# TRAFFIC ASSIGNMENT IN TRANSFORMING NETWORKS
CASE STUDY: ANKARA

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# ABSTRACT

## TRAFFIC ASSIGNMENT IN TRANSFORMING NETWORKS
## CASE STUDY: ANKARA

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This study investigates the relevance of dynamic traffic assignment models under uncertainty. In the last years researchers have dealt with advanced traffic control systems since road provision is not regarded as a proper solution to relieve congestion. Dynamic assignment which is an essential component of investment planning is regarded as a new research area in the field of urban transportation. In this study the performance of dynamic traffic assignment method, which incorporates time dependent flow, is compared with that of static model. Research outcomes showed that dynamic assignment method provides more reliable outcomes in predicting traffic flow; therefore its solution algorithm is integrated to conventional four staged model. Literature survey showed that researches have hot provided an appropriate framework for transforming networks. This study investigates travel demand variations in a dynamic city and discuses possible strategies to respond dynamic and uncertain properties of individuals' travel behavior. Research findings showed that both external and internal uncertainties have significant influences on reliability of the model. Recommended procedure aims reducing uncertainty in order to improve reliability of model. Finally, the relevancy of the problem and the applicability of recently developed methods are discussed in Ankara case.

Key words: travel demand, uncertainty, traffic assignment, static and dynamic models and transportation network.

# ÖZ

## DÖNÜŞMEKTE OLAN ULAŞIM AĞLARINDA TRAFİK ATAMASI ANKARA ÖRNEĞİ

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Bu çalışma devingen trafik atama yöntemlerinin belirsizlik koşullarındaki geçerliliğini irdelemektedir. Son yıllarda araşırmacılar yol yatırımlarının trafik sıkışıklığını azaltmak için uygun bir yöntem olmadığı düşüncesiyle ileri trafik denetim sistemleri üzerinde çalışmaktadır. Devingen trafik ataması, ki bu yöntem ulaşım yatırım analizlerinin önemli bir parçadır, kentsel ulaşım planlaması alanında yeni bir araştırma alanı olarak görülmektedir. Bu çalışmada yolculukların zamana bağlı akışını öngören dinamik trafik atama yöntemi durağan yöntemle karşılaştırılmaktadır. Araştırma sonuçları dinamik yöntemin daha güvenilir sonuçlar verdiğini göstermiştir. Bu nedenle bu yöntem geleneksel dört aşamalı ulaşım talep tahmin modeline entegre edilmiştir. Bu konudaki yazın üzerinde yapılan araştırmada, dinamik trafik atama yöntemleri üzerine yapılan çalışmalarda bu yöntemlerin dönüşmekte olan ulaşım ağlarında uygulanmasına yönelik bir çerçeve sunulmadığını tespit edilmiştir. Bu çalışmada devingen bir kentte yolculuk talebindeki değişimler araştırılmakta bireylerin yolculuk davranışlarındaki devingen ve belirsiz nitelikleri dikkate alan stratejiler tartışılmaktadır. Araştırma sonuçları hem dışsal hem de içsel belirsizliklerin model günenilirliğini önemli düzeyde etkilediklerini göstermektedir. Çalışmanın son bölümünde yakın dönemde geliştirilen yöntemlerin uygulanabilirlikleri Ankara örneğinde tartışılmaktadır.

Anahtar sözcükler: yolculuk talebi, belirsizlik, trafik ataması, durağan ve devingen modeller ve ulaşım ağı.

TO MY FAMILY

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# CHAPTER 1

# INTRODUCTION

This study investigates the relevance of network assignment models under uncertainty in order to find out relative advantages and drawbacks of dynamic traffic assignment models. The research focuses on the issues of travel demand analysis, especially traffic assignment methods which are extensively employed in urban transportation infrastructure planning and design. The study considers the issues which are essential in contemporary transportation planning and investigates the problems of travel demand models in a transforming network.

Travel demand is regarded as an "aggregation of the behaviors of all individual trip makers" within a studied area and transportation network design extremely depends on travel demand forecasting. Due to uncertain character of travel demand, researchers investigated short-term planning and management solutions which take into account temporal variations.

