A SYSTEMS DYNAMICS ECONOMIC EVALUATION
METHODOLOGY FOR HIGH SPEED INTER-CITY TRANSPORTATION

by

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(ABSTRACT)

The objective of this study is to set a methodology for the economic evaluation of high speed ground transportation systems. The main objective of this study is to establish a systematic framework, in order that planners can quickly understand and analyze the implications that different policies have on the life-cycle of the transportation system. The methodology is adaptable for different modes and also for different locations at which similar systems could be implemented. The mode under consideration here is that of Magnetically levitated vehicles and the study area is the Northeast corridor of the United States.

The economic evaluation is based on a Systems Dynamics simulation model. The model incorporates socioeconomic parameters, trip generation, mode split, traffic engineering, economic parameters and elements of mass transportation. The interactions within these subsystems and between them are studied through various policy analysis which were conducted. The range of policy covers socioeconomic parameters, traffic strategies and economic parameters. Life cycle costs and revenues are the key performance indicators.
Parameters such as elasticity values were assumed based on previous studies conducted in other locations.

Revenues from fares is the only benefit considered for implementation of the new transportation system. The model has been developed so that it can be expanded so as to include various other benefits from maglev implementation. The model is highly flexible and can be used for a wide range of policy analysis. With regard to magnetic levitated transportation system it was found to be a economically feasible transportation alternative to solve the problems facing high speed inter-city travel. The life cycle costs of such a venture were found to be highly sensitive to the cost of power and the elasticity values associated with the trip generation model.
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# Table of Contents

1. Introduction  
   1.1 Background  
   1.2 Evaluating Proposed Modes  
   1.3 Research Objectives  
   1.4 Case Study Area  

2. Literature Review  
   2.1 Introduction  
   2.2 Maglev Technology  
      2.2.1 Levitation and Guidance  
      2.2.2 Propulsion  
   2.3 Maglev Development  
      2.3.1 Pioneering Maglev Research  
      2.3.2 Development Abroad  
   2.4 Markets for Maglev in the United States  
   2.5 Overview of the Transrapid (07)  

3. Methodology  
   3.1 Methodology for Analysis  
   3.2 Systems Perspective  
   3.3 Simulation Models  
   3.4 Systems Dynamics Modelling  
   3.5 STELLA-II  

4. Model Description  
   4.1 Introduction  
   4.2 The Vehicle Model  
      4.2.1 Vehicle Model Description  
      4.2.2 Model Assumptions  
      4.2.3 Limitations of The Model  

Table of Contents
List of Figures

Figure 2.1  Electromagnetic Suspension System.  9
Figure 2.2  Electrodynamlic Suspension System.  10
Figure 3.1  Classification of Models.  21
Figure 3.2  Basic Building Blocks in STELLA II.  24
Figure 4.1  Variation of Drag Forces of The TR 06 II Maglev With Respect to Velocity.  29
Figure 4.2  Causal Diagram of Speed, Drag Forces and Thrust.  30
Figure 4.3  Causal Diagram of Acceleration, Deceleration, Cruise, Thrust and Distance.  32
Figure 4.4  Causal Diagram of Power Consumption.  33
Figure 4.5  Variation of Velocity With Respect to Time for The Vehicle Model.  34
Figure 4.6  Population Sector of The Socioeconomic Model.  38
Figure 4.7  Industry Sector of The Socioeconomic Model.  39
Figure 4.8  Causal Diagram of Revenue Model.  47
Figure 5.1  Power Consumption and Travel Time for Various Values of Cruise Velocities for Fixed Distance.  55
Figure 5.2  Life Cycle Costs and Revenues.  56
Figure 5.3  Variation of Annual Passenger Ridership for Changes in Fares.  59
Figure 5.4  Variation of Life Cycle Costs and Revenues for Changes in Unit Cost of Power.  60
Figure 5.5  Initial Capital Cost Required for Variations in Extent of Right of Way Acquisition.  62
Figure 5.6  Effect of Change in Vehicle Cost on The Life Cycle Cost.  63
Figure A.1  Euler's Integration Scheme.  79
Figure A.2  Fourth Order Runge Kutta Integration Scheme.  80

List of Figures
Figure D.1  Causal Diagram of the Socioeconomic Submodel for Boston and Trip Generation Submodel for the Boston and New York City Pair.  84

Figure D.2  Causal Diagram of the Socioeconomic Submodel for New York and Trip Generation Submodel for the Boston and Philadelphia City Pair.  85

Figure D.3  Causal Diagram of the Socioeconomic Submodel for Philadelphia and Trip Generation Submodel for the Boston and Washington City Pair.  86

Figure D.4  Causal Diagram of the Socioeconomic Submodel for Washington and Trip Generation Submodel for the Philadelphia and Washington City Pair.  87

Figure D.5  Causal Diagram of the Revenue and Maglev Frequency Submodels.  88

Figure D.6  Causal Diagram of the Guideway Capacity, Station Capacity and Additional Platform Cost Submodels.  89

Figure D.7  Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the Boston and New York City Pair.  90

Figure D.8  Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the Boston and Philadelphia City Pair.  91

Figure D.9  Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the Boston and Washington City Pair.  92

Figure D.10  Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the Philadelphia and Washington City Pair.  93

Figure D.11  Causal Diagram of the Vehicle Requirement Submodel.  94

Figure D.12  Causal Diagram of the Additional Guideway Cost Submodel.  95

Figure D.13  Causal Diagram of the Trip Generation Submodels for the New York and Philadelphia and the New York and Washington City Pair.  96

Figure D.14  Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the New York and Philadelphia City Pair.  97

Figure D.15  Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the New York and Washington City Pair.  98

Figure D.16  Causal Diagram of the Operations and Maintenance Costs Submodel.  99

Figure D.17  Causal Diagram of the Capital Cost and Total Capital Spent Submodels.  100

List of Figures
List of Tables

Table 3.1  Systems Dynamics Variables.  23
Table 5.1  Variation of Annual Maglev Passengers with Respect to Sales Factor.  57
Table 5.2  Life Cycle Costs and Revenues For Changes in Elasticity Values.  57
Table 5.3  Approximate Values of Ridership for Increase in Number of Stations.  64
1. Introduction

1.1 Background

Transportation is one of the foundations of our present day society, influencing greatly both social and economic conditions. However, the problem of moving ever increasing numbers of people from place to place, rapidly and efficiently, are now becoming so acute as to demand increased attention in all the developed countries of the world. Congestion and delays on the roads, at railroad stations, in the airways and at airports, lead not only to frustration and inefficiency, but also to an increased risk of accidents so that, in spite of measures to improve existing ways of travelling, the social and environmental problems directly linked with modern transport continue to worsen. The situation is being further aggravated by the predicted shortage of oil accompanied by its escalating cost.

Whatever the truth it is evident that cheap and plentiful supplies of oil can no longer be taken for granted and that on present day forecasting it will become a very precious commodity by the next century, if not before. If our concern for reducing our dependence on oil is at all serious, then transportation, accounting as it does for about 20 percent of all energy consumption must be one of the prime targets [DOE/EiA-0384(89)].

Faced with these considerations we are forced to turn to completely new, ground based, systems of mass transport. Preferably these should not rely entirely on one particular source of energy, in other words they should be electrically driven, as the generation of electric power is not tied to any one source of fuel. At the same time they should be able to meet the more stringent
requirements of not polluting the environment as well as improving on the safety record of present day railways which are statistically one of the safest forms of travel. Finally, they should take into account that as society continues to change so its demand for travel and transportation will continue to expand. High speed is desirable for economic reasons and this is particularly so for today's industrial societies. One way of meeting these demands is by a mass transportation system capable of speeds well in excess of those reached by conventional railroad trains and equalling or exceeding speeds of modern commercial aircraft.

To meet the growing need to move ever-increasing numbers of people quickly, safely, efficiently and economically, a number of technically advanced, ground transportation systems are being developed in several countries throughout the world. These would have the potential of providing a faster, more efficient and environmentally acceptable transportation service than is presently possible with existing conventional, wheel/rail modes. Several novel technologies, based on the principle of magnetic levitation combined with linear motor propulsion, are being investigated for the purpose of high speed, inter-city travel, inter-urban commuter services, airport links, etc.

Magnetically levitated transportation, maglev for short, represents the latest evolution in high speed ground transportation and claims to have the potential to provide a transportation system that is clean, quiet, energy efficient and environmentally sound. Maglevs have achieved speeds of 400 kilometers per hour on test tracks. Development of commercial prototypes is under way in a number of countries. This new mode promises to be technologically capable of competing with air transportation for travel distances less than 1000 kilometers.

1. Introduction
1.2 Evaluating Proposed Modes

Innovations in transportation have always attracted the attention of experts as well as the public. Inventions of entirely new modes are particularly glamorous ventures. However to become commercially viable a new mode must fulfill two basic conditions.

1. Be technologically and operationally sound.

2. Have a performance and cost package 10 percent better than that of an existing conventional mode.

Although many modes have been developed sufficiently to satisfy the first condition few have satisfied the second one. To satisfy the second condition a transportation system cannot be considered in isolation as a purely engineering system, but has to be considered as part of a socioeconomic system. Existing feasibility studies have rarely attempted to explain how technological parameters and socioeconomic factors interact to affect cost, ridership, pricing, profitability and the life cycle costs of proposed modes. The need to explain the interaction between these technological, socioeconomic and operational factors is all the more important in transportation due to various factors which make it different from investments in other fields. Large initial investments must be made in order for any of these systems to produce any benefits. Further aggravating this fact is that there are long lead times between the decision to construct and operate new transportation facilities and the commencement of actual operations. Most of these investments are made by public agencies. The reason for this is that there are likely to be broad benefits from both the technical research and development work as well as the
implementation of the actual system. These benefits cannot be captured by the actual investor. It is very difficult for a private investor to recoup the private and public gains made by these investments.

1.3 Research Objectives

The purpose of this study is to put forth a detailed methodology for studying the feasibility of inter-city transportation projects, using an approach different from traditional methods. Unlike existing methods this methodology is intended to take into consideration the interaction between technological and socioeconomic parameters and explain how they interact to affect the cost, ridership, pricing and profitability of high speed systems. A systems approach is used for the dynamic economic evaluation of inter-city transportation projects that allows the planner to see the evolution of parameters over time. This study would be microscopic in nature taking into account direct and indirect benefits from implementing such projects, specifically the model would be adaptable to similar economic feasibility studies in other parts of the United States. The thrust area of the research would be into the following areas.

1. Estimation of inter-city travel market.
2. Capital investment costs.
3. Operation Costs.
4. Indirect benefits.

1. Introduction
At present there is no standard widely accepted approach to the evaluation of inter-city transportation systems. Methods vary from region to region and from scale or type of alternative analysis to another. The aim of this study is to present a comprehensive and practical methodology for evaluation of inter-city transportation projects. For the purpose of illustrating the methodology the feasibility study of a magnetically levitated train in the Northeast Corridor of the United States is done here. The model has been developed using the simulation software STELLA II.

1.4 Case Study Area

The study area proposed for this economic feasibility study is the Northeast corridor of the United States (Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, and the District of Columbia). For the economic feasibility of high speed systems for inter-city travel the following minimum corridor characteristics are important.

1. Cities with high population and high population densities.
2. Cities with a strong travel affinity between them, generally because one is a dominant center of commercial, cultural, financial, governmental or other activity.
3. Cities grouped along a route giving major passenger traffic flows in the 150 to 500 kilometer trip range.
4. Cities with developed local transit system to feed the high-speed rail.

1. Introduction
All these conditions are satisfied in the Northeast corridor which due to its population densities and transit systems is definitely the most promising for the introduction of a maglev system of transportation. The explosive growth in travel in the corridor has led to congestion at the airports, and air traffic delays. At the present rate of traffic growth in the corridor, the enhancement of transportation capacity is inevitable in the northeast corridor. Another reason for selecting the Northeast corridor for the study was that more data on this corridor was available in comparison to other corridors in the United States.

It was apparent from the outset that limitations of data militated against a wholly satisfactory description and measurement of the various factors affecting demand. It is consequently an essential purpose of the study to define the needs for further data collection in order to fill the most important information gaps and to reduce the potential margins of errors in the demand for travel and in the economic evaluation.

1. Introduction
2. Literature Review

2.1 Introduction

The objective of this literature review is to describe, the underlying principles of magnetic levitated vehicle technology, and to present a brief overview of the status of maglev technology both in the United States and abroad. The prospective markets for maglev technology in the United States are also discussed. In addition a description of the German Transrapid 06 II vehicle is also presented. The vehicle parameters in this economic evaluation of maglev in the Northeast corridor is that of the Transrapid 06 II.

2.2 Maglev Technology

The conventional railroad train relies on the interfacial friction between steel wheels and rails for traction and guidance. This system has a number of inherent disadvantages when compared to other modes of transport. Very significant advances have been made to wheel-on-rail technology but there is a limit to the maximum speed the vehicle can cruise at due to a number of reasons, including high maintenance costs, noise and vibration. These inherent drawbacks of the wheel-on-rail friction driven system can be largely overcome by magnetic levitation technology. Unlike wheel-on-rail technology the only limitation on maglev is the economic limitations of overcoming the drag forces, including aerodynamic drag which affects all ground based systems and becomes the dominant force at high speeds. The three primary functions basic to maglev technology are levitation, propulsion and guidance. Magnetic forces can perform
all of these functions although a nonmagnetic prime mover could be used for propulsion. The relative merits and disadvantages of these systems can be fully accessed only after full scale testing of all these systems are undertaken.

2.2.1 Levitation and Guidance

The various means of levitation employed in maglev's are electromagnetic suspension (EMS), electrodynamic suspension (EDS) and by the use of permanent magnets.

1) Electromagnetic Suspension:

In the electromagnetic suspension system or EMS system of levitation electromagnets on the vehicle, are attracted towards ferromagnetic rails on the guideway. The distance between the rails and the magnets are sensed and the current to the electromagnets is adjusted using electronic control thus preventing physical contact between the magnets on the vehicle and the rails on the guideway. This system has been made possible by the recent advances in electronic control systems. The EMS system of levitation provides levitation at all speeds from standstill. It is difficult to have good ride quality at high speeds or while negotiating curves and grades [The Railway Division of The Institution of Mechanical Engineers, et al,1984]. This is because no natural restoring force acts to automatically restore the vehicle to its equilibrium position if disturbed. This can be corrected by continuous monitoring of the air gap and controlling it by adjusting the magnetic forces continuously. With sophisticated control technology and precision track construction, clearance gaps in the order of 10 mm can be readily maintained at high speeds in excess of 300 kilometers/hour [Jayawant, B. V., 1981]. The power required for levitation is

2. Literature Review
relatively low in the EMS system. A high degree of guideway precision is required due to the low clearance gap. Lateral guidance is maintained by a series of vehicle magnets positioned horizontally to the guideway rails. This is basically an attraction magnet system and is illustrated in Figure 2.1.

![Diagram of electromagnetic suspension system]

**Figure 2.1** Electromagnetic Suspension System.

2. Literature Review
2) Electrodynamic Suspension:

In the EDS or the electrodynamic system, the levitation is effected by repulsive magnetic fields as shown in Figure 2.2. These fields are produced by magnets on the moving vehicle and a passive electrically conductive guideway, consisting a series of short coils. Eddy currents are induced in the guideway which in turn produce a repulsive force between the guideway and the

![Diagram of Electrodynamic Suspension System]

Figure 2.2 Electrodynamic Suspension System.

2. Literature Review
vehicle. However the vehicle must be equipped with wheels for take-off and landing because electromagnets will not levitate at speeds below 40 kilometers/hour [DOE/EIA-0384(89)]. This technology has developed with the developments in superconductor technology, which has enabled increases in current densities over that possible in a normal electromagnetic coil. Due to this development the necessity of a heavy iron core is eliminated, enabling the design of the vehicle with relatively lighter weight. The levitation is stable and requires no active control. The clearances are in the order of 100 mm to 200 mm. In this system of levitation small irregularities in the guideway do not pose a problem due to large clearances. In the EDS system wheels are used for lateral guidance at low speeds while at higher speeds magnets used for levitation can also provide guidance or by providing separate superconducting magnets on the sides of the vehicle used with conductors mounted vertically on the guideway walls.

3) Permanent Magnets:

In permanent magnet levitation, permanent magnets are used for levitation either by attraction or repulsion. No power source is required. However, according to the Earnshaw theorem, a completely levitated vehicle would be unstable in at least one degree of freedom, [The Railway Division of The Institution of Mechanical Engineers, et al., 1984]. This would require some form of mechanical constraint such as wheels for lateral guidance. Development of maglev's using permanent magnets has been limited to lower speed applications due to lower suspension heights and higher weights and costs. However, with the recent advent of rare-earth permanent magnets there has been a renewed interest in permanent magnet levitation due to there lower weight. Commercial production of rare earth magnets is still not viable due to high costs.

2. Literature Review
2.2.2 Propulsion

A number of different propulsion systems have been tried out for magnetically levitated vehicles. Propulsion by propellers, ducted air, jet engines and linear induction motors are a few of these. Propulsion by the use of linear induction motors (LIM) is the favorite of these, as the others cannot satisfy stringent environmental requirements. The linear induction motor utilizes the levitating magnetic field between the vehicle and the guideway for propulsion. There are two types of propulsion systems using the linear induction motor they are the "short-stator" and the "long-stator" propulsion systems. Short-stator propulsion system uses a linear induction motor (LIM) winding on-board and a passive guideway. Short-stator propulsion reduces guideway cost but results in higher vehicle weight which reduces payload capacity. In addition operating costs are higher and revenue potential is lower. There are several variations of the short-stator linear induction motor. The most popular being:

1. Double sided linear induction motor (DLIM).

The double sided linear induction motor has two sets of stators on the vehicle and an aluminium vertical reaction rail mounted on the track between them. The single sided linear induction motor has a horizontally mounted stator on the vehicle and an iron backed, aluminium reactor rail on the guideway.

Long-stator propulsion uses electrically powered linear synchronous motor windings in the guideway. These windings in the guideway are energized sequentially causing a magnetic wave to travel along the guideway. This travelling magnetic wave interacts with the vehicle borne super conducting coils to propel the vehicle. The linear synchronous motor windings is more

2. Literature Review
efficient, since it uses magnetic fields produced by the superconducting magnets to interact with the weaker fields produced by normal stator windings in the guideway. Power costs are also lower because the guideway stator windings near the vehicle are energized. The advantage of the system is that the vehicle is simple and can carry higher payloads. It also is readily adaptable to automatic control resulting in optimum operation, high reliability and safety. The major disadvantage of the system is the necessity for very cost intensive guideways.

2.3 Maglev Development

2.3.1 Pioneering Maglev Research

Pioneering maglev research and development work was conducted in the United States as early as 1912. An alternating current repulsion system was first conceived by Emile Bachelet (1912) a French engineer working in the United States [Johnson, et al, 1989]. The idea lay dormant until the 1960's. In the 1960's under the high speed ground transportation act of 1965, the federal railroad administration funded a wide range of research into all forms of high speed ground transportation. Contracts were awarded to the Stanford Research Institute and the Ford Scientific Laboratories for maglev feasibility projects on the EMS and EDS levitation systems. The Massachusetts Institute of Technology produced a scale model of a magnetic levitated vehicle called the "magneplane". Additional research was conducted by The Boeing Company, Carnegie Mellon University and the Budd Company. Interest in high speed maglev was virtually abandoned after the federal government stopped federal funding in 1975 to all research into high speed ground transportation.

2. Literature Review
2.3.2 Development Abroad

Since the middle of the 1970's, when most of the federally funded efforts into magnetic levitation was stopped in the United States many countries built on the foundations of U.S. work and have separately developed operational prototypes. Major developments have taken place in a number of countries notably West Germany, Japan and Canada. A description of the progress made in these countries are given below.

1) Canada:

Research on maglev vehicles in Canada is being conducted by the Canadian Transportation Development center with contracts with several Canadian Universities. The Canadian maglev uses a EDS levitation system with a box type guideway structure with aluminium strips on its top surface for levitation and the null flux guidance coils. It is designed to cruise at 450 kilometers/hour. Superconductivity of the on-board coils is achieved by the use of Niobium-Titaniuim dust (NbTi). Separate retractable wheels are also provided for support and guidance at low speeds.

2) Japan:

Large scale research and development in maglev technology has been undertaken in Japan. The Japanese Railways (JNR) are investigating the EDS system technology. An unmanned research vehicle was tested to a maximum speed of 517 kilometers/hour [The Railway

2. Literature Review
Division of The Institution of Mechanical Engineers, et al, 1984]. Japan Airlines (JAL) initiated the development of a maglev based on EMS technology.

This is now being carried out by the High Speed Surface Transport (HSST) corporation. The HSST 04 vehicle is there latest prototype, and operates at 40 kilometers/hour with a 10 mm air gap between the vehicle and the guideway [Johnson, L. R., et al, 1989]. The vehicle uses the EMS levitation concept. Power is fed to the vehicle for levitation and propulsion by brush contact with energized cables. Development of a commercial vehicle capable of speeds up to 300 kilometers/hour is underway. HSST corporation has also done considerable development in EDS levitation resulting in the MLU vehicle series. The latest version MLU 002, is undergoing tests in Japan. The design speed is 400 kilometers/hour and the suspension height is 100 mm [Johnson, L. R., et al, 1984].

3) Germany:

The German government sponsored two independent maglev transportation research and development programs. One focused on EMS levitation and the other on EDS levitation. The EDS group developed a test vehicle called the "EET" using a double-sided, linear induction motor. The concept was later abandoned in favor of a long stator linear synchronous motor. A new prototype called the EET (02) was developed. In 1977 further development of the EDS technology was abandoned in Germany altogether.

The EMS system development in Germany led to the German Transrapid system. A number of prototypes were built starting with the Transrapid (01) vehicle in 1970. This vehicle using a single sided linear induction motor for propulsion and an EMS suspension system

2. Literature Review
attained a speed of 90 kilometers/hour [Johnson, L. R., et al, 1984]. Subsequently the Transrapid (02), Transrapid (04), Transrapid (05), Transrapid (06) and the Transrapid (07) were developed. A more detailed description of these vehicles can be seen in The Publications of The Institution of Electrical and Electronic Engineers [87 CH2443-0 and 86 CH2276-4]. The latest prototype Transrapid (07) is under testing at the Emsland Test Facility in Germany and is expected to achieve speeds in excess of 400 kilometers/hour. A more detailed description of the Transrapid (07) vehicle is given at the end of this section.

2.4 Markets for Maglev in the United States

Maglev technology appears to be feasible for inter-city trips in the 150 to 1000 kilometers range. It is believed that trips beyond the 1000 kilometers range will be served by airlines, as aircraft have clear block speed advantages for these stage length segments. The automobile would continue to be the principle means of travel for trips less than 150 kilometers in range.

Recently there has been considerable interest in maglev in the United States. Several feasibility studies are underway examining proposed projects in different parts of the country. Most of these projects are being proposed by local or state governments, the most serious ones being the California-Nevada, Florida and the Pennsylvania projects. Illinois, Michigan, the Northeast corridor, Ohio, Texas, Missouri, Washington, Georgia, upstate New York and New Mexico are also considering maglev implementation [Johnson, L. R., et al, 1989]. With the successful implementation in one of these locations, maglev would become an established alternative mode of transportation.

2. Literature Review
2.5 Overview of the Transrapid (07)

The transrapid (07) (TR 07) is the commercial prototype of a maglev vehicle developed by the Industrial consortium Transrapid International of the Federal Republic of Germany. The parameters of the Transrapid (07) vehicle was selected for this study for the following reasons. The TR 07 was the only vehicle which was a commercial prototype near its final stages of testing. Another consideration was that published information on the TR 07 was available on nearly all data required for this study.

The TR 07 vehicle uses the EMS levitation system with a long-stator linear synchronous motor for propulsion. The magnet control system used for controlling the air gap between the vehicle and the guideway is decentralized with autonomous control for each individual magnet. This overcomes some of the problems associated with EMS levitation, such as their inability to maintain the air gap while on grades and curves, the poor ride comfort at high speeds, and the inability to isolate the vehicle from the irregularities in the guideway etc. The primary braking is furnished by the Linear Synchronous motor acting as a dynamic brake, backup braking is provided by a separate set of magnetic braking units. The physical characteristics of the vehicle are as follows. The TR 07 vehicle is 51 meters long, 3.7 meters wide and 3.8 meters high. The empty weight of the vehicle is 80 tones and has a payload capacity of 20 tones. The air gap between the guideway and the vehicle is 8 mm and the vehicle is capable of a maximum speed of 400 kilometers/hour to 500 kilometers/hour [87 CH2443-0 and 86 CH2276-4].

2. Literature Review
3. Methodology

3.1 Methodology for Analysis

The purpose of this research is to develop a methodology for the economic evaluation of new transportation systems encompassing elements of inter-city travel, economic development, traffic engineering, socioeconomic parameters and mass transportation. The proposed methodology is to be developed using a dynamic mathematical computer simulation model. A systems approach to modelling is proposed, using the computer software STELLA-II.

The purpose of this model is to better understand through simulation the dynamic characteristics of transportation systems and how the various factors that affect them, interact to affect cost ridership and revenues. The model should serve as a tool to the decision maker to understand how the behavior of the actual system would respond to changes in guiding policies, and also to evaluate the performance of the system under different scenarios. In addition the methodology should be adaptable to other transportation evaluation projects in different geographical locations and using different technologies.

In this study two types of information are used, general and cost related. Published information on the various high speed rail technologies, characteristics of the technology, known characteristics of the Northeast corridor and common engineering relationships and operational experience would be used to develop the various submodels. Cost related data would come from technical cost studies of railroad and other high speed ground transportation projects.
3.2 Systems Perspective

To understand the systems approach to solving complex problems it is essential to look at the problem in a systems perspective. Systems awareness is the formal awareness, of the parts of a system, their interactions and the interdependencies between the parts of the system. This interaction and interdependency produces an information feedback which is goal seeking and self correcting. A feedback control system exists whenever the environment causes a decision which in turn affects the original environment [Forrester, J. W., 1975].

To describe a system one must describe the separate parts of a system, their functions, the methods of interconnection between the parts and and how they interdependent on each other. A dynamic system is one which is changing with the progress of time. The various parts of a system interact to create new conditions. This kind of systems can be seen in all fields, weather it be engineering, management, nature or economics to mention a few.

The systems approach is the modus operandi of dealing with complex systems. 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.].

3. Methodology
3.3 Simulation Models

A model is a substitute for some real equipment, structure or system. A model is a useful tool for understanding the behavior and characteristics of a system more effectively than can be done by observing the real system at a much lower cost. Models help obtain information quickly for conditions not observable in real life. Models are of various types and they can be classified as shown in Figure 3.1. A mathematical model is an abstract model. They are written using mathematical symbols to describe the system it represents. Mathematical models are evolved from verbal descriptions, experience, field observations and available data. By the use of mathematical notations, which are more rigid than verbal languages, more clarity in the verbal description can be obtained. Mathematical models unlike physical and verbal models can be manipulated more easily.

Mathematical models can be dynamic or static. A dynamic mathematical model deals with time varying interactions. Most often these mathematical models are not solved analytically as it becomes laborious. They are done using computers which enable it to be solved without any simplifications and at low cost. By simulating these models on a computer a continuous regeneration process is set in motion leading to new results, which in turn lead to new decisions which in turn keep the system in continuous motion through information feedback loops. Simulation in its general meaning, implies the use of one process or experiment to stand in for and play the role of some other process [Forrester, J. W., 1975]. Simulation in short consists of tracing through step by step, the actual flows of information, and observing the series of new results and new decisions that take place. A great deal more can be learned through simulation than real life as the experimental conditions are fully known, controllable and reproducible, so that changes in system behavior can be traced directly to the causes.

3. Methodology
3.4 Systems Dynamics Modelling

Systems dynamics modelling is based on feedback concepts. It makes possible the representation of decision policies and information flows. Systems dynamic modelling provides for a more efficient economic analysis. The form of a systems dynamic model should be such as to achieve several objectives. 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.

3. Methodology
4. Be extendable to large numbers of variable without exceeding the practical limits of computers.

5. Be able to handle continuous interactions 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 basic steps in the systems dynamic modelling process are 1) Verbal description, 2) Causal diagram and 3) Mathematical model. The first step is to describe verbally what one wants to model. The verbal description is then expressed as a flow diagram, also called a causal diagram. The basic building blocks for drawing a causal diagram is described in Table 3.1. The next step is to convert this causal diagram into mathematical form.

Systems dynamics modelling can be done using computer languages such as DYNAMO or by the use of simulation software such as STELLA II. DYNAMO and STELLA II are problem oriented rather than computer oriented; therefore little or no knowledge of computer programming is necessary.

3.5 STELLA-II

STELLA is an acronym for "Systems Thinking, Experimental Learning Laboratory, with Animation". STELLA executes dynamic simulation models. It is a problem oriented software rather than computer oriented. It makes available easy to use computing facilities so that the user can

3. Methodology
focus his attention on building a useful model undisturbed by complex computer requirements.

The software has built in diagramming, model building and simulation capabilities.

<table>
<thead>
<tr>
<th>Table 3.1 Systems Dynamics Variables</th>
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<tbody>
<tr>
<td>1. Levels or Stocks or State Variables</td>
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<tr>
<td>2. Rate Variables or Flows</td>
</tr>
<tr>
<td>3. Auxiliary Variables or Converters</td>
</tr>
<tr>
<td>4. Constant Parameters or Converters</td>
</tr>
<tr>
<td>5. Supplementary Variables</td>
</tr>
</tbody>
</table>

Stocks, Flows, Converters and Connectors are the basic building blocks in STELLA. These are represented as shown in Figure 3.2. Stocks or levels are accumulations or state variables and are represented by rectangles. Flows are rates of change and they regulate the flow in and out of stocks. Flows can be in flows or out flows. They 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 specific flow volume. Converters can represent auxiliary variables, constant parameters or supplementary variables. They are represented by circles. Converters can represent either information or material quantities. The other basic building block is the connector.

