTUIN = The runway technical upgrade investment normal (dim)

RWTUIR = RWTUIN/NRWTUIN

RWTUIR = The runway technical upgrade investment ratio (dim)

SC = SPP*TS

SC = The salary cost (yuan/year)

SPP = 12000*(1+K6)*(TIME-1995)

SPP = The salary per person (yuan/person)

TDAT = (DAIRR+DRW+DTN)/10000

TDAT = The total delay on the air transportation (10000 hours)

TF = TTTN
TF = The total flight (operations)
TFARCR = TTTN/ARC
TFARCR = The total flight to air route capacity ratio (dim)
TNGC=
IF(TIME<2000)THEN(TN*(0.1*HTNGC+0.4*MTNGC+0.5*LTNGC)*365)ELSE
IF(TIME<2005)THEN(TN*(0.2*HTNGC+0.5*MTNGC+0.3*LTNGC)*365)
ELSE(TN*(0.3*HTNGC+0.5*MTNGC+0.2*LTNGC)*365)
TNGC = The terminal gates capacity (operations)
TNRA = AFTN*TTTN
TNRA = The terminal revenue from aircraft (yuan/year)
TNRAP = FTTNRAP*TTNR
TNRAP = The terminal revenue to airport budget (yuan/year)
TNRPAX = AD*PAXFTN
TNRPAX = The terminal revenue from passenger (yuan/year)
TS = 120000*(1+K1)^*(TIME-1995)
TS = The total stuff(persons)
TSU = 120E8*(1+K5)^*(TIME-1995)
TSU = The total subsidy(yuan/year)
TSUAP = FTSUAP*TSU+LGF
TSUAP = The total subsidy to airport budget (yuan/year)
TSUAR = FTSUAR*TSU
TSUAR = The total subsidy to air route budget (yuan/year)
TSUNA = FTSUNA*TSU
TSUNA = The total subsidy to new aircraft budget (yuan/year)
TSUOM = FTSUOM*TSU
TSUOM = The total subsidy to operation and maintenance budget (yuan/year)
TTLT = 2*TTTN
TTLT = The total operations of landing and take-off (operations)
TTLTRWCR = TTLT/RWC
TTLTRWCR = The total operations of landing and take-off to runway capacity ratio
TTNR = TNRPAX+TNRA
TTNR = The total terminal revenue (yuan/year)
TTTN = AF*AFUF*TPAD*365+FF
TTTN = The total times at terminal (operations)
TTTN/TNGCR = TTTN/TNGC
TTTN/TNGCR = The total operations at terminal to terminal gates capacity ratio (dim)

************************************************************************* Graphical (Table) function *************************************************************************

ALOSM = GRAPH(TDAT)
ALOSM = The air transportation system level of service multiplier (dim)
(0.00, 0.00), (5.00, 0.03), (10.0, 0.05), (15.0, 0.066), (20.0, 0.087), (25.0, 0.111), (30.0, 0.144), (35.0, 0.183), (40.0, 0.2), (45.0, 0.225), (50.0, 0.248), (55.0, 0.267), (60.0, 0.297), (65.0, 0.5), (70.0, 0.5), (75.0, 0.5), (80.0, 0.5), (85.0, 0.5), (90.0, 0.5), (95.0, 0.5), (100, 0.5)

API = GRAPH(TIME)
API = The air transportation system passenger increment (person/year)

ARTUIM = GRAPH(ARTUIR)
ARTUIM = The air route technical upgrade investment multiplier (dim)
(0.00, 0.00), (0.5, 0.17), (1.00, 0.4), (1.50, 0.67), (2.00, 0.99), (2.50, 1.28), (3.00, 1.57), (3.50, 1.75), (4.00, 1.87), (4.50, 1.94), (5.00, 2.00)

AFAREM = GRAPH(FAREEC)
AFAREM = The air fare multiplier (dim)
(0.00, 0.0015), (0.5, 0.0645), (1.00, 0.102), (1.50, 0.138), (2.00, 0.155), (2.50, 0.182), (3.00, 0.209), (3.50, 0.237), (4.00, 0.264), (4.50, 0.279), (5.00, 0.297)
HARHW = GRAPH(ARTUUII)
HARHW = The high-density traffic air route headway (min)
(0.00, 20.0), (1.00, 15.0), (2.00, 10.0)

HRWHW = GRAPH(RWTUUII)
HRWHW = The high-density traffic runway headway (min)
(0.00, 5.00), (1.00, 4.20), (2.00, 3.67), (3.00, 3.32), (4.00, 3.10), (5.00, 2.90), (6.00, 2.70),
(7.00, 2.54), (8.00, 2.38), (9.00, 2.25), (10.0, 2.15)

LARHW = GRAPH(ARTUUII)
LARHW = The low-density traffic air route headway (min)
(0.00, 60.0), (1.00, 45.0), (2.00, 30.0)

LRWHW = GRAPH(RWTUUII)
LRWHW = The low-density traffic runway headway (min)
(0.00, 50.0), (1.00, 39.5), (2.00, 32.7), (3.00, 28.1), (4.00, 24.3), (5.00, 21.5), (6.00, 19.4),
(7.00, 17.6), (8.00, 16.2), (9.00, 15.4), (10.0, 15.0)

MARHW = GRAPH(ARTUUII)
MARHW = The medium-density traffic air route headway (min)
(0.00, 50.0), (1.00, 35.0), (2.00, 20.0)

MRWHW = GRAPH(RWTUUII)
MRWHW = The medium-density traffic runway headway (min)
(0.00, 15.0), (1.00, 12.8), (2.00, 11.5), (3.00, 10.5), (4.00, 9.76), (5.00, 9.16), (6.00, 8.64),
(7.00, 8.12), (8.00, 7.80), (9.00, 7.40), (10.0, 7.00)

GRPCI = GRAPH(TIME)
GRPCI = The growth rate of per capita income (percent)
(2008, 6.60), (2009, 6.50), (2010, 5.70)

RWTUIM = GRAPH(RWTUIR)
RWTUIM = The runway technical upgrade investment multiplier (dim)
(1.00, 0.00), (1.90, 2.80), (2.80, 4.35), (3.70, 5.85), (4.60, 7.05), (5.50, 8.05), (6.40, 8.75),
(7.30, 9.20), (8.20, 9.55), (9.10, 9.80), (10.0, 10.0)
TPAD = GRAPH(TIME)

TPAD = The trips per aircraft a day (flight)

(1995, 3.00), (2003, 3.50), (2010, 4.00)
Vita

Chuanwen Quan was born in China on May 20, 1962. He graduated with a bachelor's degree in weather dynamics, from the Nanjing University of Meteorology in July, 1983. He worked in the bureau of the air traffic control as an engineer for six years in China's air transportation system. From 1989, he was a vice-director aide and secretary of the vice-minister of the Civil Aviation Administration of China (CAAC) for five years. During his working, he was a lecturer in Finance and Trade college in Guizhou for a year. In 1995, he was accepted as a graduate student pursuing his Master of Science degree in Transportation Engineering at the Virginia Polytechnic Institute and State University.