"Dynamic traffic assignment", an essential component of transportation network design and traffic management, is extensively employed in order to obtain accurate prediction of traffic flow. Transportation network design process covers a broad range of issues and methods. Estimating traffic flow and proper service provision are conventional sequences of this process. Conventionally, network design involves road provision, capacity improvement, and junction design.

Through recent developments, network design showed considerable progress and involved new application areas; such as, setting one way routes, ramp metering, setting high occupancy vehicle lanes and temporal use of road space. Transportation network design depends on a set of information: road capacities, vehicle speeds in congested networks, travel cost, shortest paths, and traffic flow predictions. This information set is principally obtained by traffic assignment methods.

Traffic management systems involve traffic control measures, setting public transportation priority, provision of real-time traffic information, centralized signal control systems and driver guidance systems (Ran and Boyce, 1994).

Recently more elastic models are developed; however, such models are case sensitive or hypothetic. Besides, driver route guidance systems and intelligent transportation systems are practiced to relieve congestion. Advanced traffic management systems, extremely depending on sensitive traffic flow predictions, are developed in order to use road space efficiently. In these systems new technologies are introduced to maximize network flexibility and information technology is employed to guide travelers.

This study stresses that although many strategies are adapted to transportation planning, cities are still experiencing traffic congestion. Since provision of new infrastructure (road investment, level junctions etc.) necessitates large capital investment, in the last two decades, in the cities of developed countries most of the urban transportation investment projects are motivated around efficient use of road space. On the other hand, in the cities of developing countries, the shares of car trips within total trips are relatively less than those of developed countries; therefore there are many opportunities to implement a range of strategies.

In developing countries, cities are rapidly growing and transforming. Due to inadequate transportation service provision traffic congestion have significant negative impacts on urban environment. Especially in city centers congestion is a major urban transportation problem. Such problems are expected to reach dramatic levels. In those countries policy makers seek large capital investments; however, this may not be an appropriate solution to relieve congestion (World Bank, 2000a, 2000b). According to Dimitriou (1992), World Bank (2000) and OECD (2002) many developing countries are searching financial resources to implement major transportation projects like public transportation and road investment.

Infrastructure provision in public transportation is sometimes regarded as the single solution to cope with transportation problems, and in such cases special emphasis is not given to efficient use of road transportation. On the contrary, sometimes large capital investments are paid for road provision. However, in both cases traffic congestion may not be reduced. It is commonly accepted that road supply results in increasing traffic demand, hence capacity improvement results in additional traffic, "induced traffic" (Cervero, 2001).

Recent studies focus on appropriate and flexible planning and modeling procedures in order to achieve efficiency in major urban transportation service provision. Reliability of models is the necessary precondition of rational provision of transportation services. As far as rapid transformation of land use and transportation networks are considered, prediction models face with uncertainty. Due to complexity of individuals' travel behavior, this problem results in biased predictions that provides essential information for investment planning. Hence majority of existing models may not provide reliable predictions dealing with dynamic travel patterns.

In this study, a dynamic network assignment procedure is carried out as component of conventional travel demand estimation model in order to integrate these models with strategies aiming at the proper use of transportation infrastructure. Hence, the scope of "dynamic traffic assignment" is necessarily extended to a broader context: dynamic travel demand simulation.

Literature survey showed that, today in European and American cities construction of new roads is nearly impossible and not a practical solution due to high capital costs in built up areas (WBCSD, 2001; 2004). Therefore, in such countries traffic management strategies have been extensively applied. It is obvious that traffic management does not necessitate too costly investments. Dynamic traffic assignment models, intelligent transportation systems and traveler route guidance systems are developed in order to relieve congestion without major investments since these strategies aim at limited increase in road capacity. In this sense, network design models shall take into account the principle of "carrying capacity" and in order to implement such systems effectively uninterrupted travel demand analysis is necessary.