3. Methodology
Connectors link stocks to converters and converters to other converters. Connectors do not take on numerical values, they represent inputs. A more detailed description of the capabilities and the functions available in the software STELLA II is described in Appendix A.

3. Methodology
4. Model Description

4.1 Introduction

Before the implementation of a new transportation project the planners must reach decisions regarding the economic feasibility aspects of the new venture. This involves investigating various configurations, based on different technological, operational and financial parameters. This chapter deals with the description of a Systems Dynamic Simulation model which is designed to serve as a tool for investigating these various scenarios. The model serves as a tool for the decision maker to look at the economic feasibility of new transportation systems, from a life cycle perspective. The model analyses, whether it is likely that project revenues from users over the life cycle will cover projected costs. The economic analysis consists of two separate simulation models.

1. The vehicle model.
2. The economic feasibility model.

In addition to a full description of both these models, the input parameters, the mathematical computations involved, the assumptions of the model and the boundaries of the model are also detailed here. The models have been formulated so that they can be easily understood, yet they are sufficiently complex to realistically reflect important characteristics of a large variety of scenarios.
4.2 The Vehicle Model

4.2.1 Vehicle Model Description

In planning for new transportation systems the decision making process requires a good deal of technological data. Technological data is required to decide on the systems best operating policies. Some of the economic and life cycle decisions which govern the systems acquisition, development and operation also require considerable technological support. Putting technology data to good use in transportation decision making requires that we understand not only in what circumstances the need for this input is likely, but also what kind of data is useful. The degree to which the decision making process hinges on technological alternatives varies from case to case.

The purpose of the Vehicle model was to duplicate the technology behind the maglev in the form of a Dynamic Simulation Model so as to obtain realistic estimates of travel time and power consumption for different cruise velocities, deceleration rates and distance travelled. The outputs from this vehicle model serves as inputs for the economic feasibility model. Wherever possible, the model is based on physical principles, represented by physical algebraic equations. Most of the input data to this vehicle model is based on actual results obtained from published information, based on tests conducted on the German Transrapid 06 II vehicle.

Friction is the principal force that opposes motion in conventional ground transportation vehicles which uses wheels. At high speeds the aerodynamic drag becomes the principle force
resisting motion. As maglevs have no physical contact with the guideway, friction is eliminated. In maglevs the forces that opposes motion are radically different. The total resistance to vehicle motion consists of three components:

1. Aerodynamic drag.

2. Drag due to Lateral Guidance.

3. Drag due to Linear Generation.

Aerodynamic resistance is the predominant force opposing motion at high speeds. Aerodynamic drag increases with the square of the vehicle speed and reaches its peak value at maximum cruising speed [Johnson, L. R., et al., 1989]. Aerodynamic drag is a strong function of vehicle shape, frontal area and velocity, hence a streamlined vehicle design is essential for lower aerodynamic drag.

Another drag force contributing to the tractive resistance of the vehicle is the drag force due to linear induction magnetic generation. This is the braking force the linear generator produces. The linear generator serves for power supply on board the vehicle. Drag force due to linear generation has a more complex dependence on speed and track thickness. It peaks at relatively low speeds and diminishes at higher speeds.

The lateral guidance system of the maglev produces a drag force on the motion of the vehicle called drag due to lateral guidance. This is produced by the interaction between the eddy currents in the rails of the magnetic lateral guidance system in the guideway and the on board magnetic fields. This interaction produces the desired lateral guidance but also an undesired drag

4. Model Description
component. If vehicle weight is reduced, the lift force required for lateral guidance can be reduced and also this drag force.

For any given velocity the sum of these three drag forces is the tractive resistance experienced by the vehicle. The variation of aerodynamic drag, drag due to linear induction magnetic generation, Drag due to lateral guidance and tractive resistance, with respect to velocity is shown in Figure 4.1. This data is based on field tests on the TR 06 II magnetic levitated vehicle, at the test facility in Emsland, Germany. This same data is used in the vehicle model in the form of a table function to estimate the drag forces. The vehicle model computes the total tractive resistance for any given velocity as the sum of the aerodynamic drag, drag due to linear generation and drag due to lateral guidance. The tractive resistance is the force that has to be overcome by the vehicle for acceleration or deceleration. Thus the force required for motion is the sum of the tractive resistance and the force required for acceleration. This is referred to in the model as the thrust output. In the model this is a function of velocity and is also modeled in the form of a table function.

Thrust output multiplied by the throttle setting gives the thrust available. The energy available for acceleration, called the excess thrust is the difference of the thrust available and the tractive resistance. The causal relations of drag forces, tractive resistance, thrust output etc: are represented in STELLA format as shown in Figure 4.2. Since the excess thrust available for acceleration is known, the acceleration rate is computed internally in the model using Newton's second law of motion:

\[ F = MA \]

4. Model Description
Figure 4.1 Variation of Drag Forces of The TR 06 II Maglev With Respect to Velocity.

where $F$ is the force or excess thrust, $M$ is the mass of the vehicle which is known and equals 100 tones for the TR 06 II vehicle and $A$ is the rate of acceleration, which is computed by the model. Cruise velocity is an input to the model which is supplied by the decision maker. The acceleration rate during the cruise stage is equal to zero. The rate of deceleration is assumed to be uniform in the model and its value is 0.785 meters/second/second. This value has been assumed so as to

4. Model Description
match the distance and time required to come to a halt for the TR 08 II maglev from specific cruise speeds which were obtained from published reports. The total distance the vehicle has to travel is also an input to the model.

At the outset of simulation, the model replicates the acceleration phase. This is achieved by means of a if then statement in the model. Acceleration continues at a rate which is dependent on the thrust available. When the cruise velocity has been attained the model switches over to the cruising phase by means of the same logical if then statement. From the start of simulation, for every $dt$ the balance distance that has to be travelled is computed internally in the model by subtracting the distance travelled up to that instant of time from the total distance from origin to

4. Model Description
destination. The distance required to come to a halt or the braking distance is also calculated internally in the model for every $dt$ using the relation:

$$v^2 = u^2 + 2as$$

where $V$ is the final velocity which is zero in this case, $U$ is the initial velocity and equals the velocity at which the vehicle is moving at the particular instant of time. $S$ is the distance required to decelerate or the braking distance and $a$ is the deceleration rate. When the the balance distance to be travelled equals the braking distance the model switches over from cruise to deceleration by means of an if then statement.

Since the rate of acceleration or deceleration is known for every value of $dt$ at which the model is simulated, the velocity at these time intervals are computed in the model by the relation:

$$\int_0^t dv = \int_0^t a \, dt$$

A similar relation is used to compute the distance travelled, once the velocity is known.

$$\int_0^s dS = \int_0^t v \, dt$$

The causal diagram involving acceleration, deceleration, cruise, distance and velocity is shown in Figure 4.3. Thrust ratio is the ratio of the thrust available and the excess thrust. The power consumed for any distance and cruise velocity, is calculated internally in the model using the relation:

$$P = T^*V$$

4. Model Description
where $P$ is the power consumed, $T$ is the thrust available and $V$ is the velocity.

![Causal Diagram of Acceleration, Deceleration, Cruise, Thrust and Distance.](image)

Figure 4.3 Causal Diagram of Acceleration, Deceleration, Cruise, Thrust and Distance.

In STELLA format the causal diagram is as shown in Figure 4.4. This is how the power consumption is computed in the model. The total time the vehicle takes to travel a given distance is computed as the sum of the time required for acceleration, cruising and deceleration. These individual times are computed by the use of timers using stocks and flows.

4. Model Description
Figure 4.4 Causal Diagram of Power Consumption.

The causal Diagram of the Vehicle model and the equations of the model can be seen in Appendix B and Appendix C respectively. The variables are described in Appendix F. The output obtained from this model was compared to data from tests conducted on the prototype of the TR 06 II vehicle and was found to perform satisfactorily. Acceleration rates, travel time for travelling given distances and braking distances for various values of cruise velocities were also found to be the same as that obtained from the TR 06 II vehicle on test runs at the Emsland test facility in Germany. A sample output of the model is shown here. The vehicle was simulated to run for a distance 50 kilometers at a cruising speed of 325 kilometers/hour. The deceleration rate was 0.785 meters/second/second. The total time taken for the trip was found to be 385 seconds, the

4. Model Description
power consumed was 748.45 kilowatt hour and the variation of velocity with respect to time is shown in Figure 4.5.

Figure 4.5 Variation of Velocity With Respect to Time for The Vehicle Model.

4. Model Description
4.2.2 Model Assumptions

The following assumptions were made in the model to simplify the vehicle model, and yet to capture the essence of the system. Assumptions were also made due to limitations on the availability of technical data on the German Transrapid TR 06 II magnetic levitated vehicle:

1. The rate of deceleration of the magnetically levitated vehicle TR 06 II is assumed to be uniform.
2. For the purpose of calculating the total weight of the vehicle, the maglev was assumed to be carrying its maximum payload of 20 tonnes or 100 passengers.
3. Data on the tractive effort of the TR 06 II vehicle was unavailable, hence the force available for acceleration or tractive effort was assumed so as to match the rate of acceleration, time for acceleration, distance required for acceleration and the maximum cruise velocity published for specific conditions.

4.2.3 Limitations of The Model

The model was built for the purpose of providing input parameters for the economic evaluation model. The output of the model such as power consumption and travel time serve as inputs to the economic evaluation model. The amount of detail included in the model was based solely on the purpose for which the model was built. Only those elements that would cause significant differences in the decision making process was included.

4. Model Description
4.3 Economic Evaluation Model

The demand for any transportation service is affected by a variety of factors which can be classified in two main categories: socioeconomic and transportation. The socioeconomic factors consists of a wide range of considerations which determine the disposition and means of travel. Among the most important of the socioeconomic factors are population, income and the composition of the labor force. The transportation factors include the various attributes of the transportation service which interact with socioeconomic 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 object of this economic evaluation model was to identify and quantify through Systems Dynamic Simulation how these two groups of factors interact to affect the financial viability of the transportation system in question at the proposed location.

The model enables the policy maker to do a life cycle cost analysis for various scenarios of frequency, fare structure, change in unit capital costs etc. The economic evaluation model was designed to give realistic estimates of capital costs, operating costs, annual ridership, annual revenue, frequency of service required, number of vehicles required, when additional guideways have to be built and a host of other useful data which are detailed in this chapter. Though there are a number of urban locations in the Northeast Corridor only four of the largest cities have been considered in this analysis. They are Boston, New York, Philadelphia and Washington D.C. The base year for all input data was 1980. The causal diagram and the equations of the model are

4. Model Description
shown in Appendix D and Appendix E respectively. The variables are described in Appendix F. The model can be subdivided into the following submodels:

1. Socioeconomic Model.
2. Trip Generation Model.
3. Mode Split Model.
4. Revenue Model.
5. Capital Cost Model.
6. Operating Costs Model.

4.3.1 Socioeconomic Model

The socioeconomic model serves to generate values for socioeconomic variables over time. These socioeconomic variables namely population, per capita income and the percentage of jobs in manufacturing, serve as inputs to the trip generation model. The initial values and the inputs to these variables are based on 1980 census data. The socioeconomic model consists of a population sector, industry sector, income sector and employment sector.

The population sector of the socioeconomic submodel calculates the population of the city in question over time. Population is a function of the rate of growth of population and the rate of decrease of population. The rate of growth of population is represented as growth in the model and the rate of decrease is represented as decrease rate. Decrease rate is the product of population and the decrease normal. Growth rate is the product of population, growth normal and
the growth factor. The growth factor is part of a feedback loop. Since the growth of population of a city is affected by the employment opportunities in the city, the model calculates the fraction of the population which is supported by income from jobs with respect to the total population. The growth factor is represented as a Table function of this supported population. The population sector of the socioeconomic model is depicted as a causal diagram in the model as shown in Figure 4.6.

![Diagram](image)

Figure 4.6. Population Sector of The Socioeconomic Model.

In the industry sector of the socioeconomic submodel the total value of the industry is represented as a stock. It's value is controlled by the rate of new investment and the rate of demolition of industry. The demolition rate is the product of the industry value and the demolition normal. The demolition normal is a constant which can be varied by the user. The investment in industry in a locality can come from two sources, reinvestment by existing industry and from

4. Model Description
external sources. The rate of new investment in the socioeconomic submodel is computed as the sum of the industry value of existing industry and other sources multiplied by a industry growth factor which is a Table function of the sales to production ratio of the industry sector. The value of the products of the industry is the product of the industry value and a production factor which can be varied by the decision maker. Figure 4.7 shows the causal representation of the industry sector.

![Diagram of Industry Sector](image)

Figure 4.7 Industry Sector of The Socioeconomic Model.

The income sector traces the change in per capita income over time. Per capita income is represented as a stock. When the sales to production ratio grows so does the per capita income.

4. Model Description
Sales is a function of per capita income and a sales factor which is a constant. The employment sector of the socioeconomic submodel calculates the jobs available in the locality. The total jobs is the sum of the jobs in industry, jobs in government and other services and jobs in the retail trade. Jobs in government and other services is a function of the population, jobs in industry is a function of the industry value and the jobs in the retail trade is a function of sales. Since the number of persons employed in a household and the average household size are known from the census data, the fraction of the population which is supported by a means of income is calculated in the model. The population growth rate is a function of this supported fraction of the population. The Causal diagrams of the socioeconomic submodels of the four cities are shown in Figures D.1, D.2, D.3 and D.4 of Appendix D.

4.3.2. Trip Generation model

There are two approaches for the analysis of inter-city transport demand. One approach is multimodal in nature and the other is mode specific. These two approaches are not alternatives but should be considered complementary. In general long distance travel is handled by the mode specific approach and, short haul travel, including urban corridor travel by the multimodal approach. Even with this distinction in mind, the choice of approach should depend on the transportation system in question and be guided by the extent to which different modes may be related [Kanafani, A., 1983].

An abstract mode model is used for estimating the number of trips between city pairs in the economic evaluation model. The abstract mode model is simple in nature as it has the supply

4. Model Description
variables of two modes: the mode in question and the mode offering the best value of the attributes. A version of the model developed by Quandt and Baumol (1966) is used in this analysis. This model was used in the California corridor, for forecasting demand for novel technologies such as the short takeoff and landing aircraft [Quandt, R. E., 1967]. The form of the model used in the analysis is as given below:

\[ T_{ijm} = \alpha \beta P_i^{\gamma_1} P_j^{\gamma_2} Y_i^{\gamma_3} Y_j^{\gamma_4} M_i^{\gamma_5} M_j^{\gamma_6} (H_{ijm})^{\gamma_7} (H_{ijb})^{\gamma_8} (C_{ijm})^{\gamma_9} (C_{ijb})^{\gamma_{10}} \]

where:

- \( T_{ijm} \) = Trips between cities i and j using mode m.
- \( P_i \) = Population of city i.
- \( P_j \) = Population of city j.
- \( Y_i \) = Per capita income of city i.
- \( Y_j \) = Per capita income of city j.
- \( M_i \) = Percentage of total employment that is in manufacturing in city i.
- \( M_j \) = Percentage of total employment that is in manufacturing in city j.
- \( H_{ijm} \) = Travel time by mode m relative to best travel time between i and j.
- \( H_{ijb} \) = Best (shortest) travel time between i and j.
- \( C_{ijm} \) = Travel cost by mode m between i and j relative to best cost.
- \( C_{ijb} \) = Best travel cost between i and j.
- \( \alpha, \beta \) = Elasticity values.

4. Model Description
The population, income and manufacturing employment variables are conventional demand variables for inter-city models. These variables are the outputs of the socioeconomic model. The trips generated by the trip generation model are those of a particular mode which is the airline, before the implementation of maglev. After the maglev is implemented the trips are the combined total of airline and maglev. Maglev and airplanes have comparable travel times and cost. The best cost is that of the fare offered by bus, the value of which is in 1980 dollars. The best travel time is that of the maglev or airline whichever is smaller. This is computed internally in the model. The fare charged by maglev and the airline mode are inputs in the model, which can be varied by the decision maker.

In this study, it was not possible to realistically estimate the elasticity values for the various parameters, as a detailed survey was involved. Hence the elasticity values were assumed based on a study conducted in the California corridor. The elasticity values were calibrated to match the trips generated between city pairs. The actual fare structure of the airlines operating in the Northeast corridor, was obtained from the official airline guide. The Causal Diagrams of the trip generation submodels are shown in Figures D.1, D.2, D.3, D.4 and D.13 of Appendix D.

4.3.3 Mode Split model

The trips that the maglev transportation system would attract if implemented was estimated by doing a mode split on the total number of trips generated from the trip generation model, which is the total of the trips by all the fast modes of transport. A choice model was used since the passenger has to choose from alternative services. The following model was used:

4. Model Description
\[ P_{ijk} = \frac{e^{V_{ijk}}}{\sum_k e^{V_{ijk}}} \]

\[ V_{ijk} = \alpha H_{ijk} + \beta F_k + \alpha C_k \]

where:

- \( P_{ijk} \) = Proportion of the traffic between city i and city j that uses the kth mode.
- \( V_{ijk} \) = Choice function of the attribute of the mode k.
- \( H_{ijk} \) = Total travel time between city i and city j using mode k including access and egress time.
- \( F_k \) = Scheduled frequency on mode k measured in total weekly flights.
- \( C_k \) = Fare on mode k.
- \( \alpha, \beta \) = Elasticity values.

The elasticity values for this model, for the Northeast corridor could not be estimated due to constraints of resources. The values were assumed based on a study done on aircraft choice between San Francisco and Los Angeles [Kanafani, A., 1983]. Two modes were considered in the mode split, they were airline and maglev. The model was designed so that the time at which the maglev becomes operational could be changed by the decision maker. The Causal Diagrams of the mode split models are shown in Figures D.7, D.8, D.9, D.10, D.14 and D.15 of Appendix D.

4. Model Description
The frequency of operation of airline and maglev are calculated internally in the model. The model assumes that service is always available to meet demand. As the annual number of round trips by air is known, the frequency of airline flights is calculated in the model. From the annual number of airline trips the average number of round trips daily by air is calculated. By multiplying the average passenger capacity of an airline and the utilization factor the average utilized capacity is found. Knowing the daily number of round trips by air and the utilized capacity the number of flights between the city pair in question is found. The number of flights weekly or the airline service frequency, forms a feedback loop to the mode split model. The Causal Diagrams of the airline frequency models are shown in Figures D.7, D.8, D.9, D.10, D.14 and D.15 of Appendix D.

The frequency of service of maglev is calculated in the simulation model in a different manner from that of the airline. Since, the maglev is a ground transportation mode operating in a corridor, the model assumes that the maglev stops at all intermediate stops between its origin station and the final destination city unlike in airlines where they are assumed to fly directly. For example the frequency of service between New York and Boston would be the sum of the frequency required for meeting the demand for travel between New York and Boston, Philadelphia and Boston, and Washington and Boston, as the maglevs bound for Boston, from Philadelphia and Washington would stop at New York also. Hence a passenger travelling to Boston from New York can board any of these vehicles in addition to those starting from New York. This would produce a higher frequency of operation than when considering the city pair in isolation. The frequency required for each sector is calculated in this manner. The frequency of maglev trips in each segment of the corridor forms a feedback loop to the corresponding mode.

4. Model Description
split model where frequency of service is an input. The causal Diagram of the maglev frequency model are shown in Figure D.5 of Appendix D.

The model takes into account the delay experienced at modern day airports. This is a function of the daily frequency of operation and is in the form of a table function. The total travel time for both modes maglev and airline is the sum of the delay experienced, the time spent at intermediate stops, the access and egress time and the flying time in the case of airline or the running time in the case of maglev. The best travel time is the smaller of these two travel times. The best travel time forms a feedback loop to the trip generation model. The Causal Diagrams for calculation of travel times of maglev and airline can be seen in Figures D.7, D.8, D.9, D.10, D.14 and D.15 of Appendix D.

4.3.4 Revenue Model

The revenue submodel of the economic analysis simulation model, considers revenue from fares as the only benefit of implementing a maglev transportation system in the Northeast corridor. The annual revenue from operation between any city pair is the product of the annual passenger trips between the city pair and the maglev fare for that segment of the corridor. The total annual revenue is the sum of the revenue from all city pairs. This is represented as a rate in STELLA diagrammatic notation as shown in Figure 4.8. The cumulative revenue from fares, over the life cycle is represented as a stock. The causal diagram of the Revenue submodel is shown in Figure D.5 of Appendix D.

4. Model Description
4.3.5 Capital Costs

Various factors contribute to the cost of maglev implementation in the Northeast corridor. The major expenditure is for right of way acquisition, cost of elevated guideway, cost of guideway electrification and cost of stations. Unit costs for the various items for estimating capital costs were obtained from a cost estimation done for maglev implementation between California and Las Vegas. All costs are in 1980 dollars, in this analysis. Cost of engineering and administration for maglev implementation, is taken as a percentage of the capital costs. The number of magnetically levitated vehicles required at any instant of time is assumed to be that required to meet the demand for travel by maglev. The unit cost of a maglev is that of a TR 06 II Transrapid vehicle. A vehicle life of 10 years is assumed after which it is replaced. The costs of vehicle replacement is taken into account by the use of a table function. The causal Diagram of the capital cost and total capital spent submodel is shown in Figure D.17 of Appendix D.

In addition the cost of adding new vehicles to meet growth in demand has also been considered in the model. The Causal Diagram incorporating the cost of purchasing new vehicles to meet the demand in travel is shown in Figure D.11 of Appendix D. The model calculates the platform capacity and the guideway capacity internally. When these capacities are exceeded, the cost of new ones are added to capital costs. No delay functions have been incorporated as it is assumed that the construction of new platforms and guideways would be started way in advance and would be complete by the time it is required, that is when the capacity of the existing ones are exceeded. The Causal Diagram of the guideway capacity, station capacity, new platform cost and additional guideway cost submodels are shown in Figure D.8 and D.12 of Appendix D.

4. Model Description
Figure 4.8 Causal Diagram of Revenue Model.

4. Model Description
Station capacity is calculated using the following relation:

\[ C_s = \frac{3600 \times 17}{t_s + t_r + \sqrt{\frac{2 n l}{a} + \frac{n l}{v} + \frac{v(K + 1)}{2 b_n}}} \]

where:

- \( C_s \) = Station capacity in vehicles per day.
- \( t_s \) = Station standing time in seconds.
- \( t_r \) = Reaction time in seconds.
- \( n \) = Number of vehicles per train.
- \( l \) = Length of vehicle in meters.
- \( a \) = Vehicle acceleration rate.
- \( v \) = Cruise velocity in meters per second.
- \( K \) = Safety factor.
- \( b_n \) = Normal braking rate.
- \( 3600 \times 17 \) = Total time in seconds the vehicle operates, per day that is from 6:00AM to 11:00PM.

The capacity of the guideway is calculated internally in the model using the relation:

\[ C_w = \frac{3600 \times 17}{\frac{(n l + S_0)}{v} + t_r + \frac{v}{2 b_n}} \]

4. Model Description
where:

\[ C_w \] = Guideway capacity in number of vehicles per day.
\[ n \] = Number of vehicles per train.
\[ l' \] = Vehicle length in meters.
\[ S_\theta \] = Minimum distance in meters between adjacent maglev vehicles.
\[ v \] = Cruise velocity in meters per second.
\[ t_r \] = Reaction time in seconds.
\[ b_n \] = Normal vehicle braking rate.
\[ 3600 \times 17 \] = Total time in seconds the vehicle operates, per day that is from 6:00AM to 11:00PM.

Station capacity dictates the capacity of the system when compared to the guideway capacity. This can be illustrated by going through an example. Assuming that the cruise velocity is 90 meters/second, station standing time is 10 minutes, reaction time is 1 second, number of vehicles per train is 1, length of the vehicle is 51 meters, vehicle acceleration rate is 0.6 meters/second/second, safety factor is 1.15 the normal braking rate is 0.785 meters/second/second and the minimum distance between adjacent maglev vehicles is 100 meters. The station capacity would be 83 vehicles per day and the guideway capacity would be 1020 vehicles per day. The equation of station capacity assumes on-line stations which is highly unlikely in a real life scenario. Off-line stations with multiple stations would be a more realistic choice. For off-line stations with multiple platforms, estimates of capacity can be done by the use of queuing theory.

4. Model Description
4.3.6 Operation and Maintenance Costs

For simplicity operation and maintenance costs is subdivided into power costs, facility maintenance costs, station operations cost, train maintenance costs, other operation and maintenance costs and cost of administration and insurance. The power consumption in kilowatt hours for a single trip between each adjacent city pair is an input to the model. The values of this is obtained from the vehicle model. The power cost for all maglev trips for an entire year is computed in the model.

Facility maintenance costs consists of maintaining the guideway, maintenance costs of signals and communications, electrification maintenance costs, cost of maintenance of traffic control and maintenance of all other facilities. Station operating cost as the name suggests is the cost of operating stations. Train maintenance costs consists of routine service costs, cost of cleaning vehicles, cost of complete maintenance of vehicles and cost of facility operations. Other operation and maintenance costs include salaries of train crew, cost of ticketing and sales, train supplies and contingency expenses.

All these costs for the entire system is computed and added up to get the annual operation and maintenance costs. The annual operation and maintenance costs accumulate and add to the capital expenses to give the total capital spent over the systems life cycle. The Causal Diagram of the operation and maintenance costs submodel are shown in Figure D.16 of Appendix D.

4. Model Description
4.3.7 Model Assumptions

1. The elasticity values of the trip generation and mode split models are not based on actual surveys.

2. The elasticity values of the trip generation and mode split models are assumed to remain constant over the system's life cycle.

3. Fare structure for maglev transportation and air transportation remain constant over the life cycle of the system.

4. The economic model assumes that for any mode service is always available to meet demand.

5. The frequency of service is uniform throughout the operating hours (6:00 AM to 11:00 PM) of a day, for both maglev and airline.

6. A utilization factor of 60% is assumed for both maglev and airline for all calculations in the economic model.

4.3.8 Limitations of The Economic Model

The analysis considers revenue from fares as the only benefit of maglev implementation. Other benefits of implementing maglev technology, such as reduced dependence on fossil fuels, reduced congestion at airports and in the air, impacts of reduced air pollution and lessened airport congestion have not been considered. All unit costs are in 1980 dollars and remain constant over the life cycle of the system. In real life elasticity values change over time. In this analysis they remain constant. The model does not take into account the trips maglev would attract from modes.

4. Model Description
other than airline. The frequency of service is assumed to remain constant over the operating hours of a day. In actual practice there would be some variations.

4. Model Description
5. Model Results and Analysis

5.1 Analysis Description

The order to demonstrate the versatility and the capabilities of the model several probable scenarios that a decision maker would face while doing a policy analysis were developed. These scenarios represent possible conditions that a maglev system might face during its life cycle, if implemented. The vehicle model was analyzed by changing input parameters and exploring the changes in various performance parameters. A baseline scenario was developed for the economic analysis model using existing representative conditions. Several input parameters were varied from the baseline scenario to test the sensitivity of the model. The scenarios were analyzed by varying the following input parameters:

1. Scenario-I Sales factor in the socioeconomic model.
2. Scenario-II Elasticity values in the trip generation model.
4. Scenario-IV Unit cost of power.
5. Scenario-V Right of way acquisition.

The objective of the analysis on the vehicle model is a typical decision that has to be made before commercial operations can begin. At what cruising speed should the maglev operate to maximize ridership? The answer to this question is a tradeoff between speed and power consumption. The vehicle model was simulated for various cruise velocities namely 200
kilometers/hour, 300 kilometers/hour, 325 kilometers/hour, 340 kilometers/hour and 360 kilometers/hour. The variation of power consumption and travel time with respect to the distance is as shown in Figure 5.1. The total power consumed to travel a given distance was found to increase as the cruising velocity was increased. The travel time as can be expected was lower for higher speeds.

For the baseline scenario in the economic model a cruise velocity of 90 meters/second or 325 kilometers/hour was used. The vehicle parameters used were those of the TR 06 II magnetic levitated vehicle. The fares used was that of commercial airlines operating in the respective segments. This data was obtained from the Official Airline Guide and are in 1980 dollars. The socioeconomic parameters were obtained from the 1980 census. The baseline scenario assumes that a completely new right of way is acquired for the maglev transportation system. A life cycle cost analysis was done and the results are summarized in Figure 5.2. The system would recoup all expenses after 28 years if it became operational in 1992.

As part of the policy analysis, the first scenario analyzed was to see the behavior of the system for changes in socioeconomic parameters. The retail sales factor in each of the four cities was increased by 20 %, decreased by 20 % and the total annual passenger ridership was compared to the base line scenario. The results are as shown in Table 5.1. It may be noted that for the baseline scenario and for the increase sales factor the ridership steadily increases due to increased employment, industrial production and population. When the sales factor was reduced, similar to the retail sales during periods of recession the passenger ridership increased only nominally at the same time showing erratic behavior.

5. Model Results and Analysis
Figure 5.1 Power Consumption and Travel Time for Various Values of Cruise Velocities for Fixed Distance.

5. Model Results and Analysis
The second scenario involved the change in the life cycle costs and revenues, due to changes in elasticity values. As the elasticity values in the model are not of the Northeast corridor, but assumed on the basis of a study conducted on the California corridor which is similar in many aspects to the Northeast corridor. The elasticity values of population were decreased to 90% of the values of the baseline scenario first and then increased to 110% of the values in the baseline case. The results are shown in Table 5.2. From the table it can be seen that the model is highly

5. Model Results and Analysis
Table 5.1 Variation of Annual Maglev Passengers with Respect to Sales Factor.

<table>
<thead>
<tr>
<th>YEARS</th>
<th>TOTAL ANNUAL MAGLEV PASSENGERS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VALUE OF SALES FACTOR = BASELINE SCENARIO</td>
</tr>
<tr>
<td>12</td>
<td>1,899,336</td>
</tr>
<tr>
<td>15</td>
<td>2,436,664</td>
</tr>
<tr>
<td>18</td>
<td>4,793,074</td>
</tr>
<tr>
<td>21</td>
<td>6,933,116</td>
</tr>
<tr>
<td>24</td>
<td>7,763,049</td>
</tr>
<tr>
<td>30</td>
<td>10,451,284</td>
</tr>
</tbody>
</table>

Table 5.2 Life Cycle Costs and Revenues For Changes in Elasticity Values.