Transportation network design, the process of road network configuration, is necessarily interrelated with land use and transportation network properties. That is advanced traffic control systems are bound to network topology and activity patterns. According to this approach the performance of an existing system can be improved by implementing circulation control systems rather than major physical improvements. Hence optimal solutions between physical measures and circulation control can be searched according to reliable predictions. Due to the uncertain nature of travel demand and transformation of network properties, deciding on appropriate solution between network design (capacity improvement, road provision, and service improvement etc.) and traffic management can be assessed through uninterrupted travel demand analysis rather than static estimation.

In the literature static models are criticized in terms of their structure and capability. Oppenheim (1995) argued that static estimation methods, especially network assignment, are not able to take into account the complex behavior of travelers. Researches on travel demand models have proved that behavioral approaches have the capability to provide more accurate predictions in short time intervals; however, appropriate methods are not developed in order to cope with systematic changes in travel demand. On the other hand, the scope of dynamic assignment models is sometimes reduced to signalization, route guidance or traveler information systems. Such models are extremely dependent on "on time data" and surveying. Besides predictions are time consuming and expensive.

The research emphasizes the role of travel demand models, especially traffic assignment models, in measuring possible advantages and disadvantages of urban transportation projects. In this study, a dynamic traffic assignment model is integrated to the whole structure of travel demand modeling procedure. Since network assignment models are structurally dependent on previous stages of conventional four stage model, performances of these models in transforming networks are under question (have not been tested yet). Continuous information flow and model validation provides a capability to reduce uncertainty and prevents unexpected costs of service provision.

Taking into account the context and objectives of the research and problems underlined above, the structure of the study is presented in Figure 1.1 which draws the scope and methodology.

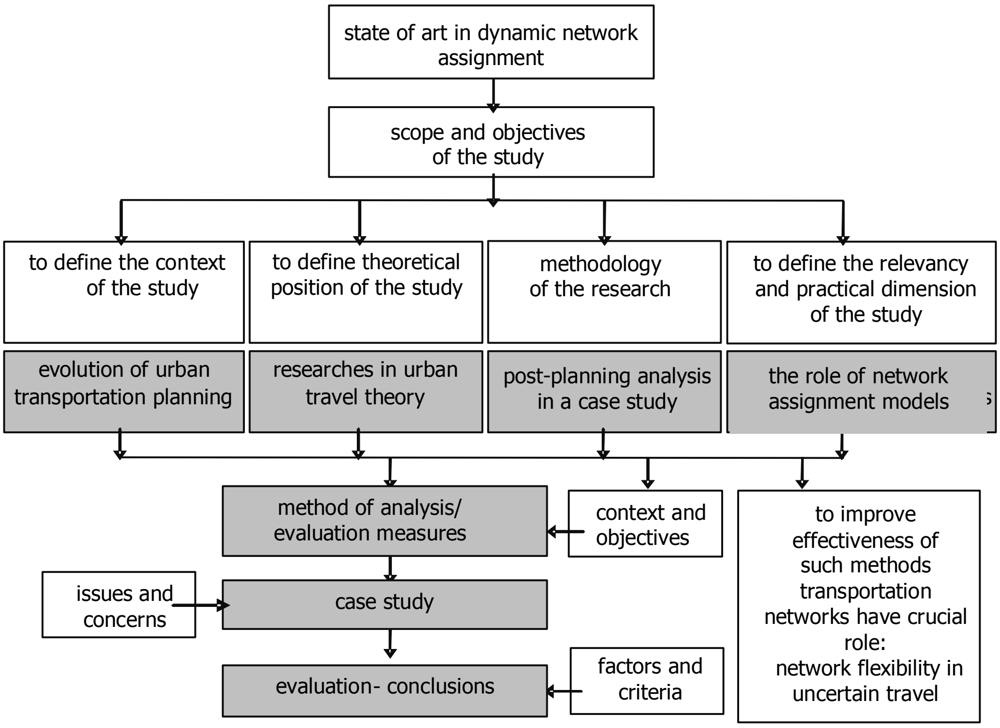



**Figure 1.1: Organization of the research**

The first part of the study comprises problem definition and scope. In the second chapter the evolution of urban transportation planning and discussions on current problems of travel demand models are presented. In addition, the role of demographic characteristics, land use, urban planning, and transportation networks in individuals' travel behavior are discussed. The literature review showed that in the field of transportation planning there are various challenging dimensions that have not been explored yet.

In the third chapter, components of conventional and recently developed travel demand estimation models are overviewed. Among them special emphasis is given to dynamic traffic assignment models. Assumptions, model inputs and solution algorithms of static and dynamic assignment models are presented in order to analyze the relevance of such approaches under uncertainty.

Objective of the research, evaluation method and expected results are presented in chapter 4. Issues in urban transportation planning, such as uncertainty, are discussed in the case study conducted in Ankara, a rapidly growing and transforming city. Urban development, trends in travel demand and transportation planning experiences are presented to provide a framework for "dynamic city". During this process several forms and sources of uncertainty are detected in the model structure. Then, the model is validated and dynamic traffic assignment model outputs are compared with those of static model with respect to performance and capability.

# CHAPTER 2

# LITERATURE REVIEW: EVOLUTION OF URBAN TRANSPORTATION PLANNING, RECENT ISSUES AND RESERACH

## 2.1. Evolution of Urban Transportation Planning

In this section, a brief summary of the evolution of urban transportation planning is provided. The objective of this part is to review recent discussions in the literature in order to draw theoretical framework of the study.

Dimitriou (1992) provided a comprehensive historiography of urban transportation planning of and summarized evolution of this field into five periods: systematic analysis, development, operational development, conceptual stability, revisionist planning and conceptual ad-hocism. A similar but more detailed historiography is provided by Weiner (1997). Meyer and Miller (1984) presented methods and models that have been employed in the theory and practice. Batty (1994) discussed problems of scientific planning and Boyce (2002) provided a summary of recent discussions on planning models. Recently Chowdhury (2003) presented latest issues, methods and developments in transportation planning practice.

According to Meyer and Miller (1984), Dimitriou (1992), and Weiner (1997) urban transportation studies and planning approaches have been conducted in a scientific manner since the beginning of 20$^{th}$ century. In each period, different issues, concerns, approaches were introduced (see Table 2.1). Researchers add that several issues have been introduced and various research methods, travel demand models, and strategies have been developed in order to provide efficient transportation infrastructure to cope with emerging transportation problems.

It is commonly stated that, increasing automobile ownership has been the main factor of urban transportation problems especially in the cities of European and North American cities (Dimitriou, 1992; Rabinovitch, 1992; Weiner, 1997 and Word Bank, 2000a; WBCSD, 2001). Hence, recent studies attempt to enhance alternative modes (or systems) of transportation against road transportation. Recent studies on urban transportation focus on emerging problems, approaches and advancements in transportation technology. In the Table 2.1, evolution of concerns, issues, approaches and methods in corresponding periods are presented.

**Table 2.1: Developments in Transportation Planning Approaches and Issues**

| PERIOD | APPROACH | ISSUES & PROBLEMS | MODELS & METHODS | PRACTICE |
|---|---|---|---|---|
| **1920's** | SYSTEMATIC ANALYSIS and CONCEPTUAL PLANNING | Congestion, air pollution, environmental quality, | Traffic surveys, | Subway and highway planning, site planning |
| **1930's** | | | | |
| **1940's** | OPERATIONAL PLANNING | Mobility, induced traffic, | Travel pattern analysis, trip generation and trip distribution analysis. | Transportation engineering, street widening |
| **1950's** | | traffic calming accessibility, safety, | Systematic analysis of urban traffic, (Mitchel and Rapkin), Wardrop principle (traveler's behavior), | Traffic planning, traffic management, expressways |
| **1960's** | COMPREHENSIVE PLANNING | Land use-transportation interaction, pubic participation, | Spatial interaction models (Lowry Model), gravity model, four-stage model, transportation master plan, | Long range highway and public transportation planning, |
| **1970's** | | Efficiency, integration of modes, | System theory, combined models, Evans' algorithm, Wilson's model, entropy models, | Advanced public transportation systems, |
| **1980's** | REVISIONIST (SHORT TERM) PLANNING | Congestion pricing, uncertainty, flexibility, affordability, | Travel time valuation methods, discrete choice models, individual utility, travel demand management, | Short term planning, transportation system management, light rail transit systems |
| **1990's** | DIVERSIFIED PLANNING | Sustainability, equity, accessibility, safety, environmental quality. | Geographic information systems, dynamic network assignment models, neural networks. | Intelligent transportation systems, Multi-modal systems. |
| **2000-** | | | | |