<table>
<thead>
<tr>
<th>YEARS</th>
<th>CUMULATIVE LIFE CYCLE COSTS AND REVENUES IN DOLLARS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ELASTICITY OF POPULATION = BASELINE SCENARIO</td>
</tr>
<tr>
<td></td>
<td>REVENUES CAPITAL EXPENDED</td>
</tr>
<tr>
<td>11</td>
<td>1.33 E 07 9.66 E 09</td>
</tr>
<tr>
<td>14</td>
<td>8.06 E 07 9.97 E 09</td>
</tr>
<tr>
<td>17</td>
<td>2.13 E 08 1.06 E 10</td>
</tr>
<tr>
<td>20</td>
<td>4.74 E 09 1.20 E 10</td>
</tr>
<tr>
<td>23</td>
<td>9.46 E 09 1.47 E 10</td>
</tr>
<tr>
<td>26</td>
<td>1.76 E 10 1.96 E 10</td>
</tr>
<tr>
<td>29</td>
<td>3.07 E 10 2.85 E 10</td>
</tr>
<tr>
<td>32</td>
<td>4.79 E 10 4.19 E 10</td>
</tr>
<tr>
<td>35</td>
<td>8.12 E 10 6.38 E 10</td>
</tr>
</tbody>
</table>

5. Model Results and Analysis
sensitive to changes in elasticity values as, one would expect. This kind of policy analysis on elasticity values of trip generation models and model split models are very important as it enables the decision maker to assess the sensitivity of the choice of a particular alternative to changes in some of the attributes such as price, travel time, frequency, per capita income etc. Correct estimates of elasticity can be quiet difficult unless good information of passenger travel characteristics are available. Most of the elasticity values of various types of travel such as business, personal and leisure also vary.

A third scenario deals with charges to the user for the service offered. The fare charged for transportation by maglev in the baseline case is the current air fare charged by airlines in the respective segments. These fares were increase by 25 % and then decreased by 25 % and the change in ridership was noted. The results are shown in Figure 5.3. The ridership as can be expected was found to increase with decrease in fares and decrease with increase in fares. The cumulative revenues were found to behave in the same manner, that is revenue increased with decrease in fare and decrease with increase in fare. This kind of analysis would enable the operator to fix the fares so as to maximize revenues.

The remaining policy analysis conducted were pertaining to capital costs involved in a maglev implementation. The fourth scenario was pertaining to unit costs of power. In the baseline scenario the cost of power is 60 cents per kilowatt-hour. This is the rate at which most power companies supply power for household use. For large scale use of power the rate can be expected to be lower. For the purpose of this analysis two scenarios were considered that is unit cost at 45 cents and at 75 cents in addition to the baseline case of 60 cents.

5. Model Results and Analysis
Figure 5.3 Variation of Annual Passenger Ridership for Changes in Fares.

The variation of the cumulative revenues from fares and the variation of cumulative capital expenses were observed. The variation of the above parameters after 30 years of operation of the system are as shown in Figure 5.4. Cost of power is a key factor for profitable implementation of a magnetically levitated ground transportation system as can be seen in the figure. Since this mode of transportation is highly power intensive, a cheap supply of power is

5. Model Results and Analysis
Figure 5.4 Variation of Life Cycle Costs and Revenues for Changes in Unit Cost of Power.

5. Model Results and Analysis
essential. If room temperature super conductors become a reality maglev technology would benefit greatly by reduced power consumption, reduced vehicle weights, which also results in smaller and lighter guideways [Johnson, L. R., et al, 1989].

Another scenario analyzed was with regard to right of way acquisition. The baseline scenario is based on acquiring a new right of way at an average cost of 15 million dollars a mile. It is possible to use part of the existing highway and railroad right of way for maglev's. At least a part of the right of way would be new as the curves required at such high velocities would be much greater than that on the existing highway and railroad right of way. The change in capital cost by acquiring 80% of the right of way and using existing right of way for the balance 20% and by acquiring 60% of the right of way and using existing right of way for the balance 40% are as shown in Figure 5.5. It may be noted that there is substantial difference in the total initial capital required for these three scenarios. By using existing right of way to the maximum extent possible considerable savings in capital costs can be made. As the width of right of way required for a single guideway is less than that required for one lane of highway, it is possible to accommodate maglev on existing highway and railroad right of way without reducing existing highway and railroad capacities.

The last scenario in this analysis was with regard to variations in cost of vehicles. Two cases were compared to the baseline scenario. The first case is a scenario in which vehicle costs increase by 20% from the present day cost of 18 million dollars. This is a possibility if superconducting materials are used or if costly lighter materials are used in order to reduce the weight of the vehicle. The second case is one in which the vehicle costs go down by 20%. This might also become a reality in the future as their are extensive efforts going on reduce vehicle

5. Model Results and Analysis
costs. These costs were included in the model in 1980 dollars and the results are shown in Figure 5.6. Vehicle cost is a major contributor to the total capital required over the life cycle as the number of vehicles required over the life cycle increases to meet the increasing demand for travel.

![Graph showing capital costs](image)

Figure 5.5 Initial Capital Cost Required for Variations in Extent of Right of Way Acquisition.

5. Model Results and Analysis
Figure 5.6 Effect of Change in Vehicle Cost on The Life Cycle Cost.

From the analysis done it was seen that the single most important cost over the life cycle was the unit cost of power. Cost of vehicles and right of way cost would affect initial capital required substantially, but their effect on total costs over the life cycle would be lower than that of the effect of changes in unit costs of power. Accurate estimate of elasticity values is essential to get good results from the model, as the ridership forecasted by the model is highly sensitive to changes in elasticity values.

5. Model Results and Analysis
There are a number of urban areas in the Northeast corridor which have not been included in this model though these localities have high ridership potential. If maglev's were to be implemented in the Northeast corridor it is certain that there would be stations at many of these cities. Approximate values for the ridership that could be generated by including some of these cities are shown in Table 5.3. It can be seen from the Table that by including more number of

<table>
<thead>
<tr>
<th>LOCATIONS SERVED</th>
<th>TOTAL TRAVEL TIME</th>
<th>ANNUAL MAGLEV PASSENGERS IN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BOSTON TO WASHINGTON</strong></td>
<td><strong>IN HOURS</strong></td>
<td><strong>1995</strong></td>
</tr>
<tr>
<td>Boston, New York, Philadelphia,</td>
<td>3.275</td>
<td>2,226,018</td>
</tr>
<tr>
<td>Washington</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boston, New York, Philadelphia,</td>
<td>3.476</td>
<td>2,848,872</td>
</tr>
<tr>
<td>Baltimore, Washington</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boston, Providence, Hartford, New York,</td>
<td>3.871</td>
<td>2,964,527</td>
</tr>
<tr>
<td>Philadelphia, Baltimore, Washington</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boston, Providence, Hartford, New Haven, Philadelphia, Baltimore, Washington</td>
<td>4.066</td>
<td>2,967,323</td>
</tr>
</tbody>
</table>

5. Model Results and Analysis
stations along the route, the travel time on the various segments would increase resulting in lower level of service, thus decreasing ridership from individual stations. From the Table it can also be seen that increasing the number of stations would result in increased overall ridership levels due to the ridership generated by the additional stations and lower average access and egress times. While using this methodology for evaluating the feasibility of implementing any particular mode of transportation at a specific area, it is essential to define all the localities at which the mode in question would have stations. These cities would have to be incorporated in the model in order to get realistic estimates of ridership and revenues.

5. Model Results and Analysis
6. Conclusions and Recommendations

6.1 Conclusions

The application of systems dynamic modelling for the evaluation of new modes for high speed ground transportation for inter-city travel has proven to be very effective. The model was found to be highly flexible so as to meet the needs of the policy analyst. The use of STELLA II enables the user to concentrate on the analysis and get results quickly, rather than spending time on complex computer requirements. As shown in Chapter 4 the English like syntax of STELLA is self documenting and readable which makes the task of future enhancements by other researchers easy.

Most economic analysis simulation models have one common drawback. They are difficult to use by decision makers other than the person who wrote them, as understanding of the model and the syntax is a time consuming task. This model overcomes this drawback by its simplicity. The model developed as part of this research also provides the provision for expansion for adding minute details, so that an analysis at a much more micro level becomes possible.

As the demand for transportation grows analysis of this nature using systems dynamic modelling has great potential, so that better insight into the interaction of the various parameters can be understood, resulting in better decision making rather than making judgements by guess work or intuition. As demonstrated in this study magnetic levitated ground transport is a technically and economically feasible solution to the problems facing high speed ground transportation. The model analysis has shown that maglev is an economically feasible investment even without
considering all the other benefits other than revenues from fares. It should be kept in mind that there are other benefits to maglev implementation. Some of these are:

1. Savings from reduced air traffic congestion.
2. Petroleum savings by replacing short-haul airline flights.
4. Savings from reduced passenger delays.
5. Benefits of job creation.

The model in its present form could be used for conducting policy analysis on the scenarios involving a change in any or more of the variables in the model. The following are a few of them:

1. Change in socioeconomic patterns.
2. Most economical cruise velocity.
3. Change in elasticity values.
4. Change in delays experienced by maglev’s and airplanes.
5. Increased station standing times.
6. Delaying the implementation of this new mode of transportation.

Simulation modelling on these lines can be applied for the evaluation of other new modes of transportation which are under development such as vertical takeoff and landing aircraft or new ideas such as smart highways and smart cars.

6. Conclusions and Recommendations
6.2 Recommendations

The following recommendations are a result of the experience gained in developing this methodology for the evaluation of high speed transportation and the analysis done using the model. The proposed recommendations for future research are:

1. Enhance the model by including indirect benefits such as implications of reduced air traffic congestion, savings on lower consumption of fossil fuels, lower pollution levels at airports and savings by reducing if not eliminating passenger delays etc.

2. There are a number of cities in the Northeast corridor which could generate additional ridership. For a complete evaluation these cities at which the maglev system would have stations should be incorporated in the model.

3. A detailed estimation of the elasticity values for the locality in question.

4. Improve the results from the model by estimating the variation of elasticity values over time and including it in the model.

5. Estimation of the ridership captured from all other existing modes such as automobiles and railroad trains.

6. The methodology can be used for evaluating the best magnetically levitated vehicle from all the different manufacturers in the field.

7. There is a large scope for comparing the new technologies available for high speed ground transportation such as vertical takeoff and landing aircraft and magnetic levitated vehicles.

8. The model can be enhanced for estimating the costs at a more micro level.

6. Conclusions and Recommendations
Although maglevs have shown to be technically and economically feasible there are a number of areas in which questions remain unanswered. Some of these are:

1. The safety aspects of magnetic levitated technology.
2. Effects on living organisms due to prolonged exposure to magnetic fields.
3. The source of funding for large scale implementation of this highly capital intensive technology.

6. Conclusions and Recommendations
Bibliography


Bibliography


Bibliography


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Bibliography


Bibliography
Appendix A. Description of STELLA II

This chapter details some of the various functions of STELLA II. The software is designed to be used on Macintosh computers. It is window driven and most of the menus are standard Macintosh menus. All the functions which have been used in this study are detailed here, in addition to some of the useful features available in STELLA II. There are a number of other functions which are available in STELLA II. A full description of these can be obtained in the STELLA II technical documentation, STELLA II applications and the STELLA II user’s guide.

A.1 Builtins

A.1.1 Test Input

PULSE: The structure of the pulse function is:

\[ \text{PULSE(<volume>,<first pulse>,<interval>)} \]

The pulse function generates a pulse input of a specified size (first pulse). Pulse will then repeat firing at a specified time interval (interval). STELLA II pulses the specified volume over a period of one time step (DT). Volume can be either variable or constant. First pulse and interval should be specified as constants.
A.1.2 Mathematical Functions

**EXP:** The structure of the exp function is:

\[ \text{EXP}(\text{expression}) \]

The exp function gives a raised to the power of expression. Expression can be a variable or a constant. The base of the natural logarithm, e is also known as Euler's number. e is equal to 2.7182828... exp is the inverse of the logn function.

**INT:** The structure of the int function is:

\[ \text{INT}(\text{expression}) \]

The int function gives the largest function less than or equal to expression. Expression can be a variable or a constant.

**LOG10:** The structure of the log10 function is:

\[ \text{LOG10}(\text{expression}) \]

The LOG10 function gives the base 10 logarithm of expression. Expression can be a variable or constant. For log10 to be meaningful, expression must have a positive value.

**LOGN:** The structure of the logn function is:

\[ \text{LOGN}(\text{expression}) \]

The logn function calculates the natural logarithm of expression. Expression can be variable or constant. Logn is the inverse of the exp function. For logn to have meaningful results, logn must be positive.

**MAX:** The structure of the max function is:

\[ \text{MAX}(\text{expression}, \text{expression}, \ldots) \]

The max function gives the maximum values among the expressions contained within parentheses.
**MEAN:** The structure of the mean function is:

\[
\text{MEAN}(<\text{expression}>,<\text{expression}>,\ldots)
\]

The mean function returns the arithmetic mean of the expressions contained within parentheses.

**MIN:** The structure of the min function is:

\[
\text{MIN}(<\text{expression}>,<\text{expression}>,\ldots)
\]

The min function gives the minimum value among the expressions contained within the parentheses.

**PCT:** The structure of the pct function is:

\[
\text{PCT}(<\text{fraction}>)
\]

The pct function gives the value of fraction, expressed as a percentage. Fraction can be variable or constant.

**ROUND:** The structure of the round function is:

\[
\text{ROUND}(<\text{expression}>)
\]

The round function rounds expression to its nearest integer value.

**SQRT:** The structure of the sqrt function is:

\[
\text{SQRT}(<\text{expression}>)
\]

The sqrt function gives the square root of the expression contained within parentheses. Expression can be a variable or constant. For meaningful results, expression must be greater than or equal to zero.

**SUM:** The structure of the sum function is:

\[
\text{SUM}(<\text{expression}>,<\text{expression}>,\ldots)
\]

The sum function returns the arithmetic summation of the expressions contained within parentheses.

Appendix A. Description of STELLA II
A.1.3 Logical Functions

The logical functions IF, THEN, ELSE, AND, OR, NOT are used to create expressions, and then give values based upon whether the resulting expression are true or false. When there are multiple conditions the expressions to be evaluated must be enclosed in parentheses.

A.1.4 Discrete Functions

DELAY: The structure of the delay function is:

```
DELAY(<input>,<delay duration>,[,<initial>])
```

The delay function returns a delayed value of input, using a fixed lag time of delay duration and an optional initial value for the delay. If the initial value is not specified, delay assumes the initial value to be the initial value of the input. If the delay duration is specified as a variable, the delay function will use the initial value for its fixed lag time.

A.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 functions, trigonometric functions, and graphical functions.

Appendix A. Description of STELLA II
A.2 Simulation Algorithms

Euler's Method: The simplest algorithm used in STELLA II is the Euler's method. In this method the computed values for flows provide the estimate for change in corresponding stocks over the interval $dt$ assuming that the rates are constant. Euler's method can give large errors if the simulation interval chosen is too large as the solution might oscillate. In general, Euler's approximation works well with functions that have a smooth behavior over the range of values tested. For highly discontinuous functions this procedure might generate large errors as it approximates the solution with a series of rectangles integrated over time as shown in Figure A.1.

2nd-Order Runge-Kutta: This is a more sophisticated procedure of calculation when the value of $dt$ is small. The 2nd-order Runge-Kutta method uses two flow calculations within a given $dt$ to create an estimate of the change in a stock over the $dt$. In this approach the rate equations are evaluated taking into account various points within a single integration interval thus enhancing the accuracy of the solution. As with the euler's method the solution of equations involves both an initialization and an iteration phase.

4th-Order Runge-Kutta: 4th-order Runge-Kutta works just like its 2nd-order counter part, except that it uses four rather than two flow calculations within a given $dt$ to create an estimate of the change in a stock over the $dt$. A weighted average of these calculations is used as the estimate for the change in the stock using the relation:

Appendix A. Description of STELLA II

78
Figure A.1 Euler’s Integration Scheme.

\[ Y_{t+1} = Y_t + \frac{\Delta t}{6} (k_{t1} + 2k_{t2} + 2k_{t3} + k_{t4}) \]

where the \( k \) values are estimated as follows:

\[ k_{t1} = f(t,Y_t) \]

Appendix A. Description of STELLA II
\[ k_{t2} = f\left( t + \frac{1}{2} \Delta t, \ Y_t + \frac{1}{2} \Delta t k_{t1} \right) \]

\[ k_{t3} = f\left( t + \frac{1}{2} \Delta t, \ Y_t + \frac{1}{2} \Delta t k_{t2} \right) \]

\[ k_{t4} = f(t + \Delta t, \ Y_t + \Delta t k_{t3}) \]

Fig A.2 illustrates the discrete points at which the RK-4 algorithm estimates the values of the rate variables.

Figure A.2 Fourth Order Runge Kutta Integration Scheme.

Appendix A. Description of STELLA II
Appendix B. Vehicle Model Causal Diagram
Appendix C. Vehicle Model Equations

\[ \text{ACCELERATION\_TIME}(t) = \text{ACCELERATION\_TIME}(t - dt) + (\text{ACCELERATION\_TIMER}) \times dt \]
\[ \text{INIT \ ACCELERATION\_TIME} = 0.0 \]
\[ \text{INFLOWS:} \]
\[ \text{ACCELERATION\_TIMER} = \text{IF (VELOCITY < CRUISE\_VELOCITY AND}
\text{DISTANCE\_TO\_TRAVEL > 0.5*TOTAL\_DISTANCE) THEN DT ELSE 0.0} \]

\[ \text{CRUISE\_TIME}(t) = \text{CRUISE\_TIME}(t - dt) + (\text{CRUISE\_TIMER}) \times dt \]
\[ \text{INIT \ CRUISE\_TIME} = 0.0 \]
\[ \text{INFLOWS:} \]
\[ \text{CRUISE\_TIMER} = \text{IF ACCL\_OR\_DEC\_DYN = 0 AND DISTANCE\_TO\_TRAVEL > 0 THEN DT ELSE 0.0} \]

\[ \text{DECELERATION\_TIME}(t) = \text{DECELERATION\_TIME}(t - dt) + (\text{DECELERATION\_TIMER}) \times dt \]
\[ \text{INIT \ DECELERATION\_TIME} = 0.0 \]
\[ \text{INFLOWS:} \]
\[ \text{DECELERATION\_TIMER} = \text{IF ACCL\_OR\_DEC\_DYN < 0 THEN DT ELSE 0.0} \]

\[ \text{DISTANCE\_TRAVELLED}(t) = \text{DISTANCE\_TRAVELLED}(t - dt) + (\text{SPEED}) \times dt \]
\[ \text{INIT \ DISTANCE\_TRAVELLED} = 0 \]
\[ \text{INFLOWS:} \]
\[ \text{SPEED} = \text{VELOCITY} \]

\[ \text{THRUST\_RATIO}(t) = \text{THRUST\_RATIO}(t - dt) + (\text{THRUST\_RATIO\_AT\_DT}) \times dt \]
\[ \text{INIT \ THRUST\_RATIO} = 0 \]
\[ \text{INFLOWS:} \]
\[ \text{THRUST\_RATIO\_AT\_DT} = \text{IF THRUST\_AVAILABLE = 0 THEN 0 ELSE}
\text{(EXCESS\_THRUST / THRUST\_AVAILABLE) - THRUST\_RATIO} \]

\[ \text{TOTAL\_POWER\_CONSUMED}(t) = \text{TOTAL\_POWER\_CONSUMED}(t - dt) +
(\text{POWER\_CONSUMPTION\_RTE}) \times dt \]
\[ \text{INIT \ TOTAL\_POWER\_CONSUMED} = 0 \]
\[ \text{INFLOWS:} \]
\[ \text{POWER\_CONSUMPTION\_RTE} = (\text{THRUST\_OUTP\_SPEED})/3600000 \]

\[ \text{VELOCITY}(t) = \text{VELOCITY}(t - dt) + (\text{ACCL\_OR\_DEC\_DYN}) \times dt \]
\[ \text{INIT \ VELOCITY} = 0 \]
\[ \text{INFLOWS:} \]
\[ \text{ACCL\_OR\_DEC\_DYN} = \text{IF (DISTANCE\_TO\_TRAVEL < BRAKING\_DISTANCE AND}
\text{DISTANCE\_TO\_TRAVEL > 0) THEN DECELERATION ELSE IF (DISTANCE\_TO\_TRAVEL}
\text{< 0 OR DISTANCE\_TO\_TRAVEL = 0) THEN 0 ELSE ACCELERATION\_OR\_CRUISE} \]

\[ \text{ACC\_EXCESS\_THRUST/MASS} \]
\[ \text{ACC\_AT\_CRUISE} = 0.0 \]
\[ \text{ACC\_OR\_CRUISE} = \text{IF (VELOCITY < CRUISE\_VELOCITY) then ACCELERATION}
\text{else (ACCELERATION\_AT\_CRUISE)} \]
\[ \text{BRAKING\_DISTANCE} = -(\text{SPEED}^2)/(2*DECELERATION) \]
\[ \text{CRUISE\_VELOCITY} = 90 \]
\[ \text{DECELERATION} = -0.785 \]
\[ \text{DISTANCE\_TO\_TRAVEL} = \text{TOTAL\_DISTANCE} - \text{DISTANCE\_TRAVELLED} \]
EXCESS_THRUST = IF (THRUST_AVAILABLE - TRACTIVE_RESISTANCE) ≥ 0 THEN
(THRUST_AVAILABLE - TRACTIVE_RESISTANCE) ELSE 0

MASS = 100000

THROTTLE_AT_ACCEL = 0.95

THROTTLE_AT_STOP = 0

THROTTLE_SETTING = IF ACCELERATION_TIMER = DT THEN THROTTLE_AT_ACCEL ELSE IF
DISTANCE_TRAVELLED ≥ TOTAL_DISTANCE THEN THROTTLE_AT_STOP ELSE
THRUFS_RATIO

THRUFS_AVAILALE = THRUST_OUTPUT*THROTTLE_SETTING

TOTAL_DISTANCE = 100000

TRACTIVE_RESISTANCE =
DRAG_DUE_TO_LINEAR_GENERATION+DRAG_DUE_TO_LATERAL_GUIDANCE+AERODYNAMIC
 DRAG

TRAVEL_TIME = IF (ACCELERATION_TIMER = 0 AND DECELERATION TIMER = 0 AND
CRUISE_TIMER = 0) THEN (CRUISE_TIME+DECELERATION_TIME+ACCELERATION_TIME)
ELSE 0

AERODYNAMIC_DRAG = GRAPH(SPEED)
(0.00, 0.00), (10.0, 2500), (20.0, 3750), (30.0, 5000), (40.0, 6500), (50.0, 9250), (60.0,
13500), (70.0, 18500), (80.0, 23500), (90.0, 28500), (100.0, 33500), (110.0, 38250), (120.0,
43250)

DRAG_DUE_TO_LATERAL_GUIDANCE = GRAPH(SPEED)
(0.00, 0.00), (10.0, 1425), (20.0, 2050), (30.0, 2475), (40.0, 2750), (50.0, 3000), (60.0,
3250), (70.0, 3500), (80.0, 3750), (90.0, 4000), (100.0, 4250), (110.0, 4500), (120.0, 4750)

DRAG_DUE_TO_LINEAR_GENERATION = GRAPH(SPEED)
(0.00, 250), (10.0, 9650), (20.0, 9750), (30.0, 9750), (40.0, 9650), (50.0, 7850), (60.0,
6500), (70.0, 5250), (80.0, 4250), (90.0, 3550), (100.0, 3050), (110.0, 2750), (120.0, 2500)

THRUST_OUTPUT = GRAPH(VELOCITY)
(0.00, 90000), (10.0, 90300), (20.0, 90300), (30.0, 90300), (40.0, 90300), (50.0,
90300), (60.0, 91000), (70.0, 93100), (80.0, 99400), (90.0, 112700), (100.0, 140000),
(110.0, 54550), (120.0, 0.00)
Appendix D. Economic Model Causal Diagram

Figure D.1 Causal Diagram of the Socioeconomic Submodel for Boston and Trip Generation Submodel for the Boston and New York City Pair.

Appendix D. Economic Model Causal Diagram
Figure D.2 Causal Diagram of the Socioeconomic Submodel for New York and Trip Generation Submodel for the Boston and Philadelphia City Pair.

Appendix D. Economic Model Causal Diagram
Figure D.3 Causal Diagram of the Socioeconomic Submodel for Philadelphia and Trip Generation Submodel for the Boston and Washington City Pair.

Appendix D. Economic Model Causal Diagram
Figure D.4 Causal Diagram of the Socioeconomic Submodel for Washington and Trip Generation Submodel for the Philadelphia and Washington City Pair.

Appendix D. Economic Model Causal Diagram.
Figure D.5 Causal Diagram of the Revenue and Maglev Frequency Submodels.

Appendix D. Economic Model Causal Diagram
Figure D.6 Causal Diagrams of the Guideway Capacity, Station Capacity and Additional Platform Cost Submodels.

Appendix D. Economic Model Causal Diagram
Figure D.7 Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the Boston and New York City Pair.

Appendix D. Economic Model Causal Diagram
Figure D.8 Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the Boston and Philadelphia City Pair.

Appendix D. Economic Model Causal Diagram
Figure D.9 Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the Boston and Washington City Pair.

Appendix D. Economic Model Causal Diagram
Figure D.10 Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the Philadelphia and Washington City Pair

Appendix D. Economic Model Causal Diagram
Figure D.11 Causal Diagram of the Vehicle Requirement Submodel.

Appendix D. Economic Model Causal Diagram
Figure D.12  Causal Diagram of the Additional Guideway Cost Submodel.

Appendix D. Economic Model Causal Diagram
Figure D.13 Causal Diagram of the Trip Generation Submodels for the New York and Philadelphia and the New York and Washington City Pair.

Appendix D. Economic Model Causal Diagram
Figure D.14 Causal Diagram of the Mode Split, Travel Time and Flight Frequency Submodels for the New York and Philadelphia City Pair.

Appendix D. Economic Model Causal Diagram
Figure D.15 Causal Diagrams of the Mode Split, Travel Time and Flight Frequency Submodels for the New York and Washington City Pair.

Appendix D. Economic Model Causal Diagram
Figure D.16 Causal Diagram of the Operations and Maintenance Costs Submodel.

Appendix D. Economic Model Causal Diagram
Figure D.17  Causal Diagram of the Capital Cost and Total Capital Spent Submodel.