Source: (After Meyer and Miller (1984; Lewis et al., 1990; Dimitriou, 1992; Batty,1994; Weiner, 1997 and WBCSD, 2001)

Researchers emphasize that urban transportation theory, comprising of research methods and solution algorithms, has evolved into a more complex and sophisticated field in the last five decades (Dickey, 1983; Meyer and Miller, 1984; Lewis et al., 1990; Dimitriou, 1992; Masser et al, 1992; Ben Akiva et al., 1996; Weiner, 1997; Peeta and Ziliaskopoulos, 2001).

According to Weiner (1997) during the 1920's and early 1930's, a number of studies, based on analyzing existing travel demand, were conducted to determine the capacity of highways to carry traffic. Wiener argued that such studies were not based on comprehensive survey methods and due to the complex structure travel patterns survey results were not able to represent actual travel demand and these methods (home-interviews and origin-destination surveys) were developed to obtain necessary data. Dimitriou (1992) and Weiner (1997) argued that developments in analytical methodology began to be applied in the late 1940s and during the 1950s. Since the 1950s many issues have been introduced and various methods have been investigated regarding the service provision in urban transportation.

In 1950s Mitchell and Rapkin (1954), have great contributions to the field of urban transportation research. They carried out their studies on a broader context and analyzed the relationship between socio-spatial structure of cities and travel demand. Their research involves land use, urban growth, socio economic characteristics of individuals and their influence on travel demand. They provided a framework for travel pattern analysis that consists of certain empirical methods which are employed to investigate traffic problems associated with urban activities. Many forecasting methods, which are commonly used in urban transportation planning, were developed with reference to their studies. Hence, their approach addressed land use solutions to urban traffic problems. Meyer (1997), referring to corresponding studies, argued that the approach expanding the road capacity were not able to cope with congestion; therefore, systematic land use-transport planning methods were introduced.

Dimitriou (1992) added that in 1960s, urban transportation planning was regarded as a comprehensive process due to major capital investments in cities of the developed countries. According to this approach major the problems of urban transportation planning were investigated in urban development and land-use patterns (Mitchell and Rapkin, 1954; Buchanan Report, 1963; Dimitriou, 1992). Buchanan Report (1963) pays attention to influence of automobile usage on movement patterns, and discusses negative impacts of road transportation on the quality of urban environment.

It is commonly accepted that "comprehensive approach" introduced fundamental issues which comprised provision of mass transportation infrastructure and a "systematic approach" to traffic flow (Dimitriou, 1992; Weiner, 1997). Since 1960s in the cities of developed countries extensive mass transportation networks have been developed and transportation service provision has been coordinated with urban development (Dimitriou, 1992; Weiner, 1997). Travel demand models were extensively employed so as to evaluate investment proposals.

Simulation models, regarded as pioneering contributions to urban travel theory, have been developed since 1960s in order to understand and predict transportation- land use interaction. Among them, Lowry Model was extensively employed in urban planning in order to evaluate sizes and locations of residential areas, work places and urban facilities (Batty, 1994). Batty (1994) classified transport models into three categories: "descriptive", "prescriptive" and "optimizing". In transportation planning practice advanced forms of these models are widely used (Lewis et al, 1990).

"Four staged model", one of the mostly referred method in urban transportation planning, is an outcome of such attempts aiming model development (Dickey, 1983; Meyer and Miller, 1984; Dimitriou, 1992; Batty, 1994; Boyce, 2002). In comprehensive transportation planning studies, "complex series of simulations" were used to estimate benefits of transportation investments that were proposed to enhance urban development (Dimitriou, 1992; Batty, 1994). Dimitriou summarized the sequences and attitudes of this process as:

1. Observing current travel behavior (field survey);
2. Understanding the relationship between urban character and travel demand. Travel demand is expressed by some sort of equations (conceptualization).
3. Testing these models that are used to estimate future travel demand (calibration and reliability tests)
4. Recommending additional transport capacity (prediction).