Appendix D. Economic Model Causal Diagram
Appendix E. Economic Model Equations

\[ \text{ACCUMULATED}_O\_\text{AND}_M(t) = \text{ACCUMULATED}_O\_\text{AND}_M(t - dt) + \]
\[ (\text{ANNUAL}_O\_\text{AND}_M\_1980) \times dt \]
\[ \text{INIT ACCUMULATED}_O\_\text{AND}_M = 0 \]

\[ \text{INFLOWS:} \]
\[ \text{ANNUAL}_O\_\text{AND}_M\_1980 = \text{IF TIME} \geq 11 \text{ THEN (O AND M SUBTOTAL +}
\[ \text{ONCE IN TEN YEAR COST + ADMNSTN AND INSUR)}{(1 + (10/100))}^6 \text{ ELSE } 0 \]

\[ \text{CUMMULATIVE SALES}(t) = \text{CUMMULATIVE SALES}(t - dt) + (\text{YEARLY SALES}) \times dt \]
\[ \text{INIT CUMMULATIVE SALES} = 0 \]

\[ \text{INFLOWS:} \]
\[ \text{YEARLY SALES} = \text{MAG INCOME NYC WAS} + \text{MAG INCOME BOS NYC} +
\[ \text{MAG INCOME BOS PHL} + \text{MAG INCOME BOS WAS} + \text{MAG INCOME NYC PHL} +
\[ \text{MAG INCOME PHL WAS} \]

\[ \text{FLIGHTS DAILY BOS NYC}(t) = \text{FLIGHTS DAILY BOS NYC}(t - dt) +
\[ (\text{CHANGE IN FLIGHTS BOS NYC}) \times dt \]
\[ \text{INIT FLIGHTS DAILY BOS NYC} = 72 \]

\[ \text{INFLOWS:} \]
\[ \text{CHANGE IN FLIGHTS BOS NYC} =
\[ (\text{DAILY AIR TRIPS BOS NYC UTILIZED CAP AIR BOS NYC}) -
\[ \text{FLIGHTS DAILY BOS NYC} \]

\[ \text{FLIGHTS DAILY BOS PHL}(t) = \text{FLIGHTS DAILY BOS PHL}(t - dt) +
\[ (\text{CHANGE IN FLIGHTS BOS PHL}) \times dt \]
\[ \text{INIT FLIGHTS DAILY BOS PHL} = 3 \]

\[ \text{INFLOWS:} \]
\[ \text{CHANGE IN FLIGHTS BOS PHL} =
\[ (\text{DAILY AIR TRIPS BOS PHL UTILIZED CAP AIR BOS PHL}) -
\[ \text{FLIGHTS DAILY BOS PHL} \]

\[ \text{FLIGHTS DAILY BOS WAS}(t) = \text{FLIGHTS DAILY BOS WAS}(t - dt) +
\[ (\text{CHANGE IN FLIGHTS BOS WAS}) \times dt \]
\[ \text{INIT FLIGHTS DAILY BOS WAS} = 5 \]

\[ \text{INFLOWS:} \]
\[ \text{CHANGE IN FLIGHTS BOS WAS} =
\[ (\text{DAILY AIR TRIPS BOS WAS UTILIZED CAP AIR BOS WAS}) -
\[ \text{FLIGHTS DAILY BOS WAS} \]

\[ \text{FLIGHTS DAILY NYC PHL}(t) = \text{FLIGHTS DAILY NYC PHL}(t - dt) +
\[ (\text{CHANGE IN FLIGHTS NYC PHL}) \times dt \]
\[ \text{INIT FLIGHTS DAILY NYC PHL} = 8 \]

\[ \text{INFLOWS:} \]
\[ \text{CHANGE IN FLIGHTS NYC PHL} =
\[ (\text{DAILY AIR TRIPS NYC PHL UTILIZED CAP AIR NYC PHL}) -
\[ \text{FLIGHTS DAILY NYC PHL} \]

\[ \text{FLIGHTS DAILY NYC WAS}(t) = \text{FLIGHTS DAILY NYC WAS}(t - dt) +
\[ (\text{CHANGE IN FLIGHTS NYC WAS}) \times dt \]
\[ \text{INIT FLIGHTS DAILY NYC WAS} = 109 \]
Appendix E. Economic Model Equations

INFLOWS:

CHANGE_IN_FLIGHTS_NYC_WAS =
(DAILY_AIR_TRIPS_NYC_WAS/UTILIZED_CAP_AIR_NYC_WAS) -
FLIGHTS_DAILY_NYC_WAS

FLIGHTS_DAILY_PHL_WAS(t) = FLIGHTS_DAILY_PHL_WAS(t - dt) +
(CHANGE_IN_FLIGHTS_PHL_WAS) * dt
INIT FLIGHTS_DAILY_PHL_WAS = 3

INFLOWS:

CHANGE_IN_FLIGHTS_PHL_WAS =
(DAILY_AIR_TRIPS_PHL_WAS/UTILIZED_CAP_AIR_PHL_WAS) -
FLIGHTS_DAILY_PHL_WAS

INDUSTRY_VALUE_BOS(t) = INDUSTRY_VALUE_BOS(t - dt) + (NEW_INVESTMENT_BOS -
DEMOLITION_BOS) * dt
INIT INDUSTRY_VALUE_BOS = 17529.2*1000000

INFLOWS:

NEW_INVESTMENT_BOS =
(INDUSTRY_VALUE_BOS+OTHER_SOURCES_BOS)*INDUSTRY_FACTOR_BOS

OUTFLOWS:

DEMOLITION_BOS = INDUSTRY_VALUE_BOS*DEMOLITION_NORMAL_BOS

INDUSTRY_VALUE_NYC(t) = INDUSTRY_VALUE_NYC(t - dt) + (NEW_INVESTMENT_NYC -
DEMOLITION_NYC) * dt
INIT INDUSTRY_VALUE_NYC = 61547.9*1000000

INFLOWS:

NEW_INVESTMENT_NYC =
(INDUSTRY_VALUE_NYC+OTHER_SOURCES_NYC)*INDUSTRY_FACTOR_NYC

OUTFLOWS:

DEMOLITION_NYC = INDUSTRY_VALUE_NYC*DEMOLITION_NORMAL_NYC

INDUSTRY_VALUE_PHL(t) = INDUSTRY_VALUE_PHL(t - dt) + (NEW_INVESTMENT_PHL -
DEMOLITION_PHL) * dt
INIT INDUSTRY_VALUE_PHL = 21161.4*1000000

INFLOWS:

NEW_INVESTMENT_PHL =
(INDUSTRY_VALUE_PHL+OTHER_SOURCES_PHL)*INDUSTRY_FACTOR_PHL

OUTFLOWS:

DEMOLITION_PHL = INDUSTRY_VALUE_PHL*DEMOLITION_NORMAL_PHL

INDUSTRY_VALUE_WAS(t) = INDUSTRY_VALUE_WAS(t - dt) + (NEW_INVESTMENT_WAS -
DEMOLITION_WAS) * dt
INIT INDUSTRY_VALUE_WAS = 3191.6*1000000

INFLOWS:

NEW_INVESTMENT_WAS =
(INDUSTRY_VALUE_WAS+OTHER_SOURCES_WAS)*INDUSTRY_FACTOR_WAS

OUTFLOWS:

DEMOLITION_WAS = INDUSTRY_VALUE_WAS*DEMOLITION_NORMAL_WAS
MAG\_DAILY\_BOS\_NYC(t) = MAG\_DAILY\_BOS\_NYC(t \cdot dt) + 
(CHANGE\_IN\_MAG\_TRIPS\_BOS\_NYC) \cdot dt
INIT MAG\_DAILY\_BOS\_NYC = 0

INFLows:

\[ \text{CHANGE\_IN\_MAG\_TRIPS\_BOS\_NYC} = \]
(DAILY\_MAGLEV\_TRIPS\_BOS\_NYC\_UTILIZED\_CAP\_MAG\_BOS\_NYC) - MAG\_DAILY\_BOS\_NYC

MAG\_DAILY\_BOS\_PHL(t) = MAG\_DAILY\_BOS\_PHL(t \cdot dt) + 
(CHANGE\_IN\_MAG\_TRIPS\_BOS\_PHL) \cdot dt
INIT MAG\_DAILY\_BOS\_PHL = 0

INFLows:

\[ \text{CHANGE\_IN\_MAG\_TRIPS\_BOS\_PHL} = \]
(DAILY\_MAGLEV\_TRIPS\_BOS\_PHL\_UTILIZED\_CAP\_MAG\_BOS\_PHL) - MAG\_DAILY\_BOS\_PHL

MAG\_DAILY\_BOS\_WAS(t) = MAG\_DAILY\_BOS\_WAS(t \cdot dt) + 
(CHANGE\_IN\_MAG\_TRIPS\_BOS\_WAS) \cdot dt
INIT MAG\_DAILY\_BOS\_WAS = 0

INFLows:

\[ \text{CHANGE\_IN\_MAG\_TRIPS\_BOS\_WAS} = \]
(DAILY\_MAGLEV\_TRIPS\_BOS\_WAS\_UTILIZED\_CAP\_MAG\_BOS\_WAS) - MAG\_DAILY\_BOS\_WAS

MAG\_DAILY\_NYC\_PHL(t) = MAG\_DAILY\_NYC\_PHL(t \cdot dt) + 
(CHANGE\_IN\_MAG\_TRIPS\_NYC\_PHL) \cdot dt
INIT MAG\_DAILY\_NYC\_PHL = 0

INFLows:

\[ \text{CHANGE\_IN\_MAG\_TRIPS\_NYC\_PHL} = \]
(DAILY\_MAGLEV\_TRIPS\_NYC\_PHL\_UTILIZED\_CAP\_MAG\_NYC\_PHL) - MAG\_DAILY\_NYC\_PHL

MAG\_DAILY\_NYC\_WAS(t) = MAG\_DAILY\_NYC\_WAS(t \cdot dt) + 
(CHANGE\_IN\_MAG\_TRIPS\_NYC\_WAS) \cdot dt
INIT MAG\_DAILY\_NYC\_WAS = 0

INFLows:

\[ \text{CHANGE\_IN\_MAG\_TRIPS\_NYC\_WAS} = \]
(DAILY\_MAGLEV\_TRIPS\_NYC\_WAS\_UTILIZED\_CAP\_MAG\_NYC\_WAS) - MAG\_DAILY\_NYC\_WAS

MAG\_DAILY\_PHL\_WAS(t) = MAG\_DAILY\_PHL\_WAS(t \cdot dt) + 
(CHANGE\_IN\_MAG\_TRIPS\_PHL\_WAS) \cdot dt
INIT MAG\_DAILY\_PHL\_WAS = 0

INFLows:

\[ \text{CHANGE\_IN\_MAG\_TRIPS\_PHL\_WAS} = \]
(DAILY\_MAGLEV\_TRIPS\_PHL\_WAS\_UTILIZED\_CAP\_MAG\_PHL\_WAS) - MAG\_DAILY\_PHL\_WAS

Appendix E. Economic Model Equations
MAG_TRIPS_DAILY_BOS_NYC(t) = MAG_TRIPS_DAILY_BOS_NYC(t - dt) +
(CHANGE_DAILY_BOS_NYC) * dt
INIT MAG_TRIPS_DAILY_BOS_NYC = 0
INFLOWS:

CHANGE_DAILY_BOS_NYC = (MAG_ANNUAL_TRIPS_BOS_NYC/(365*200)) -
MAG_TRIPS_DAILY_BOS_NYC

MAG_TRIPS_DAILY_BOS_PHL(t) = MAG_TRIPS_DAILY_BOS_PHL(t - dt) +
(CHANGE_DAILY_BOS_PHL) * dt
INIT MAG_TRIPS_DAILY_BOS_PHL = 0
INFLOWS:

CHANGE_DAILY_BOS_PHL = ((MAG_ANNUAL_TRIPS_BOS_PHL)/(365*200)) -
MAG_TRIPS_DAILY_BOS_PHL

MAG_TRIPS_DAILY_BOS_WAS(t) = MAG_TRIPS_DAILY_BOS_WAS(t - dt) +
(CHANGE_DAILY_BOS_WAS) * dt
INIT MAG_TRIPS_DAILY_BOS_WAS = 0
INFLOWS:

CHANGE_DAILY_BOS_WAS = ((MAG_ANNUAL_TRIPS_BOS_WAS)/(365*200)) -
MAG_TRIPS_DAILY_BOS_WAS

MAG_TRIPS_DAILY_NYC_PHL(t) = MAG_TRIPS_DAILY_NYC_PHL(t - dt) +
(CHANGE_DAILY_NYC_PHL) * dt
INIT MAG_TRIPS_DAILY_NYC_PHL = 0
INFLOWS:

CHANGE_DAILY_NYC_PHL = ((MAG_ANNUAL_TRIPS_NYC_PHL)/(365*200)) -
MAG_TRIPS_DAILY_NYC_PHL

MAG_TRIPS_DAILY_NYC_WAS(t) = MAG_TRIPS_DAILY_NYC_WAS(t - dt) +
(CHANGE_DAILY_NYC_WAS) * dt
INIT MAG_TRIPS_DAILY_NYC_WAS = 0
INFLOWS:

CHANGE_DAILY_NYC_WAS = ((MAG_ANNUAL_TRIPS_NYC_WAS)/(365*200)) -
MAG_TRIPS_DAILY_NYC_WAS

MAG_TRIPS_DAILY_PHL_WAS(t) = MAG_TRIPS_DAILY_PHL_WAS(t - dt) +
(CHANGE_DAILY_PHL_WAS) * dt
INIT MAG_TRIPS_DAILY_PHL_WAS = 0
INFLOWS:

CHANGE_DAILY_PHL_WAS = ((MAG_ANNUAL_TRIPS_PHL_WAS)/(365*200)) -
MAG_TRIPS_DAILY_PHL_WAS

PER_CAPITA_INCOME_BOS(t) = PER_CAPITA_INCOME_BOS(t - dt) +
(CHANGE_IN_PCI_BOS) * dt
INIT PER_CAPITA_INCOME_BOS = 14297
INFLOWS:

CHANGE_IN_PCI_BOS = PCI_FACT_BOS*PER_CAPITA_INCOME_BOS

Appendix E. Economic Model Equations
PER_CAPITA_INCOME_NYC(t) = PER_CAPITA_INCOME_NYC(t - dt) +
(CHANGE_IN_PCI_NYC) * dt
INIT PER_CAPITA_INCOME_NYC = 11230
INFLOWS:
CHANGE_IN_PCI_NYC = PCI_FACT_NYC*PER_CAPITA_INCOME_NYC

PER_CAPITA_INCOME_PHL(t) = PER_CAPITA_INCOME_PHL(t - dt) +
(CHANGE_IN_PCI_PHL) * dt
INIT PER_CAPITA_INCOME_PHL = 12728
INFLOWS:
CHANGE_IN_PCI_PHL = PCI_FACT_PHL*PER_CAPITA_INCOME_PHL

PER_CAPITA_INCOME_WAS(t) = PER_CAPITA_INCOME_WAS(t - dt) +
(CHANGE_IN_PCI_WAS) * dt
INIT PER_CAPITA_INCOME_WAS = 13647
INFLOWS:
CHANGE_IN_PCI_WAS = PCI_FACT_WAS*PER_CAPITA_INCOME_WAS

POPULATION_BOS(t) = POPULATION_BOS(t - dt) + (GROWTH_BOS -
DECREASE_RATE_BOS) * dt
INIT POPULATION_BOS = 3662988
INFLOWS:
GROWTH_BOS = POPULATION_BOS*G_NORMAL_BOS*GROWTH_FACT_BOS

OUTFLOW:
DECREASE_RATE_BOS = POPULATION_BOS*D_NORMAL_BOS

POPULATION_NYC(t) = POPULATION_NYC(t - dt) + (GROWTH_NYC -
DECREASE_RATE_NYC) * dt
INIT POPULATION_NYC = 17412203
INFLOWS:
GROWTH_NYC = POPULATION_NYC*G_NORMAL_NYC*GROWTH_FACT_NYC

OUTFLOW:
DECREASE_RATE_NYC = POPULATION_NYC*D_NORMAL_NYC

POPULATION_PHL(t) = POPULATION_PHL(t - dt) + (GROWTH_PHL -
DECREASE_RATE_PHL) * dt
INIT POPULATION_PHL = 5680509
INFLOWS:
GROWTH_PHL = POPULATION_PHL*G_NORMAL_PHL*GROWTH_FACT_PHL

OUTFLOW:
DECREASE_RATE_PHL = POPULATION_PHL*D_NORMAL_PHL

POPULATION_WAS(t) = POPULATION_WAS(t - dt) + (GROWTH_WAS -
DECREASE_RATE_WAS) * dt
INIT POPULATION_WAS = 3250489
INFLOWS:
GROWTH_WAS = POPULATION_WAS*G_NORMAL_WAS*GROWTH_FACT_WAS

OUTFLOW:
DECREASE_RATE_WAS = POPULATION_WAS*D_NORMAL_WAS

Appendix E. Economic Model Equations
TOTAL_ANNUAL_MAGLEV_PAX(t) = TOTAL_ANNUAL_MAGLEV_PAX(t - dt) +
(CHANGE_MAG_PAX) * dt

INIT TOTAL_ANNUAL_MAGLEV_PAX = 1

INFLOWS:

CHANGE_MAG_PAX = (MAG_ANNUAL_TRIPS_BOS_PHL +
MAG_ANNUAL_TRIPS_BOS_NYC + MAG_ANNUAL_TRIPS_NYC_WAS +
MAG_ANNUAL_TRIPS_BOS_WAS + MAG_ANNUAL_TRIPS_NYC_PHL +
MAG_ANNUAL_TRIPS_PHL_WAS) - TOTAL_ANNUAL_MAGLEV_PAX

ACCELERATION_RATE = 0.6

ADDITIONALGUIDEWAY_COST =
SUM(GUIDEWAY_COST_NYC_PHL,GUIDEWAY_COST_PHL_WAS,GUIDEWAY_COST_BOS_NYC)

ADMINSTN_AND_INSUR = O_AND_M_SUBTOTAL*0.1

AIR_ACCESS_EGRESSTIME_BOS_NYC = 75
AIR_ACCESS_EGRESSTIME_BOS_PHL = 60
AIR_ACCESS_EGRESSTIME_BOS_WAS = 85
AIR_ACCESS_EGRESSTIME_NYC_PHL = 75
AIR_ACCESS_EGRESSTIME_NYC_WAS = 85
AIR_ACCESS_EGRESSTIME_PHL_WAS = 70

AIR_ANNUAL_TRIPS_BOS_NYC = TG_TRIPS_BOS_NYC*AIR_PROB_BOS_NYC
AIR_ANNUAL_TRIPS_BOS_PHL = TG_TRIPS_BOS_PHL*AIR_PROB_BOS_PHL
AIR_ANNUAL_TRIPS_BOS_WAS = TG_TRIPS_BOS_WAS*AIR_PROB_BOS_WAS
AIR_ANNUAL_TRIPS_NYC_PHL = AIR_PROB_NYC_PHL*TG_TRIPS_NYC_PHL
AIR_ANNUAL_TRIPS_NYC_WAS = TG_TRIPS_NYC_WAS*AIR_PROB_NYC_WAS
AIR_ANNUAL_TRIPS_PHL_WAS = TG_TRIPS_PHL_WAS*AIR_PROB_PHL_WAS

AIR_CHOICE_EXP_BOS_NYC = EXP(AIR_CHOICE_FUNCTION_BOS_NYC)
AIR_CHOICE_EXP_BOS_PHL = EXP(AIR_CHOICE_FUNCTION_BOS_PHL)
AIR_CHOICE_EXP_BOS_WAS = EXP(AIR_CHOICE_FUNCTION_BOS_WAS)
AIR_CHOICE_EXP_NYC_PHL = EXP(AIR_CHOICE_FUNCTION_NYC_PHL)
AIR_CHOICE_EXP_NYC_WAS = EXP(AIR_CHOICE_FUNCTION_NYC_WAS)
AIR_CHOICE_EXP_PHL_WAS = EXP(AIR_CHOICE_FUNCTION_PHL_WAS)

AIR_CHOICE_FUNCTION_BOS_NYC =
(TOTAL_TT_AIR_BOS_NYC*AIR_TT_ALPHA_BOS_NYC)+(FLIGHT_FREQ_BOS_NYC*AIR_FRE
EQ_BETA_BOS_NYC)+(AIR_FARE_BOS_NYC*AIR_FARE_ALPHA_BOS_NYC)

AIR_CHOICE_FUNCTION_BOS_PHL =
(TOTAL_TT_AIR_BOS_PHL*AIR_TT_ALPHA_BOS_PHL)+(FLIGHT_FREQ_BOS_PHL*AIR_FRE
EQ_BETA_BOS_PHL)+(AIR_FARE_BOS_PHL*AIR_FARE_ALPHA_BOS_PHL)

AIR_CHOICE_FUNCTION_BOS_WAS =
(TOTAL_TT_AIR_BOS_WAS*AIR_TT_ALPHA_BOS_WAS)+(FLIGHT_FREQ_BOS_WAS*AIR_ FRE
Q_BETA_BOS_WAS)+(AIR_FARE_BOS_WAS*AIR_FARE_ALPHA_BOS_WAS)

AIR_CHOICE_FUNCTION_NYC_PHL =
(TOTAL_TT_AIR_NYC_PHL*AIR_TT_ALPHA_NYC_PHL)+(FLIGHT_FREQ_NYC_PHL*AIR_FRE
Q_BETA_NYC_PHL)+(AIR_FARE_NYC_PHL*AIR_FARE_ALPHA_NYC_PHL)

Appendix E. Economic Model Equations
\[
\text{AIR \_CHOICE \_FUNCTION \_NYC \_WAS} = (\text{TOTAL \_TT \_AIR \_NYC \_WAS} \times \text{AIR \_TT \_ALPHA \_NYC \_WAS}) + (\text{FLIGHT \_FREQ \_NYC \_WAS} \times \text{AIR \_FREQ \_BETA \_NYC \_WAS}) + (\text{AIR \_FARE \_NYC \_WAS} \times \text{AIR \_FARE \_ALPHA \_NYC \_WAS})
\]

\[
\text{AIR \_CHOICE \_FUNCTION \_PHL \_WAS} = (\text{TOTAL \_TT \_AIR \_PHL \_WAS} \times \text{AIR \_TT \_ALPHA \_PHL \_WAS}) + (\text{FLIGHT \_FREQ \_PHL \_WAS} \times \text{AIR \_FREQ \_BETA \_PHL \_WAS}) + (\text{AIR \_FARE \_PHL \_WAS} \times \text{AIR \_FARE \_ALPHA \_PHL \_WAS})
\]

\[
\text{AIR \_FARE \_ALPHA \_BOS \_NYC} = -0.05
\]

\[
\text{AIR \_FARE \_ALPHA \_BOS \_PHL} = -0.05
\]

\[
\text{AIR \_FARE \_ALPHA \_BOS \_WAS} = -0.05
\]

\[
\text{AIR \_FARE \_ALPHA \_NYC \_PHL} = -0.05
\]

\[
\text{AIR \_FARE \_ALPHA \_NYC \_WAS} = -0.05
\]

\[
\text{AIR \_FARE \_ALPHA \_PHL \_WAS} = -0.05
\]

\[
\text{AIR \_FARE \_BOS \_NYC} = 43.8
\]

\[
\text{AIR \_FARE \_BOS \_PHL} = 52.6
\]

\[
\text{AIR \_FARE \_BOS \_WAS} = 52.6
\]

\[
\text{AIR \_FARE \_NYC \_PHL} = 28
\]

\[
\text{AIR \_FARE \_NYC \_WAS} = 31.54
\]

\[
\text{AIR \_FARE \_PHL \_WAS} = 45.6
\]

\[
\text{AIR \_FREQ \_BETA \_BOS \_NYC} = 0.0025
\]

\[
\text{AIR \_FREQ \_BETA \_BOS \_PHL} = 0.0025
\]

\[
\text{AIR \_FREQ \_BETA \_BOS \_WAS} = 0.0025
\]

\[
\text{AIR \_FREQ \_BETA \_NYC \_PHL} = 0.0025
\]

\[
\text{AIR \_FREQ \_BETA \_NYC \_WAS} = 0.0025
\]

\[
\text{AIR \_FREQ \_BETA \_PHL \_WAS} = 0.0025
\]

\[
\text{AIR \_PAX \_CAP \_BOS \_NYC} = 90
\]

\[
\text{AIR \_PAX \_CAP \_BOS \_PHL} = 90
\]

\[
\text{AIR \_PAX \_CAP \_BOS \_WAS} = 90
\]

\[
\text{AIR \_PAX \_CAP \_NYC \_PHL} = 90
\]

\[
\text{AIR \_PAX \_CAP \_NYC \_WAS} = 90
\]

\[
\text{AIR \_PAX \_CAP \_PHL \_WAS} = 90
\]

\[
\text{AIR \_PROB \_BOS \_NYC} = \frac{\text{AIR \_CHOICE \_EXP \_BOS \_NYC}}{\text{SUM \_OF \_MODE \_BOS \_NYC}}
\]

\[
\text{AIR \_PROB \_BOS \_PHL} = \frac{\text{AIR \_CHOICE \_EXP \_BOS \_PHL}}{\text{SUM \_OF \_MODE \_BOS \_PHL}}
\]

\[
\text{AIR \_PROB \_BOS \_WAS} = \frac{\text{AIR \_CHOICE \_EXP \_BOS \_WAS}}{\text{SUM \_OF \_MODE \_BOS \_WAS}}
\]

\[
\text{AIR \_PROB \_NYC \_PHL} = \frac{\text{AIR \_CHOICE \_EXP \_NYC \_PHL}}{\text{SUM \_OF \_MODE \_NYC \_PHL}}
\]

\[
\text{AIR \_PROB \_NYC \_WAS} = \frac{\text{AIR \_CHOICE \_EXP \_NYC \_WAS}}{\text{SUM \_OF \_MODE \_NYC \_WAS}}
\]

\[
\text{AIR \_PROB \_PHL \_WAS} = \frac{\text{AIR \_CHOICE \_EXP \_PHL \_WAS}}{\text{SUM \_OF \_MODE \_PHL \_WAS}}
\]

\[
\text{AIR \_STOP \_TIME \_BOS \_NYC} = 0
\]

\[
\text{AIR \_STOP \_TIME \_BOS \_PHL} = 0
\]

\[
\text{AIR \_STOP \_TIME \_BOS \_WAS} = 0
\]

\[
\text{AIR \_STOP \_TIME \_NYC \_PHL} = 0
\]

\[
\text{AIR \_STOP \_TIME \_NYC \_WAS} = 0
\]

\[
\text{AIR \_STOP \_TIME \_PHL \_WAS} = 0
\]

\[
\text{AIR \_TT \_ALPHA \_BOS \_NYC} = -0.10
\]

Appendix E. Economic Model Equations

107
AIR_TT_ALPHA_BOS_PHL = -0.10
AIR_TT_ALPHA_BOS_WAS = -0.10
AIR_TT_ALPHA_NYC_PHL = -0.10
AIR_TT_ALPHA_NYC_WAS = -0.10
AIR_TT_ALPHA_PHL_WAS = -0.10
AIR_UTILIZATION_FACT_BOS_NYC = 0.60
AIR_UTILIZATION_FACT_BOS_PHL = 0.60
AIR_UTILIZATION_FACT_BOS_WAS = 0.60
AIR_UTILIZATION_FACT_NYC_PHL = 0.60
AIR_UTILIZATION_FACT_NYC_WAS = 0.60
AIR_UTILIZATION_FACT_PHL_WAS = 0.60
BEST_CT_BOS_NYC = 17.55
BEST_CT_BOS_PHL = 17.55
BEST_CT_BOS_WAS = 21
BEST_CT_NYC_PHL = 12.26
BEST_CT_NYC_WAS = 17.55
BEST_CT_PHL_WAS = 14
BEST_TIME_BOS_NYC = IF MAG_PROB_BOS_NYC = 0 THEN TOTAL_TT_AIR_BOS_NYC ELSE IF TOTAL_TT_AIR_BOS_NYC > TOTAL_TT_MAG_BOS_NYC THEN TOTAL_TT_MAG_BOS_NYC ELSE TOTAL_TT_AIR_BOS_NYC
BEST_TIME_BOS_PHL = IF MAG_PROB_BOS_PHL = 0 THEN TOTAL_TT_AIR_BOS_PHL ELSE IF TOTAL_TT_AIR_BOS_PHL > TOTAL_TT_MAG_BOS_PHL THEN TOTAL_TT_MAG_BOS_PHL ELSE TOTAL_TT_AIR_BOS_PHL
BEST_TIME_BOS_WAS = IF MAG_PROB_BOS_WAS = 0 THEN TOTAL_TT_AIR_BOS_WAS ELSE IF TOTAL_TT_AIR_BOS_WAS > TOTAL_TT_MAG_BOS_WAS THEN TOTAL_TT_MAG_BOS_WAS ELSE TOTAL_TT_AIR_BOS_WAS
BEST_TIME_NYC_PHL = IF MAG_PROB_NYC_PHL = 0 THEN TOTAL_TT_AIR_NYC_PHL ELSE IF TOTAL_TT_AIR_NYC_PHL > TOTAL_TT_MAG_NYC_PHL THEN TOTAL_TT_MAG_NYC_PHL ELSE TOTAL_TT_AIR_NYC_PHL
BEST_TIME_NYC_WAS = IF MAG_PROB_NYC_WAS = 0 THEN TOTAL_TT_AIR_NYC_WAS ELSE IF TOTAL_TT_AIR_NYC_WAS > TOTAL_TT_MAG_NYC_WAS THEN TOTAL_TT_MAG_NYC_WAS ELSE TOTAL_TT_AIR_NYC_WAS
BEST_TIME_PHL_WAS = IF MAG_PROB_PHL_WAS = 0 THEN TOTAL_TT_AIR_PHL_WAS ELSE IF TOTAL_TT_AIR_PHL_WAS > TOTAL_TT_MAG_PHL_WAS THEN TOTAL_TT_MAG_PHL_WAS ELSE TOTAL_TT_AIR_PHL_WAS
CAPITAL_COST = IF TIME >= 11 THEN (CAPITAL_COST_SUBTOTAL + TOTAL_PLATFORM_COST + ADDITIONAL_GUIDEWAY_COST + ENGNR_AND_ADMINST + (COST_PER_VEHICLE * NUMBER_OF_VEHICLES)) ELSE 0
CAPITAL_COST_SUBTOTAL = ((ROW_COST_PER_MILE+ELEVATED_GUIDEWAY_PER_MILE+ELECTRIFICATION_PER_MILE)* TOTAL_DISTANCE)+(NUMBER_OF_STATIONS*COST_PER_STATION)
CAPITAL_SPENT = (ACCUMULATED_O_AND_M+CAPITAL_COST)
CLEANING_U_C = 141740

Appendix E. Economic Model Equations
COMPLETE_MAINT_U_C = PULSE(235650.15, 4)
CONTINGENCY = 2.39
COST_PER_STATION = 2483685
COST_PER_VEHICLE = 10499215
DAILY_AIR_TRIPS_BOS_NYC = AIR_ANNUAL_TRIPS_BOS_NYC/365
DAILY_AIR_TRIPS_BOS_PHL = AIR_ANNUAL_TRIPS_BOS_PHL/365
DAILY_AIR_TRIPS_BOS_WAS = AIR_ANNUAL_TRIPS_BOS_WAS/365
DAILY_AIR_TRIPS_NYC_PHL = AIR_ANNUAL_TRIPS_NYC_PHL/365
DAILY_AIR_TRIPS_NYC_WAS = AIR_ANNUAL_TRIPS_NYC_WAS/365
DAILY_AIR_TRIPS_PHL_WAS = AIR_ANNUAL_TRIPS_PHL_WAS/365
DAILY_MAGLEV_TRIPS_BOS_NYC = MAG_ANNUAL_TRIPS_BOS_NYC/365
DAILY_MAGLEV_TRIPS_BOS_PHL = MAG_ANNUAL_TRIPS_BOS_PHL/365
DAILY_MAGLEV_TRIPS_BOS_WAS = MAG_ANNUAL_TRIPS_BOS_WAS/365
DAILY_MAGLEV_TRIPS_NYC_PHL = MAG_ANNUAL_TRIPS_NYC_PHL/365
DAILY_MAGLEV_TRIPS_NYC_WAS = MAG_ANNUAL_TRIPS_NYC_WAS/365
DAILY_MAGLEV_TRIPS_PHL_WAS = MAG_ANNUAL_TRIPS_PHL_WAS/365
DEMOLITION_NORMAL_BOS = 0.064
DEMOLITION_NORMAL_NYC = 0.048
DEMOLITION_NORMAL_PHL = 0.065
DEMOLITION_NORMAL_WAS = 0.048
DIST_BOS_NYC = 349
DIST_NYC_PHL = 143
DIST_PHL_WAS = 227
D_NORMAL_BOS = 0.01
D_NORMAL_NYC = 0.097
D_NORMAL_PHL = 0.01
D_NORMAL_WAS = 0.0064
ELECTRIFICATION_PER_MILE = 1241842
ELEVATED_GUIDEWAY_PER_MILE = 2111132
EMPLOYEES_PER_HOUSE_BOS = 1.5
EMPLOYEES_PER_HOUSE_NYC = 1.5
EMPLOYEES_PER_HOUSE_PHL = 0.7
EMPLOYEES_PER_HOUSE_WAS = 1.7
ENGJR_AND_ADMINST = CAPITAL_COST_SUBTOTAL*0.1
FACILITY_MAINTENANCE =
(UNIT_COST_TRACK_GUIDEWAY+UNIT_COST_SIGNALS_COMMUNICATION+UNIT_COST_MAINT_ELECTRIFICATION+UNIT_COST_OTHER_FACILITIES+TRAFFIC_CONTROL_U_C)*TOTAL_DISTANCE
FACILITY_OPERATION_U_C = 130400
FLIGHT_FREQ_BOS_NYC = FLIGHTS_DAILY_BOS_NYC*7
FLIGHT_FREQ_BOS_PHL = FLIGHTS_DAILY_BOS_PHL*7
FLIGHT_FREQ_BOS_WAS = FLIGHTS_DAILY_BOS_WAS*7
FLIGHT_FREQ_NYC_PHL = FLIGHTS_DAILY_NYC_PHL*7

Appendix E. Economic Model Equations
FLIGHT_FREQ_NYC_WAS = FLIGHTS_DAILY_NYC_WAS
FLIGHT_FREQ_PHL_WAS = FLIGHTS_DAILY_PHL_WAS
FLYING_TIME_BOS_NYC = 70
FLYING_TIME_BOS_PHL = 75
FLYING_TIME_BOS_WAS = 90
FLYING_TIME_NYC_PHL = 55
FLYING_TIME_NYC_WAS = 75
FLYING_TIME_PHL_WAS = 55
FM_CT_BOS_NYC = 43.8
FM_CT_BOS_PHL = 52.6
FM_CT_BOS_WAS = 52.6
FM_CT_NYC_PHL = 28
FM_CT_NYC_WAS = 31.54
FM_CT_PHL_WAS = 45.6
FREQ_BOS_NYC = (MAG_TRIPS_DAILY_BOS_NYC + MAG_TRIPS_DAILY_BOS_PHL + MAG_TRIPS_DAILY_BOS_WAS) * 7
FREQ_BOS_PHL = (MAG_TRIPS_DAILY_BOS_PHL + MAG_TRIPS_DAILY_BOS_WAS) * 7
FREQ_BOS_WAS = MAG_TRIPS_DAILY_BOS_WAS * 7
FREQ_NYC_PHL = (MAG_TRIPS_DAILY_BOS_WAS + MAG_TRIPS_DAILY_NYC_PHL + MAG_TRIPS_DAILY_NYC_WAS + MAG_TRIPS_DAILY_BOS_PHL) * 7
FREQ_NYC_WAS = (MAG_TRIPS_DAILY_NYC_WAS + MAG_TRIPS_DAILY_BOS_WAS) * 7
FREQ_PHL_WAS = (MAG_TRIPS_DAILY_BOS_WAS + MAG_TRIPS_DAILY_PHL_WAS + MAG_TRIPS_DAILY_NYC_WAS) * 7
GUIDEWAY_CAPACITY = ((3600 * 17) / (((NUMBER_OF_VEH_PER_TRAIN * LENGTH_OF_MAGLEV) + LENGTH_FOR_BRAKE_VAR) / VELOCITY_MAGLEV) + REACTION_TIME + (VELOCITY_MAGLEV / (2 * NORMAL_BRAKE_FORCE))))
GUIDEWAYS_BOS_NYC = ROUND(0.5 + ((FREQ_BOS_NYC / 7) / GUIDEWAY_CAPACITY))
GUIDEWAY_COST_BOS_NYC = IF GUIDEWAYS_BOS_NYC > 1 THEN ((GUIDEWAYS_BOS_NYC - 1) * NEW_GUIDEWAY_UC * DIST_BOS_NYC) ELSE 0
GUIDEWAY_COST_NYC_PHL = IF GUIDEWAY_NYC_PHL > 1 THEN ((GUIDEWAY_NYC_PHL - 1) * NEW_GUIDEWAY_UC * DIST_NYC_PHL) ELSE 0
GUIDEWAY_COST_PHL_WAS = IF GUIDEWAY_PHL_WAS > 1 THEN ((GUIDEWAY_PHL_WAS - 1) * NEW_GUIDEWAY_UC * DIST_PHL_WAS) ELSE 0
GUIDEWAY_NYC_PHL = ROUND(0.5 + ((FREQ_NYC_PHL / 7) / GUIDEWAY_CAPACITY))
GUIDEWAY_PHL_WAS = ROUND(0.5 + ((FREQ_PHL_WAS / 7) / GUIDEWAY_CAPACITY))
G_NORMAL_BOS = 0.01222
G_NORMAL_NYC = 0.122229
G_NORMAL_PHL = 0.0148
G_NORMAL_WAS = 0.02
HOUSE_SIZE_BOS = 2.73
HOUSE_SIZE_NYC = 2.73
HOUSE_SIZE_PHL = 2.91

Appendix E. Economic Model Equations
HOUSE_SIZE_WAS = 2.71
JOB_MFG_BOS = INDUSTRY_VALUE_BOS/JOB_VALUE_RATIO_BOS
JOB_MFG_NYC = INDUSTRY_VALUE_NYC/JOB_VALUE_RATIO_NYC
JOB_MFG_PHL = INDUSTRY_VALUE_PHL/JOB_VALUE_RATIO_PHL
JOB_MFG_WAS = INDUSTRY_VALUE_WAS/JOB_VALUE_RATIO_WAS
JOB_VALUE_RATIO_BOS = 43400
JOB_VALUE_RATIO_NYC = 39970
JOB_VALUE_RATIO_PHL = 41130
JOB_VALUE_RATIO_WAS = 43000
LENGTH_FOR BRAKE_VAR = 100
LENGTH_OF_MAGLEV = 54
MAG_ACCESS_EGRESS.TIME_BOS_NYC = 75
MAG_ACCESS_EGRESS.TIME_BOS_PHL = 60
MAG_ACCESS_EGRESS.TIME_BOS_WAS = 85
MAG_ACCESS_EGRESS.TIME_NYC_PHL = 75
MAG_ACCESS_EGRESS.TIME_NYC_WAS = 85
MAG_ACCESS_EGRESS.TIME_PHL_WAS = 70
MAG_ANNUAL_TRIPS_BOS_NYC = TG_TRIPS_BOS_NYC*MAG_PROB_BOS_NYC
MAG_ANNUAL_TRIPS_BOS_PHL = TG_TRIPS_BOS_PHL*MAG_PROB_BOS_PHL
MAG_ANNUAL_TRIPS_BOS_WAS = TG_TRIPS_BOS_WAS*MAG_PROB_BOS_WAS
MAG_ANNUAL_TRIPS_NYC_PHL = TG_TRIPS_NYC_PHL*MAG_PROB_NYC_PHL
MAG_ANNUAL_TRIPS_NYC_WAS = MAG_PROB_NYC_WAS*TG_TRIPS_NYC_WAS
MAG_ANNUAL_TRIPS_PHL_WAS = TG_TRIPS_PHL_WAS*MAG_PROB_PHL_WAS
MAG_CHOICE_EXP_BOS_NYC =
MAG_CONTROL_BOS_NYC*EXP(MAG_CHOICE_FUNCT_BOS_NYC)
MAG_CHOICE_EXP_BOS_PHL =
MAG_CONTROL_BOS_PHL*EXP(MAG_CHOICE_FUNCT_BOS_PHL)
MAG_CHOICE_EXP_BOS_WAS =
MAG_CONTROL_BOS_WAS*EXP(MAG_CHOICE_FUNCT_BOS_WAS)
MAG_CHOICE_EXP_NYC_PHL =
MAG_CONTROL_NYC_PHL*EXP(MAG_CHOICE_FUNCT_NYC_PHL)
MAG_CHOICE_EXP_NYC_WAS =
MAG_CONTROL_NYC_WAS*EXP(MAG_CHOICE_FUNCT_NYC_WAS)
MAG_CHOICE_EXP_PHL_WAS =
MAG_CONTROL_PHL_WAS*EXP(MAG_CHOICE_FUNCT_PHL_WAS)
MAG_CHOICE_FUNCT_BOS_PHL =
(TOTAL_TT_MAG_BOS_PHL*MAG_TT_ALPHA_BOS_PHL)*(FREQ_BOS_PHL*MAG_FREQ_BEA_TA_BOS_PHL)+(MAG_FARE_BOS_PHL*MAG_FARE_ALPHA_BOS_PHL)
MAG_CHOICE_FUNCT_BOS_PHL =
(TOTAL_TT_MAG_BOS_PHL*MAG_TT_ALPHA_BOS_PHL)*(FREQ_BOS_PHL*MAG_FREQ_BEA_TA_BOS_PHL)+(MAG_FARE_BOS_PHL*MAG_FARE_ALPHA_BOS_PHL)
Appendix E. Economic Model Equations

○ MAG_CHOICE_FUNCNT_BOS_WAS = 
  (TOTAL_TT_MAG_BOS_WAS*FREQ_BOS_WAS*MAG_FREQ_BETA_BOS_WAS) + (MAG_FARE_BOS_WAS*MAG_FARE_ALPHA_BOS_WAS) 

○ MAG_CHOICE_FUNCNT_NYC_PHL = 
  (TOTAL_TT_MAG_NYC_PHL*MAG_FREQ_BETA_NYC_PHL) + (TOTAL_TT_MAG_BOS_WAS*MAG_FREQ_BETA_BOS_WAS) + (MAG_FARE_NYC_PHL*MAG_FARE_ALPHA_NYC_PHL) 

○ MAG_CHOICE_FUNCNT_NYC_WAS = 
  (TOTAL_TT_MAG_BOS_WAS*MAG_FREQ_BETA_BOS_WAS) + (TOTAL_TT_MAG_NYC_PHL*MAG_FREQ_BETA_NYC_PHL) + (MAG_FARE_NYC_WAS*MAG_FARE_ALPHA_NYC_WAS) 

○ MAG_CHOICE_FUNCNT_PHL_WAS = 
  (TOTAL_TT_MAG_PHL_WAS*MAG_FREQ_BETA_PHL_WAS) + (TOTAL_TT_MAG_PHL_WAS*MAG_FREQ_BETA_PHL_WAS) + (TOTAL_TT_MAG_BOS_WAS*MAG_FREQ_BETA_BOS_WAS) + (TOTAL_TT_MAG_NYC_PHL*MAG_FREQ_BETA_NYC_PHL) + (TOTAL_TT_MAG_PHL_WAS*MAG_FREQ_BETA_PHL_WAS) + (TOTAL_TT_MAG_BOS_WAS*MAG_FREQ_BETA_BOS_WAS) + (TOTAL_TT_MAG_NYC_PHL*MAG_FREQ_BETA_NYC_PHL) + (TOTAL_TT_MAG_PHL_WAS*MAG_FREQ_BETA_PHL_WAS) 

○ MAG_FARE_ALPHA_BOS_NYC = -0.05
○ MAG_FARE_ALPHA_BOS_PHL = -0.05
○ MAG_FARE_ALPHA_BOS_WAS = -0.05
○ MAG_FARE_ALPHA_NYC_PHL = -0.05
○ MAG_FARE_ALPHA_NYC_WAS = -0.05
○ MAG_FARE_ALPHA_PHL_WAS = -0.05
○ MAG_FARE_BOS_NYC = 43.8
○ MAG_FARE_BOS_PHL = 52.6
○ MAG_FARE_BOS_WAS = 52.6
○ MAG_FARE_NYC_PHL = 28
○ MAG_FARE_NYC_WAS = 31.54
○ MAG_FARE_PHL_WAS = 45.8
○ MAG_FREQ_BETA_BOS_NYC = 0.0025
○ MAG_FREQ_BETA_BOS_PHL = 0.0025
○ MAG_FREQ_BETA_BOS_WAS = 0.0025
○ MAG_FREQ_BETA_NYC_PHL = 0.0025
○ MAG_FREQ_BETA_NYC_WAS = 0.0025
○ MAG_FREQ_BETA_PHL_WAS = 0.0025
○ MAG_INCOME_BOS_NYC = MAG_ANNUAL_TRIPS_BOS_NYC*MAG_FARE_BOS_NYC
○ MAG_INCOME_BOS_PHL = MAG_ANNUAL_TRIPS_BOS_PHL*MAG_FARE_BOS_PHL
○ MAG_INCOME_BOS_WAS = MAG_ANNUAL_TRIPS_BOS_WAS*MAG_FARE_BOS_WAS
○ MAG_INCOME_NYC_PHL = MAG_ANNUAL_TRIPS_NYC_PHL*MAG_FARE_NYC_PHL
○ MAG_INCOME_NYC_WAS = MAG_ANNUAL_TRIPS_NYC_WAS*MAG_FARE_NYC_WAS
○ MAG_INCOME_PHL_WAS = MAG_ANNUAL_TRIPS_PHL_WAS*MAG_FARE_PHL_WAS
○ MAG_PAX_CAP_BOS_NYC = 200
○ MAG_PAX_CAP_BOS_PHL = 200
○ MAG_PAX_CAP_BOS_WAS = 200
○ MAG_PAX_CAP_NYC_PHL = 200
○ MAG_PAX_CAP_NYC_WAS = 200
○ MAG_PAX_CAP_PHL_WAS = 200
○ MAG_PROB_BOS_NYC = MAG_CHOICE_EXP_BOS_NYC/SUM_OF_MODE_BOS_NYC
MAG_PROB_BOS_PHL = MAG_CHOICE_EXP_BOS_PHL/SUM_OF_MODE_BOS_PHL
MAG_PROB_BOS_WAS = MAG_CHOICE_EXP_BOS_WAS/SUM_OF_MODE_BOS_WAS
MAG_PROB_NYC_PHL = MAG_CHOICE_EXP_NYC_PHL/SUM_OF_MODE_NYC_PHL
MAG_PROB_NYC_WAS = MAG_CHOICE_EXP_NYC_WAS/SUM_OF_MODE_NYC_WAS
MAG_PROB_PHL_WAS = MAG_CHOICE_EXP_PHL_WAS/SUM_OF_MODE_PHL_WAS
MAG_RUN_TIME_BOS_NYC = 66.25
MAG_RUN_TIME_BOS_PHL = 94.4
MAG_RUN_TIME_BOS_WAS = 138.1
MAG_RUN_TIME_NYC_PHL = 28.2
MAG_RUN_TIME_NYC_WAS = 71.8
MAG_RUN_TIME_PHL_WAS = 43.7
MAG_STOP_TIME_BOS_NYC = 0
MAG_STOP_TIME_BOS_PHL = 15
MAG_STOP_TIME_BOS_WAS = 30
MAG_STOP_TIME_NYC_PHL = 0
MAG_STOP_TIME_NYC_WAS = 15
MAG_STOP_TIME_PHL_WAS = 0
MAG_TT_ALPHA_BOS_NYC = -0.10
MAG_TT_ALPHA_BOS_PHL = -0.10
MAG_TT_ALPHA_BOS_WAS = -0.10
MAG_TT_ALPHA_NYC_PHL = -0.10
MAG_TT_ALPHA_NYC_WAS = -0.10
MAG_TT_ALPHA_PHL_WAS = -0.10
MAG_TT_BOS_NYC = MAG_DELAY_BOS_NYC + MAG_RUN_TIME_BOS_NYC + MAG_STOP_TIME_BOS_NYC
MAG_TT_BOS_PHL = MAG_STOP_TIME_BOS_PHL + MAG_DELAY_BOS_PHL + MAG_RUN_TIME_BOS_PHL
MAG_TT_BOS_WAS = MAG_DELAY_BOS_WAS + MAG_STOP_TIME_BOS_WAS + MAG_RUN_TIME_BOS_WAS
MAG_TT_NYC_PHL = MAG_STOP_TIME_NYC_PHL + MAG_RUN_TIME_NYC_PHL + MAG_DELAY_NYC_PHL
MAG_TT_NYC_WAS = MAG_DELAY_NYC_WAS + MAG_STOP_TIME_NYC_WAS + MAG_RUN_TIME_NYC_WAS
MAG_TT_PHL_WAS = MAG_RUN_TIME_PHL_WAS + MAG_DELAY_PHL_WAS + MAG_STOP_TIME_PHL_WAS
MAG_UTILIZATION_FACT_BOS_NYC = 0.60
MAG_UTILIZATION_FACT_BOS_PHL = 0.60
MAG_UTILIZATION_FACT_BOS_WAS = 0.50
MAG_UTILIZATION_FACT_NYC_PHL = 0.60
MAG_UTILIZATION_FACT_NYC_WAS = 0.60
MAG_UTILIZATION_FACT_PHL_WAS = 0.60
MAX_FREQ_NYC = MAX(FREQ_BOS_NYC,FREQ_NYC_PHL)
MAX_FREQ_PHL = MAX(FREQ_NYC_PHL,FREQ_PHL_WAS)

Appendix E. Economic Model Equations
NEW_GUIDEWAY_UC = 
ELEVATED_GUIDEWAY_PER_MILE *(ELECTRIFICATION_PER_MILE * 0.7)

NORMAL_BRAKE_RATE = 0.785

NUMBER_OF_STATIONS = 4

NUMBER_OF_VEHICLES = NUMBER_OF_VEH_NYC_WAS + NUMBER_OF_VEH_BOS_WAS + 
NUMBER_OF_VEH_PHL_WAS + NUMBER_OF_VEH_NYC_PHL + NUMBER_OF_VEH_BOS_NYC + 
NUMBER_OF_VEH_BOS_PHL

NUMBER_OF_VEH_BOS_NYC = ROUND(0.5 + (MAG_TRIPS_DAILY_BOS_NYC / 
TRIPS_PER_VEH_DAILY_BOS_NYC))

NUMBER_OF_VEH_BOS_PHL = ROUND(0.5 + (MAG_TRIPS_DAILY_BOS_PHL / 
TRIPS_PER_VEH_DAILY_BOS_PHL))

NUMBER_OF_VEH_BOS_WAS = ROUND(0.5 + (MAG_TRIPS_DAILY_BOS_WAS / 
TRIPS_PER_VEH_DAILY_BOS_WAS))

NUMBER_OF_VEH_NYC_PHL = ROUND(0.5 + (MAG_TRIPS_DAILY_NYC_PHL / 
TRIPS_PER_VEH_DAILY_NYC_PHL))

NUMBER_OF_VEH_NYC_WAS = ROUND(0.5 + (MAG_TRIPS_DAILY_NYC_WAS / 
TRIPS_PER_VEH_DAILY_NYC_WAS))

NUMBER_OF_VEH_PER_TRAIN = 1

NUMBER_OF_VEH_PHL_WAS = ROUND(0.5 + (MAG_TRIPS_DAILY_PHL_WAS / 
TRIPS_PER_VEH_DAILY_PHL_WAS))

ONCE_IN_TEN_YEAR_COST = PULSE((COST_PER_VEHICLE * VEH), 21, 10)

OTHER_O_AND_M = 
(TRAIN_CREW_U_C + TRAIN_SUPPLIES + SALES_U_C + CONTINGENCY) * TOTAL_ANNUAL_MAGLEV

OTHER_SOURCES_BOS = 4965000000

OTHER_SOURCES_NYC = 178000000

OTHER_SOURCES_PHL = 38700000

OTHER_SOURCES_WAS = 17000000

O_AND_M_SUBTOTAL = 
(STATION_OPERATIONS + OTHER_O_AND_M + TRAIN_Maintenance + FACILITY_MAINTENANCE + TOTAL_POWER_COST)

PCT_MFG_BOS = (JOB_MFG_BOS/TOTAL_J_BOS) * 100

PCT_MFG_NYC = (JOB_MFG_NYC/TOTAL_J_NYC) * 100

PCT_MFG_PHL = (JOB_MFG_PHL/TOTAL_J_PHL) * 100

PCT_MFG_WAS = (JOB_MFG_WAS/TOTAL_J_WAS) * 100

PDN_FACT_BOS = 1.79

PDN_FACT_NYC = 2.02

PDN_FACT_PHL = 2.75

PDN_FACT_WAS = 1.855

PLATFORMS_BOS = ROUND(0.5 + (FREQ_BOS_NYC/STATION_CAPACITY))

PLATFORMS_NYC = ROUND(0.5 + (MAX_FREQ_NYC/STATION_CAPACITY))

PLATFORMS_PHL = ROUND(0.5 + (MAX_FREQ_PHL/STATION_CAPACITY))

Appendix E. Economic Model Equations
PLATFORM_COST_BOS = IF PLATFORMS_BOS > 1 THEN ((PLATFORMS_BOS - 1) * COST_PER_STATION * 0.5) ELSE 0
PLATFORM_COST_NYC = IF PLATFORMS_NYC > 1 THEN ((PLATFORMS_NYC - 1) * COST_PER_STATION * 0.5) ELSE 0
PLATFORM_COST_PHL = IF PLATFORMS_PHL > 1 THEN ((PLATFORMS_PHL - 1) * COST_PER_STATION * 0.5) ELSE 0
PLATFORM_COST_WAS = IF PLATFORMS_WAS > 1 THEN ((PLATFORMS_WAS - 1) * COST_PER_STATION * 0.5) ELSE 0
PLATFORM_WAS = ROUND(0.5 + ((FREQ_PHL_WAS / STATION_CAPACITY))
POWER_BOS_NYC = ((FREQ_BOS_NYC * 365) / 7) * POWER_CONSUMED_BOS_NYC
POWER_CONSUMED_BOS_NYC = 10933.5
POWER_CONSUMED_NYC_PHL = 4459.31
POWER_CONSUMED_PHL_WAS = 7106.35
POWER_NYC_PHL = ((FREQ_NYC_PHL * 365) / 7) * POWER_CONSUMED_NYC_PHL
POWER_PHL_WAS = ((FREQ_PHL_WAS * 365) / 7) * POWER_CONSUMED_PHL_WAS
PRODUCTION_BOS = INDUSTRY_VALUE_BOS * PDTN_FACT_BOS
PRODUCTION_NYC = INDUSTRY_VALUE_NYC * PDTN_FACT_NYC
PRODUCTION_PHL = INDUSTRY_VALUE_PHL * PDTN_FACT_PHL
PRODUCTION_WAS = INDUSTRY_VALUE_WAS * PDTN_FACT_WAS
REACTION_TIME = 1.5
RELATIVE_CT_BOS_NYC = FM_CT_BOS_NYC / BEST_CT_BOS_NYC
RELATIVE_CT_BOS_PHL = FM_CT_BOS_PHL / BEST_CT_BOS_PHL
RELATIVE_CT_BOS_WAS = FM_CT_BOS_WAS / BEST_CT_BOS_WAS
RELATIVE_CT_NYC_PHL = FM_CT_NYC_PHL / BEST_CT_NYC_PHL
RELATIVE_CT_NYC_WAS = FM_CT_NYC_WAS / BEST_CT_NYC_WAS
RELATIVE_CT_PHL_WAS = FM_CT_PHL_WAS / BEST_CT_PHL_WAS
RELATIVE_TT_BOS_NYC = BEST_TIME_BOS_NYC / BEST_TIME_BOS_NYC
RELATIVE_TT_BOS_PHL = BEST_TIME_BOS_PHL / BEST_TIME_BOS_PHL
RELATIVE_TT_BOS_WAS = BEST_TIME_BOS_WAS / BEST_TIME_BOS_WAS
RELATIVE_TT_NYC_PHL = BEST_TIME_NYC_PHL / BEST_TIME_NYC_PHL
RELATIVE_TT_NYC_WAS = BEST_TIME_NYC_WAS / BEST_TIME_NYC_WAS
RELATIVE_TT_PHL_WAS = BEST_TIME_PHL_WAS / BEST_TIME_PHL_WAS
ROUTINE_SERVICE_UNIT_U_C = 450400
ROW_COST_PER_MILE = 8770189
SAFETY_FACTOR_K = 1.15
SALES_BOS = POPULATION_BOS * PER_CAPITA_INCOME_BOS * SALES_FACTOR_BOS
SALES_FACTOR_BOS = 0.6
SALES_FACTOR_NYC = 0.63
SALES_FACTOR_PHL = 0.75
SALES_FACTOR_WAS = 0.1125
SALES_NYC = POPULATION_NYC * PER_CAPITA_INCOME_NYC * SALES_FACTOR_NYC
SALES_PHL = POPULATION_PHL * PER_CAPITA_INCOME_PHL * SALES_FACTOR_PHL
SALES_U_C = 1.80

Appendix E. Economic Model Equations
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\[\begin{align*}
&\text{TG\_BETA\_2\_NYC\_WAS = -0.99} \\
&\text{TG\_BETA\_2\_PHL\_WAS = -0.99} \\
&\text{TG\_BETA\_3\_BOS\_NYC = -3.15} \\
&\text{TG\_BETA\_3\_BOS\_PHL = -3.15} \\
&\text{TG\_BETA\_3\_BOS\_WAS = -3.15} \\
&\text{TG\_BETA\_3\_NYC\_PHL = -3.15} \\
&\text{TG\_BETA\_3\_NYC\_WAS = -3.15} \\
&\text{TG\_BETA\_3\_PHL\_WAS = -3.15} \\
&\text{TG\_BETA\_4\_BOS\_NYC = -0.61} \\
&\text{TG\_BETA\_4\_BOS\_PHL = -0.61} \\
&\text{TG\_BETA\_4\_BOS\_WAS = -0.61} \\
&\text{TG\_BETA\_4\_NYC\_PHL = -0.61} \\
&\text{TG\_BETA\_4\_NYC\_WAS = -0.61} \\
&\text{TG\_BETA\_4\_PHL\_WAS = -0.61} \\
&\text{TG\_TRIPS\_BOS\_NYC = TG\_ALPHA\_0\_BOS\_NYC*\left(\frac{\text{POPULATION\_BOS}}{1000000}\right)\times TG\_ALPHA\_1\_BOS\_NYC*\left(\frac{\text{POPULATION\_NYC}}{1000000}\right)\times TG\_ALPHA\_2\_BOS\_NYC*\left(\frac{\text{PER\_CAPITA\_INCOME\_BOS}}{1000}\right)\times TG\_ALPHA\_3\_BOS\_NYC*\left(\frac{\text{PER\_CAPITA\_INCOME\_NYC}}{1000}\right)\times TG\_ALPHA\_4\_BOS\_NYC*\left(\frac{\text{PCT\_MFG\_BOS}}{100}\right)\times TG\_ALPHA\_5\_BOS\_NYC*\left(\frac{\text{TT\_BOS\_NYC}}{100}\right)\times TG\_BETA\_1\_BOS\_NYC*\left(\frac{\text{BEST\_TIME\_BOS\_NYC}}{100}\right)\times TG\_BETA\_2\_BOS\_NYC*\left(\frac{\text{RELATIVE\_CT\_BOS\_NYC}}{100}\right)\times TG\_BETA\_3\_BOS\_NYC*\left(\frac{\text{BEST\_CT\_BOS\_NYC}}{100}\right)\times TG\_BETA\_4\_BOS\_NYC*\left(\frac{\text{RELATIVE\_CT\_BOS\_NYC}}{100}\right) \\
&\text{TG\_TRIPS\_BOS\_PHL = TG\_ALPHA\_0\_BOS\_PHL*\left(\frac{\text{POPULATION\_BOS}}{1000000}\right)\times TG\_ALPHA\_1\_BOS\_PHL*\left(\frac{\text{POPULATION\_PHL}}{1000000}\right)\times TG\_ALPHA\_2\_BOS\_PHL*\left(\frac{\text{PER\_CAPITA\_INCOME\_BOS}}{1000}\right)\times TG\_ALPHA\_3\_BOS\_PHL*\left(\frac{\text{PER\_CAPITA\_INCOME\_PHL}}{1000}\right)\times TG\_ALPHA\_4\_BOS\_PHL*\left(\frac{\text{PCT\_MFG\_BOS}}{100}\right)\times TG\_ALPHA\_5\_BOS\_PHL*\left(\frac{\text{TT\_BOS\_PHL}}{100}\right)\times TG\_BETA\_1\_BOS\_PHL*\left(\frac{\text{BEST\_TIME\_BOS\_PHL}}{100}\right)\times TG\_BETA\_2\_BOS\_PHL*\left(\frac{\text{RELATIVE\_CT\_BOS\_PHL}}{100}\right)\times TG\_BETA\_3\_BOS\_PHL*\left(\frac{\text{BEST\_CT\_BOS\_PHL}}{100}\right)\times TG\_BETA\_4\_BOS\_PHL*\left(\frac{\text{RELATIVE\_CT\_BOS\_PHL}}{100}\right) \\
&\text{TG\_TRIPS\_BOS\_WAS = TG\_ALPHA\_0\_BOS\_WAS*\left(\frac{\text{POPULATION\_BOS}}{1000000}\right)\times TG\_ALPHA\_1\_BOS\_WAS*\left(\frac{\text{POPULATION\_WAS}}{1000000}\right)\times TG\_ALPHA\_2\_BOS\_WAS*\left(\frac{\text{PER\_CAPITA\_INCOME\_BOS}}{1000}\right)\times TG\_ALPHA\_3\_BOS\_WAS*\left(\frac{\text{PER\_CAPITA\_INCOME\_WAS}}{1000}\right)\times TG\_ALPHA\_4\_BOS\_WAS*\left(\frac{\text{PCT\_MFG\_BOS}}{100}\right)\times TG\_ALPHA\_5\_BOS\_WAS*\left(\frac{\text{TT\_BOS\_WAS}}{100}\right)\times TG\_BETA\_1\_BOS\_WAS*\left(\frac{\text{BEST\_TIME\_BOS\_WAS}}{100}\right)\times TG\_BETA\_2\_BOS\_WAS*\left(\frac{\text{RELATIVE\_CT\_BOS\_WAS}}{100}\right)\times TG\_BETA\_3\_BOS\_WAS*\left(\frac{\text{BEST\_CT\_BOS\_WAS}}{100}\right)\times TG\_BETA\_4\_BOS\_WAS \\
\end{align*}\]
○ TG_TRIPS_NYC_PHL =
  TG_ALPHA_0_NYC_PHL*((POPULATION_NYC/1000000)*TG_ALPHA_1_NYC_PHL)*((POPULATION_PHL/1000000)*TG_ALPHA_2_NYC_PHL)*((PER_CAPITA_INCOME_NYC/1000)*TG_ALPHA_3_NYC_PHL)*((PER_CAPITA_INCOME_PHL/1000)*TG_ALPHA_4_NYC_PHL)*((PCT_MFG_NYC/TG_ALPHA_5_NYC_PHL)*PCT_MFG_PHL*TG_ALPHA_6_NYC_PHL)*(RELATIVE_TIME_NYC_PHL*TG_BETA_1_NYC_PHL)*(BEST_TIME_NYC_PHL*TG_BETA_2_NYC_PHL)*(RELATIVE_CT_NYC_PHL*TG_BETA_3_NYC_PHL)*(BEST_CT_NYC_PHL*TG_BETA_4_NYC_PHL)

○ TG_TRIPS_NY_WAS =
  TG_ALPHA_0_NYC_WAS*((POPULATION_NYC/1000000)*TG_ALPHA_1_NYC_WAS)*((POPULATION_WAS/1000000)*TG_ALPHA_2_NYC_WAS)*((PER_CAPITA_INCOME_NYC/1000)*TG_ALPHA_3_NYC_WAS)*((PER_CAPITA_INCOME_WAS/1000)*TG_ALPHA_4_NYC_WAS)*((PCT_MFG_NYC/TG_ALPHA_5_NYC_WAS)*PCT_MFG_WAS*TG_ALPHA_6_NYC_WAS)*(RELATIVE_TIME_NYC_WAS*TG_BETA_1_NYC_WAS)*(BEST_TIME_NYC_WAS*TG_BETA_2_NYC_WAS)*(RELATIVE_CT_NYC_WAS*TG_BETA_3_NYC_WAS)*(BEST_CT_NYC_WAS*TG_BETA_4_NYC_WAS)

○ TG_TRIPS_PHL_WAS =
  TG_ALPHA_0_PHL_WAS*((POPULATION_PHL/1000000)*TG_ALPHA_1_PHL_WAS)*((POPULATION_WAS/1000000)*TG_ALPHA_2_PHL_WAS)*((PER_CAPITA_INCOME_PHL/1000)*TG_ALPHA_3_PHL_WAS)*((PER_CAPITA_INCOME_WAS/1000)*TG_ALPHA_4_PHL_WAS)*((PCT_MFG_PHL/TG_ALPHA_5_PHL_WAS)*PCT_MFG_WAS*TG_ALPHA_6_PHL_WAS)*(RELATIVE_TIME_PHL_WAS*TG_BETA_1_PHL_WAS)*(BEST_TIME_PHL_WAS*TG_BETA_2_PHL_WAS)*(RELATIVE_CT_PHL_WAS*TG_BETA_3_PHL_WAS)*(BEST_CT_PHL_WAS*TG_BETA_4_PHL_WAS)

○ TOTAL_DISTANCE = DIST_BOS_NYC+DIST_NYC_PHL+DIST_PHL_WAS
○ TOTAL_J_BOS = JOB_MFG_BOS+T_AND_O_JOBS_BOS+SERVICE_JOBS_BOS
○ TOTAL_J_NYC = JOB_MFG_NYC+T_AND_O_JOBS_NYC+SERVICE_JOBS_NYC
○ TOTAL_J_PHL = JOB_MFG_PHL+T_AND_O_JOBS_PHL+SERVICE_JOBS_PHL
○ TOTAL_J_WAS = JOB_MFG_WAS+T_AND_O_JOBS_WAS+SERVICE_JOBS_WAS
○ TOTAL_PLATFORM_COST =
  PLATFORM_COST_BOS+PLATFORM_COST_PHL+PLATFORM_COST_WAS+PLATFORM_COST_NYC+PLATFORM_COST_PHL
○ TOTAL_POWER = SUM(Power_BOS_NYC,POWER_NYC_PHL,POWER_PHL_WAS)
○ TOTAL_POWER_COST = UNIT_COST_POWER*TOTAL_POWER
○ TOTAL_FF_TT_AIR_BOS_NYC =
  AIR_ACCESS_EGRESS_TIME_BOS_NYC+FLIGHT_DELAY_BOS_NYC+FLYING_TIME_BOS_NYC+AIR_STOP_TIME_BOS_NYC
○ TOTAL_FF_TT_AIR_BOS_PHL =
  AIR_ACCESS_EGRESS_TIME_BOS_PHL+FLIGHT_DELAY_BOS_PHL+FLYING_TIME_BOS_PHL+AIR_STOP_TIME_BOS_PHL
○ TOTAL_FF_TT_AIR_BOS_WAS =
  AIR_ACCESS_EGRESS_TIME_BOS_WAS+FLIGHT_DELAY_BOS_WAS+FLYING_TIME_BOS_WAS+AIR_STOP_TIME_BOS_WAS

Appendix E. Economic Model Equations
TOTAL TT AIR NYC-PHL =
  AIR_ACCESS_EGRESS_TIME_NYC-PHL + FLIGHT_DELAY_NYC-PHL + FLYING_TIME_NYC-PHL + AIR_STOP_TIME_NYC-PHL

TOTAL TT AIR NYC-WAS =
  AIR_ACCESS_EGRESS_TIME_NYC-WAS + FLIGHT_DELAY_NYC-WAS + FLYING_TIME_NYC-WAS + AIR_STOP_TIME_NYC-WAS

TOTAL TT AIR PHL-WAS =
  AIR_ACCESS_EGRESS_TIME_PHL-WAS + FLIGHT_DELAY_PHL-WAS + FLYING_TIME_PHL-WAS + AIR_STOP_TIME_PHL-WAS

TOTAL TT MAG BOS NYC =
  MAG_ACCESS_EGRESS_TIME_BOS_NYC + MAG_DELAY_BOS_NYC + MAG_RUN_TIME_BOS_NYC + MAG_STOP_TIME_BOS_NYC

TOTAL TT MAG BOS PHL =
  MAG_ACCESS_EGRESS_TIME_BOS_PHL + MAG_DELAY_BOS_PHL + MAG_RUN_TIME_BOS_PHL + MAG_STOP_TIME_BOS_PHL

TOTAL TT MAG PHL WAS =
  MAG_ACCESS_EGRESS_TIME_PHL_WAS + MAG_DELAY_PHL_WAS + MAG_RUN_TIME_PHL_WAS + MAG_STOP_TIME_PHL_WAS

TOTAL TT MAG NYC WAS =
  MAG_ACCESS_EGRESS_TIME_NYC_PHL + MAG_DELAY_NYC_PHL + MAG_RUN_TIME_NYC_PHL + MAG_STOP_TIME_NYC_PHL

TOTAL TT MAG NYC WAS =
  MAG_ACCESS_EGRESS_TIME_NYC_WAS + MAG_DELAY_NYC_WAS + MAG_RUN_TIME_NYC_WAS + MAG_STOP_TIME_NYC_WAS

TOTAL TT MAG PHL WAS =
  MAG_ACCESS_EGRESS_TIME_PHL_WAS + MAG_DELAY_PHL_WAS + MAG_RUN_TIME_PHL_WAS + MAG_STOP_TIME_PHL_WAS

TRAFFIC_CONTROL_U_C = 3520

TRAIN_CREW_U_C = 1.73

TRAIN_MAINTENANCE =
  (ROUTINE_SERVICE_UNIT_U_C + CLEANING_U_C + COMPLETE_MAINT_U_C + FACILITY_OPERATION_U_C)*NUMBER_OFVEHICLES

TRAIN_SUPPLIES = 0.25

TRIPS_PER_VEH_DAILY_BOS_NYC = (17*60)/MAG TT BOS_NYC

TRIPS_PER_VEH_DAILY_BOS_PHL = 1020/MAG TT BOS_PHL

TRIPS_PER_VEH_DAILY_BOS_WAS = 1020/MAG TT BOS_WAS

TRIPS_PER_VEH_DAILY_NYC_PHL = (17*60)/MAG TT NYC_PHL

TRIPS_PER_VEH_DAILY_NYC_WAS = 1020/MAG TT NYC_WAS

TRIPS_PER_VEH_DAILY_PHL_WAS = 1020/MAG TT PHL_WAS

T_AND_O_FACT_BOS = 33636

T_AND_O_FACT_NYC = 37880

T_AND_O_FACT_PHL = 27740

T_AND_O_FACT_WAS = 23500

Appendix E. Economic Model Equations
T_AND_O_JOBS_BOS = SALES_BOS/T_AND_O_FACT_BOS
T_AND_O_JOBS_NYC = SALES_NYC/T_AND_O_FACT_NYC
T_AND_O_JOBS_PHL = SALES_PHL/T_AND_O_FACT_PHL
T_AND_O_JOBS_WAS = SALES_WAS/T_AND_O_FACT_WAS
UNIT_COST_MAINT_ELECTRIFICATION = 20670
UNIT_COST_OTHER_FACILITIES = 2850
UNIT_COST_POWER = 0.6
UNIT_COST_SIGNALS_COMMUNICATION = 3485
UNIT_COST_TRACK_GUIDEWAY = 7535
UTILIZED_CAP_AIR_BOS_NYC = AIR_UTILIZATION_FACT_BOS_NYC*AIR_PAX_CAP_BOS_NYC
UTILIZED_CAP_AIR_BOS_PHL = AIR_UTILIZATION_FACT_BOS_PHL*AIR_PAX_CAP_BOS_PHL
UTILIZED_CAP_AIR_BOS_WAS = AIR_UTILIZATION_FACT_BOS_WAS*AIR_PAX_CAP_BOS_WAS
UTILIZED_CAP_AIR_NYC_PHL = AIR_UTILIZATION_FACT_NYC_PHL*AIR_PAX_CAP_NYC_PHL
UTILIZED_CAP_AIR_NYC_WAS = AIR_UTILIZATION_FACT_NYC_WAS*AIR_PAX_CAP_NYC_WAS
UTILIZED_CAP_AIR_PHL_WAS = AIR_UTILIZATION_FACT_PHL_WAS*AIR_PAX_CAP_PHL_WAS
UTILIZED_CAP_MAG_BOS_NYC = MAG_PAX_CAP_BOS_NYC*MAG_UTILIZATION_FACT_BOS_NYC
UTILIZED_CAP_MAG_BOS_PHL = MAG_PAX_CAP_BOS_PHL*MAG_UTILIZATION_FACT_BOS_PHL
UTILIZED_CAP_MAG_BOS_WAS = MAG_PAX_CAP_BOS_WAS*MAG_UTILIZATION_FACT_BOS_WAS
UTILIZED_CAP_MAG_NYC_PHL = MAG_PAX_CAP_NYC_PHL*MAG_UTILIZATION_FACT_NYC_PHL
UTILIZED_CAP_MAG_NYC_WAS = MAG_PAX_CAP_NYC_WAS*MAG_UTILIZATION_FACT_NYC_WAS
UTILIZED_CAP_MAG_PHL_WAS = MAG_PAX_CAP_PHL_WAS*MAG_UTILIZATION_FACT_PHL_WAS
VELOCITY_MAGLEV = 90
FLIGHT_DELAY_BOS_NYC = GRAPH(FLIGHTS_DAILY_BOS_NYC)
(0.00, 0.00), (10.0, 0.00), (20.0, 0.00), (30.0, 0.00), (40.0, 0.00), (50.0, 0.00), (60.0, 24.0), (70.0, 54.0), (80.0, 94.5), (90.0, 136), (100, 194), (110, 256), (120, 285), (130, 300), (140, 300), (150, 300), (160, 300), (170, 300), (180, 300), (190, 300), (200, 300), (210, 300), (220, 300), (230, 300), (240, 300), (250, 300), (260, 300), (270, 300), (280, 300), (290, 300), (300, 300), (310, 300), (320, 300), (330, 300), (340, 300), (350, 300), (360, 300), (370, 300)

Appendix E. Economic Model Equations

121
Appendix E. Economic Model Equations
GROWTH_FACT_PHL = GRAPH(SUPPORTED_POP_PHL/POPULATION_PHL)
(0.4, 0.68), (0.5, 0.71), (0.6, 0.745), (0.7, 0.78), (0.8, 0.81), (0.9, 0.82), (1.0, 0.83),
(1.1, 0.84), (1.2, 0.845), (1.3, 0.86), (1.4, 0.875), (1.5, 0.88), (1.6, 0.89)
GROWTH_FACT_WAS = GRAPH(SUPPORTED_POP_WAS/POPULATION_WAS)
(0.4, 0.65), (0.5, 0.675), (0.6, 0.715), (0.7, 0.755), (0.8, 0.775), (0.9, 0.78), (1.0, 0.79),
(1.1, 0.795), (1.2, 0.8), (1.3, 0.805), (1.4, 0.815), (1.5, 0.82), (1.6, 0.825)

INDUSTRY_FACTOR_BOS = GRAPH(S_P_RATIO_BOS)
(0.4, 0.0915), (0.5, 0.0965), (0.6, 0.1), (0.7, 0.104), (0.8, 0.108), (0.9, 0.111), (1.0, 0.116),
(1.1, 0.121), (1.2, 0.125), (1.3, 0.131), (1.4, 0.138), (1.5, 0.144), (1.6, 0.149)
INDUSTRY_FACTOR_NYC = GRAPH(S_P_RATIO_NYC)
(0.75, 0.0965), (0.8, 0.0975), (0.85, 0.0995), (0.9, 0.103), (0.95, 0.107), (1.0, 0.112),
(1.05, 0.117), (1.1, 0.123), (1.15, 0.127), (1.2, 0.134), (1.25, 0.14), (1.3, 0.147),
(1.35, 0.154), (1.4, 0.16)
INDUSTRY_FACTOR_PHL = GRAPH(S_P_RATIO_PHL)
(0.75, 0.0965), (0.8, 0.0975), (0.85, 0.0995), (0.9, 0.103), (0.95, 0.107), (1.0, 0.112),
(1.05, 0.117), (1.1, 0.123), (1.15, 0.127), (1.2, 0.134), (1.25, 0.14), (1.3, 0.147),
(1.35, 0.154), (1.4, 0.16)
INDUSTRY_FACTOR_WAS = GRAPH(S_P_RATIO_WAS)
(0.75, 0.0965), (0.8, 0.0975), (0.85, 0.0995), (0.9, 0.103), (0.95, 0.107), (1.0, 0.112),
(1.05, 0.117), (1.1, 0.123), (1.15, 0.127), (1.2, 0.134), (1.25, 0.14), (1.3, 0.147),
(1.35, 0.154), (1.4, 0.16)
MAG_CONTROL_BOS_NYC = GRAPH(TIME)
-1-
(0.0, 0.0), (1.0, 0.0), (2.0, 0.0), (3.0, 0.0), (4.0, 0.0), (5.0, 0.0), (6.0, 0.0),
(7.0, 0.0), (8.0, 0.0), (9.0, 0.0), (10.0, 0.0), (11.0, 0.0), (12.0, 1.0),
(13.0, 1.0), (14.0, 1.0), (15.0, 1.0), (16.0, 1.0), (17.0, 1.0), (18.0, 1.0),
(19.0, 1.0), (20.0, 1.0), (21.0, 1.0), (22.0, 1.0), (23.0, 1.0)
MAG_CONTROL_BOS_PHL = GRAPH(TIME)
(0.0, 0.0), (1.0, 0.0), (2.0, 0.0), (3.0, 0.0), (4.0, 0.0), (5.0, 0.0), (6.0, 0.0),
(7.0, 0.0), (8.0, 0.0), (9.0, 0.0), (10.0, 0.0), (11.0, 0.0), (12.0, 1.0),
(13.0, 1.0), (14.0, 1.0), (15.0, 1.0), (16.0, 1.0), (17.0, 1.0), (18.0, 1.0),
(19.0, 1.0), (20.0, 1.0), (21.0, 1.0), (22.0, 1.0), (23.0, 1.0)
MAG_CONTROL_BOS_WAS = GRAPH(TIME)
(0.0, 0.0), (1.0, 0.0), (2.0, 0.0), (3.0, 0.0), (4.0, 0.0), (5.0, 0.0), (6.0, 0.0),
(7.0, 0.0), (8.0, 0.0), (9.0, 0.0), (10.0, 0.0), (11.0, 0.0), (12.0, 1.0),
(13.0, 1.0), (14.0, 1.0), (15.0, 1.0), (16.0, 1.0), (17.0, 1.0), (18.0, 1.0),
(19.0, 1.0), (20.0, 1.0), (21.0, 1.0), (22.0, 1.0), (23.0, 1.0)
MAG_CONTROL_NYC_PHL = GRAPH(TIME)
(0.0, 0.0), (1.0, 0.0), (2.0, 0.0), (3.0, 0.0), (4.0, 0.0), (5.0, 0.0), (6.0, 0.0),
(7.0, 0.0), (8.0, 0.0), (9.0, 0.0), (10.0, 0.0), (11.0, 0.0), (12.0, 1.0),
(13.0, 1.0), (14.0, 1.0), (15.0, 1.0), (16.0, 1.0), (17.0, 1.0), (18.0, 1.0),
(19.0, 1.0), (20.0, 1.0), (21.0, 1.0), (22.0, 1.0), (23.0, 1.0)

Appendix E. Economic Model Equations
\textbf{MAG\_CONTROL\_NYC\_WAS = GRAPH(TIME)}

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00)

\textbf{MAG\_CONTROL\_PHL\_WAS = GRAPH(TIME)}

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00)

\textbf{MAG\_DELAY\_BOS\_NYC = GRAPH(MAG\_DAILY\_BOS\_NYC)}

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 1.00), (8.00, 1.50), (9.00, 2.00), (10.0, 2.50), (11.0, 3.00), (12.0, 3.50), (13.0, 4.00), (14.0, 4.50), (15.0, 5.00), (16.0, 5.50), (17.0, 6.00), (18.0, 6.50), (19.0, 7.00), (20.0, 7.50), (21.0, 8.00), (22.0, 8.50), (23.0, 9.00), (24.0, 9.50), (25.0, 10.0), (26.0, 10.5), (27.0, 11.0), (28.0, 11.5), (29.0, 12.0), (30.0, 12.5), (31.0, 13.0), (32.0, 13.5), (33.0, 14.0), (34.0, 14.5), (35.0, 15.0), (36.0, 15.5), (37.0, 16.0), (38.0, 16.5), (39.0, 17.0), (40.0, 17.5), (41.0, 18.0), (42.0, 18.5), (43.0, 19.0), (44.0, 19.5), (45.0, 20.0), (46.0, 20.5), (47.0, 21.0), (48.0, 221), (49.0, 230), (50.0, 240), (51.0, 250), (52.0, 260)

\textbf{MAG\_DELAY\_BOS\_PHL = GRAPH(MAG\_DAILY\_BOS\_PHL)}

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 1.00), (8.00, 1.50), (9.00, 2.00), (10.0, 2.50), (11.0, 3.00), (12.0, 3.50), (13.0, 4.00), (14.0, 4.50), (15.0, 5.00), (16.0, 5.50), (17.0, 6.00), (18.0, 6.50), (19.0, 7.00), (20.0, 7.50), (21.0, 8.00), (22.0, 8.50), (23.0, 9.00), (24.0, 9.50), (25.0, 10.0), (26.0, 10.5), (27.0, 11.0), (28.0, 11.5), (29.0, 12.0), (30.0, 12.5), (31.0, 13.0), (32.0, 13.5), (33.0, 14.0), (34.0, 14.5), (35.0, 15.0), (36.0, 15.5), (37.0, 16.0), (38.0, 16.5), (39.0, 17.0), (40.0, 17.5), (41.0, 18.0), (42.0, 18.5), (43.0, 19.0), (44.0, 19.5), (45.0, 20.0), (46.0, 20.5), (47.0, 21.0), (48.0, 221), (49.0, 230), (50.0, 240), (51.0, 250), (52.0, 260)

\textbf{MAG\_DELAY\_BOS\_WAS = GRAPH(MAG\_DAILY\_BOS\_WAS)}

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 1.00), (8.00, 1.50), (9.00, 2.00), (10.0, 2.50), (11.0, 3.00), (12.0, 3.50), (13.0, 4.00), (14.0, 4.50), (15.0, 5.00), (16.0, 5.50), (17.0, 6.00), (18.0, 6.50), (19.0, 7.00), (20.0, 7.50), (21.0, 8.00), (22.0, 8.50), (23.0, 9.00), (24.0, 9.50), (25.0, 10.0), (26.0, 10.5), (27.0, 11.0), (28.0, 11.5), (29.0, 12.0), (30.0, 12.5), (31.0, 13.0), (32.0, 13.5), (33.0, 14.0), (34.0, 14.5), (35.0, 15.0), (36.0, 15.5), (37.0, 16.0), (38.0, 16.5), (39.0, 17.0), (40.0, 17.5), (41.0, 18.0), (42.0, 18.5), (43.0, 19.0), (44.0, 19.5), (45.0, 20.0), (46.0, 20.5), (47.0, 21.0), (48.0, 221), (49.0, 230), (50.0, 240), (51.0, 250), (52.0, 260)
\[ \text{MAG\_DELAY\_NYC\_PHL} = \text{GRAPH(MAG\_DAILY\_NYC\_PHL)} \]
\[ (0.00, 0.00), (10.0, 0.00), (20.0, 0.00), (30.0, 0.00), (40.0, 0.00), (50.0, 0.00), (60.0, 5.00), (70.0, 10.0), (80.0, 15.0), (90.0, 20.0), (100, 25.0), (110, 30.0), (120, 35.0), (130, 40.0), (140, 45.0), (150, 50.0), (160, 55.0), (170, 60.0), (180, 65.0), (190, 70.0), (200, 75.0), (210, 80.0), (220, 85.0), (230, 90.0), (240, 95.0), (250, 100), (260, 105), (270, 110), (280, 115), (290, 120), (300, 125), (310, 130), (320, 135), (330, 140), (340, 145), (350, 150), (360, 155), (370, 160), (380, 165), (390, 170), (400, 175), (410, 180), (420, 185), (430, 190), (440, 195), (450, 200), (460, 206), (470, 213), (480, 221), (490, 230), (500, 240), (510, 250), (520, 260) \]
\[ \text{MAG\_DELAY\_NYC\_WAS} = \text{GRAPH(MAG\_DAILY\_NYC\_WAS)} \]
\[ (0.00, 0.00), (10.0, 0.00), (20.0, 0.00), (30.0, 0.00), (40.0, 0.00), (50.0, 0.00), (60.0, 5.00), (70.0, 10.0), (80.0, 15.0), (90.0, 20.0), (100, 25.0), (110, 30.0), (120, 35.0), (130, 40.0), (140, 45.0), (150, 50.0), (160, 55.0), (170, 60.0), (180, 65.0), (190, 70.0), (200, 75.0), (210, 80.0), (220, 85.0), (230, 90.0), (240, 95.0), (250, 100), (260, 105), (270, 110), (280, 115), (290, 120), (300, 125), (310, 130), (320, 135), (330, 140), (340, 145), (350, 150), (360, 155), (370, 160), (380, 165), (390, 170), (400, 175), (410, 180), (420, 185), (430, 190), (440, 195), (450, 200), (460, 206), (470, 213), (480, 221), (490, 230), (500, 240), (510, 250), (520, 260) \]
\[ \text{MAG\_DELAY\_PHL\_WAS} = \text{GRAPH(MAG\_DAILY\_PHL\_WAS)} \]
\[ (0.00, 0.00), (10.0, 0.00), (20.0, 0.00), (30.0, 0.00), (40.0, 0.00), (50.0, 0.00), (60.0, 5.00), (70.0, 10.0), (80.0, 15.0), (90.0, 20.0), (100, 25.0), (110, 30.0), (120, 35.0), (130, 40.0), (140, 45.0), (150, 50.0), (160, 55.0), (170, 60.0), (180, 65.0), (190, 70.0), (200, 75.0), (210, 80.0), (220, 85.0), (230, 90.0), (240, 95.0), (250, 100), (260, 105), (270, 110), (280, 115), (290, 120), (300, 125), (310, 130), (320, 135), (330, 140), (340, 145), (350, 150), (360, 155), (370, 160), (380, 165), (390, 170), (400, 175), (410, 180), (420, 185), (430, 190), (440, 195), (450, 200), (460, 206), (470, 213), (480, 221), (490, 230), (500, 240), (510, 250), (520, 260) \]
\[ \text{PCI\_FACT\_BOS} = \text{GRAPH(S\_P\_RATIO\_BOS)} \]
\[ (0.4, 0.05), (0.5, 0.05), (0.6, 0.05), (0.7, 0.05), (0.8, 0.05), (0.9, 0.05), (1.00, 0.05), (1.10, 0.0495), (1.20, 0.0485), (1.30, 0.048), (1.40, 0.0475), (1.50, 0.047), (1.60, 0.0465) \]
\[ \text{PCI\_FACT\_NYC} = \text{GRAPH(S\_P\_RATIO\_NYC)} \]
\[ (0.4, 0.0515), (0.5, 0.0515), (0.6, 0.0515), (0.7, 0.0515), (0.8, 0.0515), (0.9, 0.0515), (1.00, 0.0515), (1.10, 0.0495), (1.20, 0.049), (1.30, 0.0485), (1.40, 0.048), (1.50, 0.0475), (1.60, 0.0465) \]
\[ \text{PCI\_FACT\_PHL} = \text{GRAPH(S\_P\_RATIO\_PHL)} \]
\[ (0.4, 0.0515), (0.5, 0.0515), (0.6, 0.0515), (0.7, 0.0515), (0.8, 0.0515), (0.9, 0.0515), (1.00, 0.0515), (1.10, 0.0495), (1.20, 0.049), (1.30, 0.0485), (1.40, 0.048), (1.50, 0.0475), (1.60, 0.0465) \]
\[ \text{PCI\_FACT\_WAS} = \text{GRAPH(S\_P\_RATIO\_WAS)} \]
\[ (0.4, 0.0515), (0.5, 0.0515), (0.6, 0.0515), (0.7, 0.0515), (0.8, 0.0515), (0.9, 0.0515), (1.00, 0.0515), (1.10, 0.0495), (1.20, 0.049), (1.30, 0.0485), (1.40, 0.048), (1.50, 0.0475), (1.60, 0.0465) \]

Appendix E. Economic Model Equations
Appendix F. Description of Variables

VEHICLE MODEL

ACCELERATION_TIME = The time spent in the acceleration phase.
ACCELERATION_TIMER = A variable used to calculate the time spent in the acceleration phase.
CRUISE_TIME = The time spent in the cruise phase.
CRUISE_TIMER = A variable used to calculate the time spent in the cruise phase.
DECELERATION_TIME = The time spent in the deceleration phase.
DECELERATION_TIMER = A variable used to calculate the time spent in the deceleration phase.
DISTANCE_TRAVELLED = The total distance travelled at any instant of time.
SPEED = The speed or velocity at any instant of time.
THRUST_RATIO = The ratio of excess thrust to thrust available.
THRUST_RATIO_AT_DT = A variable used to Calculate the thrust ratio.
TOTAL_POWER_CONSUMED = The total power consumed from the start to the particular instant of time.
POWER_CONSUMPTION_RATE = The rate of consumption of power in kilowatt hour.
VELOCITY = The speed or velocity at any instant of time.
ACCLN_OR_DECLN = A rate variable which controls the velocity.
ACCELERATION = The rate of change of increase in speed.
ACCELERATION_AT_CRUISE = The rate of change of speed in the cruising phase.
BRAKING_DISTANCE = The distance required for the vehicle to come to a halt from the speed at which it is moving.
CRUISE VELOCITY = The velocity of the vehicle during the cruising phase.
DECELERATION = The rate of change of decrease in speed.
DISTANCE_TO_TRAVEL = The balance distance the vehicle has to travel in order to reach the destination.
EXCESS_THRUST = The thrust available for acceleration, deceleration and cruise.
MASS = The mass of the vehicle including the payload.
THROTTLE_AT_ACCEL = The throttle setting during the acceleration phase.
THROTTLE_AT_STOP = The throttle setting when the vehicle is at a stand still.
THROTTLE_SETTING = A variable which controls, at which of the three throttle settings the vehicle is operating.
THRUST_AVAILABLE = The thrust available for overcoming the forces opposing motion and for traction combined.
TOTAL_DISTANCE = The total distance in kilometers from origin to destination the maglev has to travel.
TRACTIVE_RESISTANCE = The combined total of the drag forces opposing motion.
TRAVEL_TIME = The total time the vehicle took to travel the given distance.
AERODYNAMIC_DRAG = The drag force due to aerodynamic resistance.
DRAG_DUE_TO_LATERAL_GUIDANCE = The drag force due to lateral guidance.
DRAG_DUE_TO_LINEAR_GENERATION = The drag force produced by the linear generators.
THRUST_OUTPUT = The total thrust which the vehicle can produce.

ECONOMIC MODEL

ACCUMULATED_O_AND_M = The cumulative cost of the annual operation and maintenance costs.
ANNUAL_O_AND_M_1980 = The annual operation and maintenance costs in 1980 dollars.
CUMMULATIVE_SALES = The cumulative total of the annual revenues from operating the maglev.
YEARLY_SALES = The total annual income from revenues from fares charged for travelling by maglev.
FLIGHTS_DAILY_BOS_NYC = The total number of airline flights required daily between Boston and New York.
CHANGE_IN_FLIGHTS_BOS_NYC = A rate variable used to calculate the total daily airline flights required between Boston and New York.
FLIGHTS_DAILY_BOS_PHL = The total number of airline flights required daily between Boston and Philadelphia.
CHANGE_IN_FLIGHTS_BOS_PHL = A rate variable used to calculate the total daily airline flights required between Boston and Philadelphia.

Appendix F. Description of Variables
FLIGHTS\_DAILY\_BOS\_WAS = The total number of airline flights required daily between Boston and Washington.

CHANGE\_IN\_FLIGHTS\_BOS\_WAS = A rate variable used to calculate the total daily airline flights required between Boston and Washington.

FLIGHTS\_DAILY\_NYC\_PHL = The total number of airline flights required daily between New York and Philadelphia.

CHANGE\_IN\_FLIGHTS\_NYC\_PHL = A rate variable used to calculate the total daily airline flights required between New York and Philadelphia.

FLIGHTS\_DAILY\_NYC\_WAS = The total number of airline flights required daily between New York and Washington.

CHANGE\_IN\_FLIGHTS\_NYC\_WAS = A rate variable used to calculate the total daily airline flights required between New York and Washington.

FLIGHTS\_DAILY\_PHL\_WAS = The total number of airline flights required daily between Philadelphia and Washington.

CHANGE\_IN\_FLIGHTS\_PHL\_WAS = A rate variable used to calculate the total daily airline flights required between Philadelphia and Washington.

INDUSTRY\_VALUE\_BOS = The annual value of the total industrial investment in Boston.

NEW\_INVESTMENT\_BOS = Annual rate of new investment in industry in Boston.

DEMOLITION\_BOS = The demolition rate of existing industry in Boston.

INDUSTRY\_VALUE\_NYC = The annual value of the total industrial investment in New York.

NEW\_INVESTMENT\_NYC = Annual rate of new investment in industry in New York.

DEMOLITION\_NYC = The demolition rate of existing industry in New York.

INDUSTRY\_VALUE\_PHL = The annual value of the total industrial investment in Philadelphia.

NEW\_INVESTMENT\_PHL = Annual rate of new investment in industry in Philadelphia.

DEMOLITION\_PHL = The demolition rate of existing industry in Philadelphia.

INDUSTRY\_VALUE\_WAS = The annual value of the total industrial investment in Washington.

NEW\_INVESTMENT\_WAS = Annual rate of new investment in industry in Washington.

DEMOLITION\_WAS = The demolition rate of existing industry in Washington.

MAG\_DAILY\_BOS\_NYC = The daily number of maglev round trips required between Boston and New York.

CHANGE\_IN\_MAG\_TRIPS\_BOS\_NYC = A variable used for calculating the number of maglev trips between Boston and New York.

Appendix F. Description of Variables
MAG_DAILY_BOS_PHL = The daily number of maglev round trips required between Boston and Philadelphia.
CHANGE_IN_MAG_TRIPS_BOS_PHL = A variable used for calculating the number of maglev trips between Boston and Philadelphia.
MAG_DAILY_BOS_WAS = The daily number of maglev round trips required between Boston and Washington.
CHANGE_IN_MAG_TRIPS_BOS_WAS = A variable used for calculating the number of maglev trips between Boston and Washington.
MAG_DAILY_NYC_PHL = The daily number of maglev round trips required between New York and Philadelphia.
CHANGE_IN_MAG_TRIPS_NYC_PHL = A variable used for calculating the number of maglev trips between New York and Philadelphia.
MAG_DAILY_NYC_WAS = The daily number of maglev round trips required between New York and Washington.
CHANGE_IN_MAG_TRIPS_NYC_WAS = A variable used for calculating the number of maglev trips between New York and Washington.
MAG_DAILY_PHL_WAS = The daily number of maglev round trips required between Philadelphia and Washington.
CHANGE_IN_MAG_TRIPS_PHL_WAS = A variable used for calculating the number of maglev trips between Philadelphia and Washington.
MAG_TRIPS_DAILY_BOS_NYC = The daily number of maglev round trips between Boston and New York.
CHANGE_DAILY_BOS_NYC = Variable used to calculate the daily round trips between Boston and New York.
MAG_TRIPS_DAILY_BOS_PHL = The daily number of maglev round trips between Boston and Philadelphia.
CHANGE_DAILY_BOS_PHL = Variable used to calculate the daily round trips between Boston and Philadelphia.
MAG_TRIPS_DAILY_BOS_WAS = The daily number of maglev round trips between Boston and Washington.
CHANGE_DAILY_BOS_WAS = Variable used to calculate the daily round trips between Boston and Washington.

Appendix F. Description of Variables
MAG_TRIPS_DAILY_NYC_PHL = The daily number of maglev round trips between New York and Philadelphia.
CHANGE_DAILY_NYC_PHL = Variable used to calculate the daily round trips between New York and Philadelphia.
MAG_TRIPS_DAILY_NYC_WAS = The daily number of maglev round trips between New York and Washington.
CHANGE_DAILY_NYC_WAS = Variable used to calculate the daily round trips between New York and Washington.
MAG_TRIPS_DAILY_PHL_WAS = The daily number of maglev round trips between Philadelphia and Washington.
CHANGE_DAILY_PHL_WAS = Variable used to calculate the daily round trips between Philadelphia and Washington.
PER_CAPITA_INCOME_BOS = The Per capita income in Boston.
CHANGE_IN_PCI_BOS = The rate of change of per capita income in Boston.
PER_CAPITA_INCOME_NYC = The per capita income in New York.
CHANGE_IN_PCI_NYC = The rate of change of per capita income in New York.
PER_CAPITA_INCOME_PHL = The per capita income in Philadelphia.
CHANGE_IN_PCI_PHL = The rate of change of per capita income in Philadelphia.
PER_CAPITA_INCOME_WAS = The per capita income in Washington.
CHANGE_IN_PCI_WAS = The rate of change of per capita income in Washington.
POPULATION_BOS = Population of Boston.
GROWTH_BOS = The rate of growth of population in Boston.
DECREASE_RATE_BOS = The rate of decrease in population in Boston.
POPULATION_NYC = Population of New York.
GROWTH_NYC = The rate of growth of population in New York.
DECREASE_RATE_NYC = The rate of decrease of population in New York.
POPULATION_PHL = Population of Philadelphia.
GROWTH_PHL = The rate of growth of population in Philadelphia.
DECREASE_RATE_PHL = The rate of decrease of population in Philadelphia.
POPULATION_WAS = Population of Washington.
GROWTH_WAS = The rate of growth of population in Washington.
DECREASE_RATE_WAS = The rate of decrease of population in Washington.
TOTAL_ANNUAL_MAGLEV_PAX = Total number of passenger round trips by maglev.

Appendix F. Description of Variables
CHANGE_MAG_PAX = The rate of change of total annual maglev passenger round trips.

ACCELERATION_RATE = The rate of change of increase in speed.

ADDITIONAL_GUIDEWAY_COST = Annual cost of providing additional guideway to handle increasing ridership.

ADMNSTN_AND_INSUR = Annual cost of administration and insurance.

AIR_ACESS_EGRESS_TIME_BOS_NYC = Time spent to get to the airport and to the final destination from the airport for the Boston New York city pair.

AIR_ACESS_EGRESS_TIME_BOS_PHL = Time spent to get to the airport and to the final destination from the airport for the Boston Philadelphia city pair.

AIR_ACESS_EGRESS_TIME_BOS_WAS = Time spent to get to the airport and to the final destination from the airport for the Boston Washington city pair.

AIR_ACESS_EGRESS_TIME_NYC_PHL = Time spent to get to the airport and to the final destination from the airport for the New York Philadelphia city pair.

AIR_ACESS_EGRESS_TIME_NYC_WAS = Time spent to get to the airport and to the final destination from the airport for the New York Washington city pair.

AIR_ACESS_EGRESS_TIME_PHL_WAS = Time spent to get to the airport and to the final destination from the airport for the Philadelphia Washington city pair.

AIR_ANNUAL_TRIPS_BOS_NYC = Annual trips by air between Boston and New York.

AIR_ANNUAL_TRIPS_BOS_PHL = Annual trips by air between Boston and Philadelphia.

AIR_ANNUAL_TRIPS_BOS_WAS = Annual trips by air between Boston and Washington.

AIR_ANNUAL_TRIPS_NYC_PHL = Annual trips by air between New York and Philadelphia.

AIR_ANNUAL_TRIPS_NYC_WAS = Annual trips by air between New York and Washington.

AIR_ANNUAL_TRIPS_PHL_WAS = Annual trips by air between Philadelphia and Washington.

AIR_CHOICE_EXP_BOS_NYC = Variable for calculating the exponential of the choice function in the mode split model for the Boston and New York city pair.

AIR_CHOICE_EXP_BOS_PHL = Variable for calculating the exponential of the choice function in the mode split model for the Boston and Philadelphia city pair.

AIR_CHOICE_EXP_BOS_WAS = Variable for calculating the exponential of the choice function in the mode split model for the Boston and Washington city pair.

AIR_CHOICE_EXP_NYC_PHL = Variable for calculating the exponential of the choice function in the mode split model for the New York and Philadelphia city pair.

AIR_CHOICE_EXP_NYC_WAS = Variable for calculating the exponential of the choice function in the mode split model for the New York and Washington city pair.

Appendix F. Description of Variables

132
AIR_CHOICE_EXP_PHL_WAS = Variable for calculating the exponential of the choice function in the mode split model for the Philadelphia and Washington city pair.

AIR_CHOICE_FUNCTION_BOS_NYC = Variable for calculating the choice function between modes in the mode split model for the Boston and New York city pair.

AIR_CHOICE_FUNCTION_BOS_PHL = Variable for calculating the choice function between modes in the mode split model for the Boston and Philadelphia city pair.

AIR_CHOICE_FUNCTION_BOS_WAS = Variable for calculating the choice function between modes in the mode split model for the Boston and Washington city pair.

AIR_CHOICE_FUNCTION_NYC_PHL = Variable for calculating the choice function between modes in the mode split model for the New York and Philadelphia city pair.

AIR_CHOICE_FUNCTION_NYC_WAS = Variable for calculating the choice function between modes in the mode split model for the New York and Washington city pair.

AIR_CHOICE_FUNCTION_PHL_WAS = Variable for calculating the choice function between modes in the mode split model for the Philadelphia and Washington city pair.

AIR_FARE_ALPHA_BOS_NYC = Elasticity value of the fare between Boston and New York.

AIR_FARE_ALPHA_BOS_PHL = Elasticity value of the air fare between Boston and Philadelphia.

AIR_FARE_ALPHA_BOS_WAS = Elasticity value of the air fare between Boston and Washington.

AIR_FARE_ALPHA_NYC_PHL = Elasticity value of the air fare between New York and Philadelphia.

AIR_FARE_ALPHA_NYC_WAS = Elasticity value of the air fare between New York and Washington.

AIR_FARE_ALPHA_PHL_WAS = Elasticity value of the air fare between Philadelphia and Washington.

AIR_FARE_BOS_NYC = The air fare between Boston and New York.

AIR_FARE_BOS_PHL = The air fare between Boston and Philadelphia.

AIR_FARE_BOS_WAS = The air fare between Boston and Washington.

AIR_FARE_NYC_PHL = The air fare between New York and Philadelphia.

AIR_FARE_NYC_WAS = The air fare between New York and Washington.

AIR_FARE_PHL_WAS = The air fare between Philadelphia and Washington.

AIR_FREQ_BETA_BOS_NYC = The elasticity value of the frequency of service between Boston and New York.

Appendix F. Description of Variables
AIR_FREQ_BETA_BOS_PHL = The elasticity value of the frequency of service between Boston and Philadelphia.
AIR_FREQ_BETA_BOS_WAS = The elasticity value of the frequency of service between Boston and Washington.
AIR_FREQ_BETA_NYC_PHL = The elasticity value of the frequency of service between New York and Philadelphia.
AIR_FREQ_BETA_NYC_WAS = The elasticity value of the frequency of service between New York and Washington.
AIR_FREQ_BETA_PHL_WAS = The elasticity value of the frequency of service between Philadelphia and Washington.
AIR_PAX_CAP_BOS_NYC = The passenger capacity of an average aircraft operating between Boston and New York.
AIR_PAX_CAP_BOS_PHL = The passenger capacity of an average aircraft operating between Boston and Philadelphia.
AIR_PAX_CAP_BOS_WAS = The passenger capacity of an average aircraft operating between Boston and Washington.
AIR_PAX_CAP_NYC_PHL = The passenger capacity of an average aircraft operating between New York and Philadelphia.
AIR_PAX_CAP_NYC_WAS = The passenger capacity of an average aircraft operating between New York and Washington.
AIR_PAX_CAP_PHL_WAS = The passenger capacity of an average aircraft operating between Philadelphia and Washington.
AIR_PROB_BOS_NYC = The probability of travelling by airplane between Boston and New York.
AIR_PROB_BOS_PHL = The probability of travelling by airplane between Boston and Philadelphia.
AIR_PROB_BOS_WAS = The probability of travelling by airplane between Boston and Washington.
AIR_PROB_NYC_PHL = The probability of travelling by airplane between New York and Philadelphia.
AIR_PROB_NYC_WAS = The probability of travelling by airplane between New York and Washington.
AIR_PROB_PHL_WAS = The probability of travelling by airplane between Philadelphia and Washington.

Appendix F. Description of Variables
AIR_STOP_TIME_BOS_NYC = The time spent at intermediate stops by aircraft flying between Boston and New York.
AIR_STOP_TIME_BOS_PHL = The time spent at intermediate stops by aircraft flying between Boston and Philadelphia.
AIR_STOP_TIME_BOS_WAS = The time spent at intermediate stops by aircraft flying between Boston and Washington.
AIR_STOP_TIME_NYC_PHL = The time spent at intermediate stops by aircraft flying between New York and Philadelphia.
AIR_STOP_TIME_NYC_WAS = The time spent at intermediate stops by aircraft flying between New York and Washington.
AIR_STOP_TIME_PHL_WAS = The time spent at intermediate stops by aircraft flying between Philadelphia and Washington.
AIR_TT_ALPHA_BOS_NYC = The elasticity value of travel time by airplane for the Boston and New York city pair.
AIR_TT_ALPHA_BOS_PHL = The elasticity value of travel time by airplane for the Boston and Philadelphia city pair.
AIR_TT_ALPHA_BOS_WAS = The elasticity value of travel time by airplane for the Boston and Washington city pair.
AIR_TT_ALPHA_PHL_WAS = The elasticity value of travel time by airplane for the Philadelphia and Washington city pair.
AIR_UTILIZATION_FACT_BOS_NYC = The average utilization factor of an aircraft operating between Boston and New York.
AIR_UTILIZATION_FACT_BOS_PHL = The average utilization factor of an aircraft operating between Boston and Philadelphia.
AIR_UTILIZATION_FACT_BOS_WAS = The average utilization factor of an aircraft operating between Boston and Washington.
AIR_UTILIZATION_FACT_NYC_PHL = The average utilization factor of an aircraft operating between New York and Philadelphia.

Appendix F. Description of Variables
AIR_UTILIZATION_FACT_NYC_WAS = The average utilization factor of an aircraft operating between New York and Washington.
AIR_UTILIZATION_FACT_PHL_WAS = The average utilization factor of an aircraft operating between Philadelphia and Washington.
BEST_CT_BOS_NYC = The lowest fare for all modes between Boston and New York.
BEST_CT_BOS_PHL = The lowest fare for all modes between Boston and Philadelphia.
BEST_CT_BOS_WAS = The lowest fare for all modes between Boston and Washington.
BEST_CT_NYC_PHL = The lowest fare for all modes between New York and Philadelphia.
BEST_CT_NYC_WAS = The lowest fare for all modes between New York and Washington.
BEST_CT_PHL_WAS = The lowest fare for all modes between Philadelphia and Washington.
BEST_TIME_BOS_NYC = The fastest travel time between Boston and New York for all modes.
BEST_TIME_BOS_PHL = The fastest travel time between Boston and Philadelphia for all modes.
BEST_TIME_BOS_WAS = The fastest travel time between Boston and Washington for all modes.
BEST_TIME_NYC_PHL = The fastest travel time between New York and Philadelphia for all modes.
BEST_TIME_NYC_WAS = The fastest travel time between New York and Washington for all modes.
BEST_TIME_PHL_WAS = The fastest travel time between Philadelphia and Washington for all modes.
CAPITAL_COST = The total capital cost required.
CAPITAL_COST_SUBTOTAL = Capital cost before commercial operations begin.
CAPITAL_SPENT = The cumulative capital spent at any instant of time.
CLEANING_U_C = The unit annual cost of cleaning a vehicle.
COMPLETE MAINT_U_C = The unit annual cost of complete maintenance of a vehicle.
CONTINGENCY = Average annual contingency expenditure by the operator per passenger.
COST_PER_STATION = Cost of construction of a station.
COST_PER_VEHICLE = The cost of one magnetically levitated vehicle.
DAILY_AIR_TRIPS_BOS_NYC = The daily passenger round trips by air between Boston and New York.
DAILY_AIR_TRIPS_BOS_PHL = The daily passenger round trips by air between Boston and Philadelphia.
DAILY_AIR_TRIPS_BOS_WAS = The daily passenger round trips by air between Boston and Washington.
DAILY_AIR_TRIPS_NYC_PHL = The daily passenger round trips by air between Boston and New York.
DAILY_AIR_TRIPS_NYC_WAS = The daily passenger round trips by air between New York and Washington.
DAILY_AIR_TRIPS_PHL_WAS = The daily passenger round trips by air between Philadelphia and Washington.
DAILY_MAGLEV_TRIPS_BOS_NYC = The daily passenger round trips by maglev between Boston and New York.
DAILY_MAGLEV_TRIPS_BOS_PHL = The daily passenger round trips by maglev between Boston and Philadelphia.
DAILY_MAGLEV_TRIPS_BOS_WAS = The daily passenger round trips by maglev between Boston and Washington.
DAILY_MAGLEV_TRIPS_NYC_PHL = The daily passenger round trips by maglev between New York and Philadelphia.
DAILY_MAGLEV_TRIPS_NYC_WAS = The daily passenger round trips by maglev between New York and Washington.
DAILY_MAGLEV_TRIPS_PHL_WAS = The daily passenger round trips by maglev between Philadelphia and Washington.
DEMOLITION_NORMAL_BOS = The fraction of industry which goes out of business annually in Boston.
DEMOLITION_NORMAL_NYC = The fraction of industry which goes out of business annually in New York.
DEMOLITION_NORMAL_PHL = The fraction of industry which goes out of business annually in Philadelphia.
DEMOLITION_NORMAL_WAS = The fraction of industry which goes out of business annually in Washington.
DIST_BOS_NYC = Distance in Kilometers between Boston and New York.
DIST_NYC_PHL = Distance in Kilometers between New York and Philadelphia.
DIST_PHL_WAS = Distance in Kilometers between Philadelphia and Washington.
D_NORMAL_BOS = The fraction by which population decreases annually in Boston.
D_NORMAL_NYC = The fraction by which population decreases annually in New York.

Appendix F. Description of Variables
D_NORMAL_PHL = The fraction by which population decreases annually in Philadelphia.
D_NORMAL_WAS = The fraction by which population decreases annually in Washington.
ELECTRIFICATION_PER_MILE = Cost per mile for electrification of the guideway.
ELEVATED_GUIDEWAY_PER_MILE = cost of elevated guideway per mile.
EMPLOYEES_PER_HOUSE_BOS = Average number of persons employed in a household in Boston.
EMPLOYEES_PER_HOUSE_NYC = Average number of persons employed in a household in New York.
EMPLOYEES_PER_HOUSE_PHL = Average number of persons employed in a household in Philadelphia.
EMPLOYEES_PER_HOUSE_WAS = Average number of persons employed in a household in Washington.
ENGRN_AND_ADMNST = Cost of engineering and administration expressed as a percentage of total capital cost.
FACILITY_MAINTENANCE = Total annual maintenance cost of all facilities.
FACILITY_OPERATION_U_C = Annual unit cost of operating facilities.
FLIGHT_FREQ_BOS_NYC = Frequency of aircraft operation in flights per week between Boston and New York.
FLIGHT_FREQ_BOS_PHL = Frequency of aircraft operation in flights per week between Boston and Philadelphia.
FLIGHT_FREQ_BOS_WAS = Frequency of aircraft operation in flights per week between Boston and Washington.
FLIGHT_FREQ_NYC_PHL = Frequency of aircraft operation in flights per week between New York and Philadelphia.
FLIGHT_FREQ_NYC_WAS = Frequency of aircraft operation in flights per week between New York and Washington.
FLIGHT_FREQ_PHL_WAS = Frequency of aircraft operation in flights per week between Philadelphia and Washington.
FLYING_TIME_BOS_NYC = Flying time between Boston and New York.
FLYING_TIME_BOS_PHL = Flying time between Boston and Philadelphia.
FLYING_TIME_BOS_WAS = Flying time between Boston and Washington.
FLYING_TIME_NYC_PHL = Flying time between New York and Philadelphia.
FLYING_TIME_NYC_WAS = Flying time between New York and Washington.

Appendix F. Description of Variables

FM\_CT\_BOS\_NYC = Lower of the fare charged by maglev and airline between Boston and New York.

FM\_CT\_BOS\_PHL = Lower of the fare charged by maglev and airline between Boston and Philadelphia.

FM\_CT\_BOS\_WAS = Lower of the fare charged by maglev and airline between Boston and Washington.

FM\_CT\_NYC\_PHL = Lower of the fare charged by maglev and airline between New York and Philadelphia.

FM\_CT\_NYC\_WAS = Lower of the fare charged by maglev and airline between New York and Washington.

FM\_CT\_PHL\_WAS = Lower of the fare charged by maglev and airline between Philadelphia and Washington.

FREQ\_BOS\_NYC = Frequency of maglev service in round trips per week between Boston and New York.

FREQ\_BOS\_PHL = Frequency of maglev service in round trips per week between Boston and Philadelphia.

FREQ\_BOS\_WAS = Frequency of maglev service in round trips per week between Boston and Washington.

FREQ\_NYC\_PHL = Frequency of maglev service in round trips per week between New York and Philadelphia.

FREQ\_NYC\_WAS = Frequency of maglev service in round trips per week between New York and Washington.

FREQ\_PHL\_WAS = Frequency of maglev service in round trips per week between Philadelphia and Washington.

GUIDEWAY\_CAPACITY = The capacity of the guideway in vehicles per day.

GUIDEWAYS\_BOS\_NYC = Number of guideways required between Boston and New York.

GUIDEWAY\_NYC\_PHL = Number of guideways required between New York and Philadelphia.

GUIDEWAY\_PHL\_WAS = Number of guideways required between Philadelphia and Washington.

GUIDEWAY\_COST\_BOS\_NYC = Cost of additional guideways between Boston and New York.

GUIDEWAY\_COST\_NYC\_PHL = Cost of additional guideways between New York and Philadelphia.

Appendix F. Description of Variables
GUIDEWAY_COST_PHL_WAS = Cost of additional guideways between Philadelphia and Washington.

G_NORMAL_BOS = The fraction by which population grows annually in Boston.

G_NORMAL_NYC = The fraction by which population grows annually in New York.

G_NORMAL_PHL = The fraction by which population grows annually in Philadelphia.

G_NORMAL_WAS = The fraction by which population grows annually in Washington.

HOUSE_SIZE_BOS = The average household size in Boston.

HOUSE_SIZE_NYC = The average household size in New York.

HOUSE_SIZE_PHL = The average household size in Philadelphia.

HOUSE_SIZE_WAS = The average household size in Washington.

JOB_MFG_BOS = The number of jobs in the manufacturing industry in Boston.

JOB_MFG_NYC = The number of jobs in the manufacturing industry in New York.

JOB_MFG_PHL = The number of jobs in the manufacturing industry in Philadelphia.

JOB_MFG_WAS = The number of jobs in the manufacturing industry in Washington.

JOB_VALUE_RATIO_BOS = The ratio of jobs to industrial value in Boston.

JOB_VALUE_RATIO_NYC = The ratio of jobs to industrial value in New York.

JOB_VALUE_RATIO_PHL = The ratio of jobs to industrial value in Philadelphia.

JOB_VALUE_RATIO_WAS = The ratio of jobs to industrial value in Washington.

LENGTH_FOR_BRAKE_VAR = Additional distance added to the safe braking distance to account for the variation in the braking distance.

LENGTH_OF_MAGLEV = The length of a magnetically levitated vehicle.

MAG_ACESS_EGRESS_TIME_BOS_NYC = The time spent to get to the maglev station and the time spent to get to the final destination for the Boston and New York city pair.

MAG_ACESS_EGRESS_TIME_BOS_PHL = The time spent to get to the maglev station and the time spent to get to the final destination for the Boston and Philadelphia city pair.

MAG_ACESS_EGRESS_TIME_BOS_WAS = The time spent to get to the maglev station and the time spent to get to the final destination for the Boston and Washington city pair.

MAG_ACESS_EGRESS_TIME_NYC_PHL = The time spent to get to the maglev station and the time spent to get to the final destination for the New York and Philadelphia city pair.

MAG_ACESS_EGRESS_TIME_NYC_WAS = The time spent to get to the maglev station and the time spent to get to the final destination for the New York and Washington city pair.

MAG_ACESS_EGRESS_TIME_PHL_WAS = The time spent to get to the maglev station and the time spent to get to the final destination for the Philadelphia and Washington city pair.

Appendix F. Description of Variables
MAG_ANNUAL_TRIPS_BOS_NYC = Total annual trips by maglev between Boston and New York.

MAG_ANNUAL_TRIPS_BOS_PHL = Total annual trips by maglev between Boston and Philadelphia.

MAG_ANNUAL_TRIPS_BOS_WAS = Total annual trips by maglev between Boston and Washington.

MAG_ANNUAL_TRIPS_NYC_PHL = Total annual trips by maglev between New York and Philadelphia.

MAG_ANNUAL_TRIPS_NYC_WAS = Total annual trips by maglev between New York and Washington.

MAG_ANNUAL_TRIPS_PHL_WAS = Total annual trips by maglev between Philadelphia and Washington.

MAG_CHOICE_EXP_BOS_NYC = Variable for calculating the exponential of the mode choice in the mode split model for the Boston and New York city pair.

MAG_CHOICE_EXP_BOS_PHL = Variable for calculating the exponential of the mode choice in the mode split model for the Boston and Philadelphia city pair.

MAG_CHOICE_EXP_BOS_WAS = Variable for calculating the exponential of the mode choice in the mode split model for the Boston and Washington city pair.

MAG_CHOICE_EXP_NYC_PHL = Variable for calculating the exponential of the mode choice in the mode split model for the New York and Philadelphia city pair.

MAG_CHOICE_EXP_NYC_WAS = Variable for calculating the exponential of the mode choice in the mode split model for the New York and Washington city pair.

MAG_CHOICE_EXP_PHL_WAS = Variable for calculating the exponential of the mode choice in the mode split model for the Philadelphia and Washington city pair.

MAG_CHOICE_FUNCT_BOS_NYC = Variable for calculating the mode choice function in the mode split model for the Boston and New York city pair.

MAG_CHOICE_FUNCT_BOS_PHL = Variable for calculating the mode choice function in the mode split model for the Boston and Philadelphia city pair.

MAG_CHOICE_FUNCT_BOS_WAS = Variable for calculating the mode choice function in the mode split model for the Boston and Washington city pair.

MAG_CHOICE_FUNCT_NYC_PHL = Variable for calculating the mode choice function in the mode split model for the New York and Philadelphia city pair.

Appendix F. Description of Variables
MAG_CHOICE_FUNCT_NYC_WAS = Variable for calculating the mode choice function in the mode split model for the New York and Washington city pair.
MAG_CHOICE_FUNCT_PHL_WAS = Variable for calculating the mode choice function in the mode split model for the Philadelphia and Washington city pair.
MAG_FARE_ALPHA_BOS_NYC = The Elasticity value of maglev fare between Boston and New York.
MAG_FARE_ALPHA_BOS_PHL = The Elasticity value of maglev fare between Boston and Philadelphia.
MAG_FARE_ALPHA_BOS_WAS = The Elasticity value of maglev fare between Boston and Washington.
MAG_FARE_ALPHA_NYC_PHL = The Elasticity value of maglev fare between New York and Philadelphia.
MAG_FARE_ALPHA_NYC_WAS = The Elasticity value of maglev fare between New York and Washington.
MAG_FARE_ALPHA_PHL_WAS = The Elasticity value of maglev fare between Philadelphia and Washington.
MAG_FARE_BOS_NYC = The fare charged by maglev between Boston and New York.
MAG_FARE_BOS_PHL = The fare charged by maglev between Boston and Philadelphia.
MAG_FARE_BOS_WAS = The fare charged by maglev between Boston and Washington.
MAG_FARE_NYC_PHL = The fare charged by maglev between New York and Philadelphia.
MAG_FARE_NYC_WAS = The fare charged by maglev between New York and Washington.
MAG_FARE_PHL_WAS = The fare charged by maglev between Philadelphia and Washington.
MAG_FREQ_BETA_BOS_NYC = The Elasticity value of maglev frequency between Boston and New York.
MAG_FREQ_BETA_BOS_PHL = The Elasticity value of maglev frequency between Boston and Philadelphia.
MAG_FREQ_BETA_BOS_WAS = The Elasticity value of maglev frequency between Boston and Washington.
MAG_FREQ_BETA_NYC_PHL = The Elasticity value of maglev frequency between New York and Philadelphia.
MAG_FREQ_BETA_NYC_WAS = The Elasticity value of maglev frequency between New York and Washington.

Appendix F. Description of Variables
MAG_FREQ_BETA_PHL_WAS = The Elasticity value of maglev frequency between Philadelphia and Washington.
MAG_INCOME_BOS_NYC = Annual income from maglev fares between Boston and New York.
MAG_INCOME_BOS_PHL = Annual income from maglev fares between Boston and Philadelphia.
MAG_INCOME_BOS_WAS = Annual income from maglev fares between Boston and Washington.
MAG_INCOME_NYC_PHL = Annual income from maglev fares between New York and Philadelphia.
MAG_INCOME_NYC_WAS = Annual income from maglev fares between New York and Washington.
MAG_INCOME_PHL_WAS = Annual income from maglev fares between Philadelphia and Washington.
MAG_PAX_CAP_BOS_NYC = Passenger capacity of a maglev operating between Boston and New York.
MAG_PAX_CAP_BOS_PHL = Passenger capacity of a maglev operating between Boston and Philadelphia.
MAG_PAX_CAP_BOS_WAS = Passenger capacity of a maglev operating between Boston and Washington.
MAG_PAX_CAP_NYC_PHL = Passenger capacity of a maglev operating between New York and Philadelphia.
MAG_PAX_CAP_PHL_WAS = Passenger capacity of a maglev operating between Philadelphia and Washington.
MAG_PROB_BOS_NYC = The probability of a passenger travelling by maglev between Boston and New York.
MAG_PROB_BOS_PHL = The probability of a passenger travelling by maglev between Boston and Philadelphia.
MAG_PROB_BOS_WAS = The probability of a passenger travelling by maglev between Boston and Washington.
MAG_PROB_NYC_PHL = The probability of a passenger travelling by maglev between New York and Philadelphia.

Appendix F. Description of Variables
MAG_PROB_NYC_WAS = The probability of a passenger travelling by maglev between New York and Washington.
MAG_PROB_PHL_WAS = The probability of a passenger travelling by maglev between Philadelphia and Washington.
MAG_RUN_TIME_BOS_NYC = Travel time of maglev between Boston and New York.
MAG_RUN_TIME_BOS_PHL = Travel time of maglev between Boston and Philadelphia.
MAG_RUN_TIME_BOS_WAS = Travel time of maglev between Boston and Washington.
MAG_RUN_TIME_NYC_PHL = Travel time of maglev between New York and Philadelphia.
MAG_RUN_TIME_NYC_WAS = Travel time of maglev between New York and Washington.
MAG_RUN_TIME_PHL_WAS = Travel time of maglev between Philadelphia and Washington.
MAG_STOP_TIME_BOS_NYC = Time spent at a stand still at intermediate stops between Boston and New York.
MAG_STOP_TIME_BOS_PHL = Time spent at a stand still at intermediate stops between Boston and Philadelphia.
MAG_STOP_TIME_BOS_WAS = Time spent at a stand still at intermediate stops between Boston and Washington.
MAG_STOP_TIME_NYC_PHL = Time spent at a stand still at intermediate stops between New York and Philadelphia.
MAG_STOP_TIME_NYC_WAS = Time spent at a stand still at intermediate stops between New York and Washington.
MAG_STOP_TIME_PHL_WAS = Time spent at a stand still at intermediate stops between Philadelphia and Washington.
MAG_TT_ALPHA_BOS_NYC = Elasticity value of maglev travel time between Boston and New York.
MAG_TT_ALPHA_BOS_PHL = Elasticity value of maglev travel time between Boston and Philadelphia.
MAG_TT_ALPHA_BOS_WAS = Elasticity value of maglev travel time between Boston and Washington.
MAG_TT_ALPHA_NYC_PHL = Elasticity value of maglev travel time between New York and Philadelphia.
MAG_TT_ALPHA_NYC_WAS = Elasticity value of maglev travel time between New York and Washington.

Appendix F. Description of Variables
MAG_TT_ALPHA_PHL_WAS = Elasticity value of maglev travel time between Philadelphia and Washington.
MAG_TT_BOS_NYC = Total travel time by maglev between Boston and New York.
MAG_TT_BOS_PHL = Total travel time by maglev between Boston and Philadelphia.
MAG_TT_BOS_WAS = Total travel time by maglev between Boston and Washington.
MAG_TT_NYC_PHL = Total travel time by maglev between New York and Philadelphia.
MAG_TT_NYC_WAS = Total travel time by maglev between New York and Washington.
MAG_TT_PHL_WAS = Total travel time by maglev between Philadelphia and Washington.
MAG_UTILIZATION_FACT_BOS_NYC = The utilization factor of a maglev between Boston and New York.
MAG_UTILIZATION_FACT_BOS_PHL = The utilization factor of a maglev between Boston and Philadelphia.
MAG_UTILIZATION_FACT_BOS_WAS = The utilization factor of a maglev between Boston and Washington.
MAG_UTILIZATION_FACT_NYC_PHL = The utilization factor of a maglev between New York and Philadelphia.
MAG_UTILIZATION_FACT_PHL_WAS = The utilization factor of a maglev between Philadelphia and Washington.
MAX_FREQ_NYC = The maximum frequency of service at New York maglev station.
MAX_FREQ_PHL = The maximum frequency of service at Philadelphia maglev station.
NEW_GUIDEWAY_UC = Annual unit cost of constructing new guideways.
NORMAL BRAKE RATE = Normal rate of braking.
NUMBER_OF_STATIONS = Total number of stations.
NUMBER_OF_VEHICLES = Number of vehicles required.
NUMBER_OF_VEH_BOS_NYC = Number of vehicles required to satisfy passenger demand between Boston and New York.
NUMBER_OF_VEH_BOS_PHL = Number of vehicles required to satisfy passenger demand between Boston and Philadelphia.
NUMBER_OF_VEH_BOS_WAS = Number of vehicles required to satisfy passenger demand between Boston and Washington.

Appendix F. Description of Variables
NUMBER_OF_VEH_NYC_PHL = Number of vehicles required to satisfy passenger demand between New York and Philadelphia.
NUMBER_OF_VEH_NYC_WAS = Number of vehicles required to satisfy passenger demand between New York and Washington.
NUMBER_OF_VEH_PHL_WAS = Number of vehicles required to satisfy passenger demand between Philadelphia and Washington.
NUMBER_OF_VEH_PER_TRAIN = Number of individual trains coupled together to make up a train.
ONCE_IN_TEN_YEAR_COST = Cost of replacing vehicles after ten years of use.
OTHER_O_AND_M = Other operating and maintenance unit cost not accounted for individually.
OTHER_SOURCES_BOS = New sources of investment to industry in Boston from external sources.
OTHER_SOURCES_NYC = New sources of investment to industry in New York from external sources.
OTHER_SOURCES_PHL = New sources of investment to industry in Philadelphia from external sources.
OTHER_SOURCES_WAS = New sources of investment to industry in Washington from external sources.
O_AND_M_SUBTOTAL = Subtotal of operating and maintenance costs.
PCT_MFG_BOS = Percent of the jobs in Boston in manufacturing industry.
PCT_MFG_NYC = Percent of the jobs in New York in manufacturing industry.
PCT_MFG_PHL = Percent of the jobs in Philadelphia in manufacturing industry.
PCT_MFG_WAS = Percent of the jobs in Washington in manufacturing industry.
PDTN_FACT_BOS = Ratio of annual production to the total industry value for Boston.
PDTN_FACT_NYC = Ratio of annual production to the total industry value for New York.
PDTN_FACT_PHL = Ratio of annual production to the total industry value for Philadelphia.
PDTN_FACT_WAS = Ratio of annual production to the total industry value for Washington.
PLATFORMS_BOS = Number of platforms at the maglev station in Boston.
PLATFORMS_NYC = Number of platforms at the maglev station in New York.
PLATFORMS_PHL = Number of platforms at the maglev station in Philadelphia.
PLATFORMS_WAS = Number of platforms at the maglev station in Washington.
PLATFORM_COST_BOS = Cost of additional platforms at Boston.
PLATFORM_COST_NYC = Cost of additional platforms at New York.

Appendix F. Description of Variables
PLATFORM_COST_PHL = Cost of additional platforms at Philadelphia.
PLATFORM_COST_WAS = Cost of additional platforms at Washington.
POWER_BOS_NYC = Annual power consumption for all maglev trips between Boston and New York.
POWER_NYC_PHL = Annual power consumption for all maglev trips between New York and Philadelphia.
POWER_PHL_WAS = Annual power consumption for all maglev trips between Philadelphia and Washington.
POWER_CONSUMED_BOS_NYC = Power consumed for one maglev trip between Boston and New York.
POWER_CONSUMED_NYC_PHL = Power consumed for one maglev trip between New York and Philadelphia.
POWER_CONSUMED_PHL_WAS = Power consumed for one maglev trip between Philadelphia and Washington.
PRODUCTION_BOS = Annual industrial production at Boston.
PRODUCTION_NYC = Annual industrial production at New York.
PRODUCTION_PHL = Annual industrial production at Philadelphia.
PRODUCTION_WAS = Annual industrial production at Washington.
REACTION_TIME = The reaction time for braking.
RELATIVE_CT_BOS_NYC = The relative cost of fares between Boston and New York.
RELATIVE_CT_BOS_PHL = The relative cost of fares between Boston and Philadelphia.
RELATIVE_CT_BOS_WAS = The relative cost of fares between Boston and Washington.
RELATIVE_CT_NYC_PHL = The relative cost of fares between New York and Philadelphia.
RELATIVE_CT_NYC_WAS = The relative cost of fares between New York and Washington.
RELATIVE_CT_PHL_WAS = The relative cost of fares between Philadelphia and Washington.
RELATIVE_TT_BOS_NYC = The relative travel time between modes between Boston and New York.
RELATIVE_TT_BOS_PHL = The relative travel time between modes between Boston and Philadelphia.
RELATIVE_TT_BOS_WAS = The relative travel time between modes between Boston and Washington.
RELATIVE_TT_NYC_PHL = The relative travel time between modes between New York and Philadelphia.

Appendix F. Description of Variables
RELATIVE_TT_NYC_WAS = The relative travel time between modes between New York and Washington.
RELATIVE_TT_PHL_WAS = The relative travel time between modes between Philadelphia and Washington.
ROUTINE_SERVICE_UNIT_U_C = Annual unit cost of routine servicing of vehicles.
ROW_COST_PER_MILE = Cost per mile for acquiring the right of way.
SAFETY_FACTOR_K = A safety factor for computing the station capacity.
SALES_BOS = The value of retail sales in Boston.
SALES_NYC = The value of retail sales in New York.
SALES_PHL = The value of retail sales in Philadelphia.
SALES_WAS = The value of retail sales in Washington.
SALES_FACTOR_BOS = The fraction of per capita income which is spent in Boston.
SALES_FACTOR_NYC = The fraction of per capita income which is spent in New York.
SALES_FACTOR_PHL = The fraction of per capita income which is spent in Philadelphia.
SALES_FACTOR_WAS = The fraction of per capita income which is spent in Washington.
SALES_U_C = Unit cost of sales and advertising per passenger.
SERVICE_JOBS_BOS = Total jobs in administrative and other services in Boston.
SERVICE_JOBS_NYC = Total jobs in administrative and other services in New York.
SERVICE_JOBS_PHL = Total jobs in administrative and other services in Philadelphia.
SERVICE_JOBS_WAS = Total jobs in administrative and other services in Washington.
SERVICE_J_FACT_BOS = The fraction of population per job in Boston.
SERVICE_J_FACT_NYC = The fraction of population per job in New York.
SERVICE_J_FACT_PHL = The fraction of population per job in Philadelphia.
SERVICE_J_FACT_WAS = The fraction of population per job in Washington.
STATION_CAPACITY = The number of vehicles a station can process per day.
STATION_OPERATIONS = Total cost of operations at stations.
STATION_OPERATIONS_U_C = Annual unit cost for operating one station.
STATION_STANDING_TIME = The time the vehicle stops at a station.
SUM_OF_MODE_BOS_NYC = The sum of the choice function for both modes for travel between Boston and New York.
SUM_OF_MODE_BOS_PHL = The sum of the choice function for both modes for travel between Boston and Philadelphia.

Appendix F. Description of Variables
SUM_OF_MODE_BOS_WAS = The sum of the choice function for both modes for travel between Boston and Washington.
SUM_OF_MODE_NYC_PHL = The sum of the choice function for both modes for travel between New York and Philadelphia.
SUM_OF_MODE_NYC_WAS = The sum of the choice function for both modes for travel between New York and Washington.
SUM_OF_MODE_PHL_WAS = The sum of the choice function for both modes for travel between Philadelphia and Washington.
SUPPORTED_POP_BOS = The total population which has a source of income for support in Boston.
SUPPORTED_POP_NYC = The total population which has a source of income for support in New York.
SUPPORTED_POP_PHL = The total population which has a source of income for support in Philadelphia.
SUPPORTED_POP_WAS = The total population which has a source of income for support in Washington.
S_P_RATIO_BOS = The ratio of sales to production in Boston.
S_P_RATIO_NYC = The ratio of sales to production in New York.
S_P_RATIO_PHL = The ratio of sales to production in Philadelphia.
S_P_RATIO_WAS = The ratio of sales to production in Washington.
TG_ALPHA_0_BOS_NYC = Elasticity value of the trip generation by mode model for trips between Boston and New York.
TG_ALPHA_0_BOS_PHL = Elasticity value of the trip generation by mode model for trips between Boston and Philadelphia.
TG_ALPHA_0_BOS_WAS = Elasticity value of the trip generation by mode model for trips between Boston and Washington.
TG_ALPHA_0_NYC_PHL = Elasticity value of the trip generation by mode model for trips between New York and Philadelphia.
TG_ALPHA_0_NYC_WAS = Elasticity value of the trip generation by mode model for trips between New York and Washington.
TG_ALPHA_0_PHL_WAS = Elasticity value of the trip generation by mode model for trips between Philadelphia and Washington.

Appendix F. Description of Variables
TG_ALPHA_1_BOS_NYC = Elasticity value of population of Boston for trips between Boston and New York.
TG_ALPHA_1_BOS_PHL = Elasticity value of population of Boston for trips between Boston and Philadelphia.
TG_ALPHA_1_BOS_WAS = Elasticity value of population of Boston for trips between Boston and Washington.
TG_ALPHA_1_NYC_PHL = Elasticity value of population of New York for trips between New York and Philadelphia.
TG_ALPHA_1_NYC_WAS = Elasticity value of population of New York for trips between New York and Washington.
TG_ALPHA_1_PHL_WAS = Elasticity value of population of Philadelphia for trips between Philadelphia and Washington.
TG_ALPHA_2_BOS_NYC = Elasticity value of population of New York for trips between Boston and New York.
TG_ALPHA_2_BOS_PHL = Elasticity value of population of Philadelphia for trips between Boston and Philadelphia.
TG_ALPHA_2_BOS_WAS = Elasticity value of population of Washington for trips between Boston and Washington.
TG_ALPHA_2_PHL_WAS = Elasticity value of population of Washington for trips between Philadelphia and Washington.
TG_ALPHA_3_BOS_NYC = Elasticity value of per capita income of Boston for trips between Boston and New York.
TG_ALPHA_3_BOS_PHL = Elasticity value of per capita income of Boston for trips between Boston and Philadelphia.
TG_ALPHA_3_BOS_WAS = Elasticity value of per capita income of Boston for trips between Boston and Washington.

Appendix F. Description of Variables
TG_ALPHA_4_BOS_NYC = Elasticity value of per capita income of New York for trips between Boston and New York.
TG_ALPHA_4_BOS_PHL = Elasticity value of per capita income of Philadelphia for trips between Boston and Philadelphia.
TG_ALPHA_4_BOS_WAS = Elasticity value of per capita income of Washington for trips between Boston and Washington.
TG_ALPHA_5_BOS_NYC = Elasticity value of percentage of the total employment that is in manufacturing for Boston for trips between Boston and New York.
TG_ALPHA_5_BOS_PHL = Elasticity value of percentage of the total employment that is in manufacturing for Boston for trips between Boston and Philadelphia.
TG_ALPHA_5_BOS_WAS = Elasticity value of percentage of the total employment that is in manufacturing for Boston for trips between Boston and Washington.
TG_ALPHA_5_NYC_PHL = Elasticity value of percentage of the total employment that is in manufacturing for New York for trips between New York and Philadelphia.
TG_ALPHA_5_NYC_WAS = Elasticity value of percentage of the total employment that is in manufacturing for New York for trips between New York and Washington.
TG_ALPHA_5_PHL_WAS = Elasticity value of percentage of the total employment that is in manufacturing for Philadelphia for trips between Philadelphia and Washington.
TG_ALPHA_6_BOS_NYC = Elasticity value of percentage of the total employment that is in manufacturing for New York for trips between Boston and New York.
TG_ALPHA_6_BOS_PHL = Elasticity value of percentage of the total employment that is in manufacturing for Philadelphia for trips between Boston and Philadelphia.

Appendix F. Description of Variables
TG_ALPHA_6_BOS_WAS = Elasticity value of percentage of the total employment that is in manufacturing for Washington for trips between Boston and Washington.

TG_ALPHA_6_NYC_PHL = Elasticity value of percentage of the total employment that is in manufacturing for Philadelphia for trips between New York and Philadelphia.

TG_ALPHA_6_NYC_WAS = Elasticity value of percentage of the total employment that is in manufacturing for Washington for trips between New York and Washington.

TG_ALPHA_6_PHL_WAS = Elasticity value of percentage of the total employment that is in manufacturing for Philadelphia and Washington.

TG_BETA_1_BOS_NYC = Elasticity value of travel time for trips between Boston and New York.

TG_BETA_1_BOS_PHL = Elasticity value of travel time for trips between Boston and Philadelphia.

TG_BETA_1_BOS_WAS = Elasticity value of travel time for trips between Boston and Washington.

TG_BETA_1_NYC_PHL = Elasticity value of travel time for trips between New York and Philadelphia.

TG_BETA_1_NYC_WAS = Elasticity value of travel time for trips between New York and Washington.

TG_BETA_1_PHL_WAS = Elasticity value of travel time for trips between Philadelphia and Washington.

TG_BETA_2_BOS_NYC = Elasticity value of best travel time of all modes for trips between Boston and New York.

TG_BETA_2_BOS_PHL = Elasticity value of best travel time of all modes for trips between Boston and Philadelphia.

TG_BETA_2_BOS_WAS = Elasticity value of best travel time of all modes for trips between Boston and Washington.

TG_BETA_2_NYC_PHL = Elasticity value of best travel time of all modes for trips between New York and Philadelphia.

TG_BETA_2_NYC_WAS = Elasticity value of best travel time of all modes for trips between New York and Washington.

TG_BETA_2_PHL_WAS = Elasticity value of best travel time of all modes for trips between Philadelphia and Washington.

TG_BETA_3_BOS_NYC = Elasticity value of travel cost for trips between Boston and New York.

Appendix F. Description of Variables
TG_BETA_3_BOS_PHL = Elasticity value of travel cost for trips between Boston and Philadelphia.
TG_BETA_3_BOS_WAS = Elasticity value of travel cost for trips between Boston and Washington.
TG_BETA_3_NYC_PHL = Elasticity value of travel cost for trips between New York and Philadelphia.
TG_BETA_3_NYC_WAS = Elasticity value of travel cost for trips between New York and Washington.
TG_BETA_3_PHL_WAS = Elasticity value of travel cost for trips between Philadelphia and Washington.
TG_BETA_4_BOS_NYC = Elasticity value of best travel cost for all modes for trips between Boston and New York.
TG_BETA_4_BOS_PHL = Elasticity value of best travel cost for all modes for trips between Boston and Philadelphia.
TG_BETA_4_BOS_WAS = Elasticity value of best travel cost for all modes for trips between Boston and Washington.
TG_BETA_4_NYC_PHL = Elasticity value of best travel cost for all modes for trips between New York and Philadelphia.
TG_BETA_4_NYC_WAS = Elasticity value of best travel cost for all modes for trips between New York and Washington.
TG_BETA_4_PHL_WAS = Elasticity value of best travel cost for all modes for trips between Philadelphia and Washington.
TG_TRIPS_BOS_NYC = Total round trips by airplane and maglev combined between Boston and New York.
TG_TRIPS_BOS_PHL = Total round trips by airplane and maglev combined between Boston and Philadelphia.
TG_TRIPS_BOS_WAS = Total round trips by airplane and maglev combined between Boston and Washington.
TG_TRIPS_NYC_PHL = Total round trips by airplane and maglev combined between New York and Philadelphia.
TG_TRIPS_NYC_WAS = Total round trips by airplane and maglev combined between New York and Washington.

Appendix F. Description of Variables
TG_TRIPS_PHL_WAS = Total round trips by airplane and maglev combined between Philadelphia and Washington.
TOTAL_J_BOS = The total number of jobs in Boston.
TOTAL_J_NYC = The total number of jobs in New York.
TOTAL_J_PHL = The total number of jobs in Philadelphia.
TOTAL_J_WAS = The total number of jobs in Washington.
TOTAL_PLATFORM_COST = Total cost of additional platforms required to handle the increase in traffic.
TOTAL_POWER = The total annual power consumed by the system.
TOTAL_POWER_COST = The total annual cost of power.
TOTAL_TT_AIR_BOS_NYC = The total travel time by air between Boston and New York.
TOTAL_TT_AIR_BOS_PHL = The total travel time by air between Boston and Philadelphia.
TOTAL_TT_AIR_BOS_WAS = The total travel time by air between Boston and Washington.
TOTAL_TT_AIR_NYC_PHL = The total travel time by air between New York and Philadelphia.
TOTAL_TT_AIR_NYC_WAS = The total travel time by air between New York and Washington.
TOTAL_TT_AIR_PHL_WAS = The total travel time by air between Philadelphia and Washington.
TOTAL_TT_MAG_BOS_NYC = The total travel time by maglev between Boston and New York.
TOTAL_TT_MAG_BOS_PHL = The total travel time by maglev between Boston and Philadelphia.
TOTAL_TT_MAG_BOS_WAS = The total travel time by maglev between Boston and Washington.
TOTAL_TT_MAG_NYC_PHL = The total travel time by maglev between New York and Philadelphia.
TOTAL_TT_MAG_NYC_WAS = The total travel time by maglev between New York and Washington.
TOTAL_TT_MAG_PHL_WAS = The total travel time by maglev between Philadelphia and Washington.
TRAFFIC_CONTROL_U_C = The unit annual cost of traffic control systems.
TRAIN_CREW_U_C = The unit annual cost of staff and crew.
TRAIN_MAINTENANCE = The total annual maintenance cost.
TRAIN_SUPPLIES = Unit annual cost of train supplies per passenger.

Appendix F. Description of Variables
TRIPS_PER_VEH_DAILY_BOS_NYC = Trips done per day per vehicle between Boston and New York.
TRIPS_PER_VEH_DAILY_BOS_PHL = Trips done per day per vehicle between Boston and Philadelphia.
TRIPS_PER_VEH_DAILY_BOS_WAS = Trips done per day per vehicle between Boston and Washington.
TRIPS_PER_VEH_DAILY_NYC_PHL = Trips done per day per vehicle between New York and Philadelphia.
TRIPS_PER_VEH_DAILY_NYC_WAS = Trips done per day per vehicle between New York and Washington.
TRIPS_PER_VEH_DAILY_PHL_WAS = Trips done per day per vehicle between Philadelphia and Washington.
T_AND_O_FACT_BOS = Fraction of sales per job in the trade and other service sector in Boston.
T_AND_O_FACT_NYC = Fraction of sales per job in the trade and other service sector in New York.
T_AND_O_FACT_PHL = Fraction of sales per job in the trade and other service sector in Philadelphia.
T_AND_O_FACT_WAS = Fraction of sales per job in the trade and other service sector in Washington.
T_AND_O_JOBS_BOS = Total number of jobs in retail trade and other services in Boston.
T_AND_O_JOBS_NYC = Total number of jobs in retail trade and other services in New York.
T_AND_O_JOBS_PHL = Total number of jobs in retail trade and other services in Philadelphia.
T_AND_O_JOBS_WAS = Total number of jobs in retail trade and other services in Washington.
UNIT_COST_MAINT_ELECTRIFICATION = Unit annual cost for maintenance of electrification.
UNIT_COST_OTHER_FACILITIES = Unit annual cost for providing supporting facilities.
UNIT_COST_POWER = The cost of power per kilowatt hour.
UNIT_COST_SIGNALS_COMMUNICATION = Unit annual cost of signals and communications.
UNIT_COST_TRACK_GUIDEWAY = The unit cost per mile for Guideways.
UTILIZED_CAP_AIR_BOS_NYC = The utilized capacity of an average aircraft operating between Boston and New York.
UTILIZED_CAP_AIR_BOS_PHL = The utilized capacity of an average aircraft operating between Boston and Philadelphia.

Appendix F. Description of Variables
UTILIZED_CAP_AIR_BOS_WAS = The utilized capacity of an average aircraft operating between Boston and Washington.
UTILIZED_CAP_AIR_NYC_PHL = The utilized capacity of an average aircraft operating between New York and Philadelphia.
UTILIZED_CAP_AIR_NYC_WAS = The utilized capacity of an average aircraft operating between New York and Washington.
UTILIZED_CAP_AIR_PHL_WAS = The utilized capacity of an average aircraft operating between Philadelphia and Washington.
UTILIZED_CAP_MAG_BOS_NYC = The utilized capacity of a maglev operating between Boston and New York.
UTILIZED_CAP_MAG_BOS_PHL = The utilized capacity of a maglev operating between Boston and Philadelphia.
UTILIZED_CAP_MAG_BOS_WAS = The utilized capacity of a maglev operating between Boston and Washington.
UTILIZED_CAP_MAG_NYC_PHL = The utilized capacity of a maglev operating between New York and Philadelphia.
UTILIZED_CAP_MAG_NYC_WAS = The utilized capacity of a maglev operating between New York and Washington.
UTILIZED_CAP_MAG_PHL_WAS = The utilized capacity of a maglev operating between Philadelphia and Washington.
VELOCITY_MAGLEV = The cruising speed of the maglev.
FLIGHT_DELAY_BOS_NYC = A graph representing the delay experienced by airplanes between Boston and New York.
FLIGHT_DELAY_BOS_PHL = A graph representing the delay experienced by airplanes between Boston and Philadelphia.
FLIGHT_DELAY_BOS_WAS = A graph representing the delay experienced by airplanes between Boston and Washington.
FLIGHT_DELAY_NYC_PHL = A graph representing the delay experienced by airplanes between New York and Philadelphia.
FLIGHT_DELAY_NYC_WAS = A graph representing the delay experienced by airplanes between New York and Washington.
FLIGHT_DELAY_PHL_WAS = A graph representing the delay experienced by airplanes between Philadelphia and Washington.

Appendix F. Description of Variables
GROWTH_FACT_BOS = A table function which controls the rate of change of population in Boston.
GROWTH_FACT_NYC = A table function which controls the rate of change of population in New York.
GROWTH_FACT_PHL = A table function which controls the rate of change of population in Philadelphia.
GROWTH_FACT_WAS = A table function which controls the rate of change of population in Washington.
INDUSTRY_FACT_BOS = A table function which controls the rate at which investments are made in industry in Boston.
INDUSTRY_FACT_NYC = A table function which controls the rate at which investments are made in industry in New York.
INDUSTRY_FACT_PHL = A table function which controls the rate at which investments are made in industry in Philadelphia.
INDUSTRY_FACT_WAS = A table function which controls the rate at which investments are made in industry in Washington.
MAG_CONTROL_BOS_NYC = A control variable which controls the year in which the magnetically levitated transportation system should be implemented between Boston and New York.
MAG_CONTROL_BOS_PHL = A control variable which controls the year in which the magnetically levitated transportation system should be implemented between Boston and Philadelphia.
MAG_CONTROL_BOS_WAS = A control variable which controls the year in which the magnetically levitated transportation system should be implemented between Boston and Washington.
MAG_CONTROL_NYC_PHL = A control variable which controls the year in which the magnetically levitated transportation system should be implemented between New York and Philadelphia.
MAG_CONTROL_NYC_WAS = A control variable which controls the year in which the magnetically levitated transportation system should be implemented between New York and Washington.
MAG_CONTROL_PHL_WAS = A control variable which controls the year in which the magnetically levitated transportation system should be implemented between Philadelphia and Washington.

Appendix F. Description of Variables
MAG_DELAY_BOS_NYC = A graph representing the delay experienced by maglevs between Boston and New York.

MAG_DELAY_BOS_PHL = A graph representing the delay experienced by maglevs between Boston and Philadelphia.

MAG_DELAY_BOS_WAS = A graph representing the delay experienced by maglevs between Boston and Washington.

MAG_DELAY_NYC_PHL = A graph representing the delay experienced by maglevs between New York and Philadelphia.

MAG_DELAY_NYC_WAS = A graph representing the delay experienced by maglevs between New York and Washington.

MAG_DELAY_PHL_WAS = A graph representing the delay experienced by maglevs between Philadelphia and Washington.

PCI_FACT_BOS = A table function which controls the rate of change of per capita income in Boston.

PCI_FACT_NYC = A table function which controls the rate of change of per capita income in New York.

PCI_FACT_PHL = A table function which controls the rate of change of per capita income in Philadelphia.

PCI_FACT_WAS = A table function which controls the rate of change of per capita income in Washington.

VEH = A table function used for calculating the time at which vehicles ten years old or more have to be replaced.

Appendix F. Description of Variables
Vita

Anil Thomas Panicker was born in India on May 13, 1964. He graduated with a Bachelor's degree in Civil Engineering from the Manipal Institute of Technology in July, 1985. He worked on various construction projects in India from 1985 to 1989. In 1989 he was accepted as a graduate student pursuing his Master of Science degree in Transportation Engineering at the Virginia Polytechnic Institute and State University. The author is currently pending graduation. He is presently employed with the Fifth Planning District Commission in Roanoke, Virginia.