Researchers, such as Weiner (1997) stated that in 1970s, urban transportation planning evolved into a more "diverse and complex activity" compared to the methods practiced during 1960s. Weiner noted that advanced transit technologies, transportation system management measures, and traffic engineering tools were investigated in this period. Weiner (1997) and Meyer and Miller (1984) add that due to oil crisis social, economic, and environmental impacts of urban transportation have been considered in project assessment studies. Meyer and Miller (1984) argued that due to rapid urban transformation of cities and oil crisis in 1970s "uncertainty" led to searching new models and proposing alternative transportation systems. Uncertainty is regarded as one of major factors in theoretical shift in transportation planning.

Researchers (Weiner, 1997; Wright et al, 1998) stated that since 1980s, transportation system improvement and traffic management methods have been investigated in order to use road space efficiently. Efficiency implied reduction in fuel and time costs and improvement of transportation service quality. Due to financial concerns and changing political preferences urban transportation planning transformed into a short term process which was motivated around low capital improvements. Weiner, (1997) adds that after 1980s special emphasis is given to flexibility in transportation service provision and through this period light rail transit systems are introduced to public transportation. In addition, reducing automobile access, ramp metering, and congestion pricing strategies have been introduced against congestion (Weiner, 1997).

At the beginning of 1990s sustainable transportation planning approach, which emphasize "carrying capacity" rather than "demand", have gained attention in transportation planning agenda. This approach implies some principles; such as efficient use of resources and conservation of environmental capacity. According to this approach transportation problems emerge due to "increasing demand" rather than "needs" (Rabinowitch, 1992; Newman ad Kenworthy, 1999; WBCSD, 2001).

> "Sustainable mobility" is a term that can mean different things to different people. The World Business Council for Sustainable Development defines "sustainable mobility" as "the ability to meet the needs of society to move freely, gain access, communicate, trade, and establish relationships without sacrificing other essential human or ecological values today or in the future." This definition emphasizes the social aspects of mobility (WBCSD, 2001:1-2).

In this sense, sustainability provides a framework for efficient use of resources. This approach introduced challenging principles to urban transportation planning: encouragement of non-motorized modes, enhancement of public transportation, and carrying capacity of urban environment and efficient use of energy resources.

In recent years, researchers have focused on the role of individuals' behavior in traffic flow order to develop more flexible methods by means of information and communication technology. Traffic operations, like dynamic traffic assignment, route guidance, traveler information systems and network design methods like temporal organization of road space are widely used especially in the cities of North America. In the literature various studies have been conducted and solution algorithms are developed in order to improve the performance of the transportation networks (some are referred in Appendix A).

Although various methods have been employed and numerous strategies have been implemented in urban transportation planning, today, congestion is still a major problem in the majority of the cities around the world. Researchers state that extensive automobile usage is the central factor of traffic congestion in the cities of developed countries (World Bank, 2000a; WBCSD, 2001; OECD, 2002). Those researches noted opportunities to implement alternative policies and strategies in developing countries since in the cities of those countries automobile usage is relatively low.

In the last two decades researchers emphasized non-motorized transportation modes and effective land use solutions to urban transportation in order to reduce adverse effects of traffic congestion (World Bank, 2000a; 2000b; WBSD, 2001). Those attempts recall issues and policies that were introduced in 1950s. Similar paradigm shifts, which were observed in 1950s and at the beginning of 1980s, are called "revisionist planning" Dimitriou (1992). According to this approach transportation problems shall be reduced by paying more attention to non-motorized modes. Limited roadway supply and efficient use of public resources are key principles of this approach.

Travel demand analysis is still an essential part of travel demand models and transportation planning since efficient use of resources requires rational decision making. In the next part, related studies in urban travel demand are overviewed to understand the dynamics of travel behavior, which is a key concept in travel demand models. The following part provides a general framework for understanding and forecasting travel demand characteristics.

### 2.2. Research on Urban Travel

Analysis of travel demand is necessary to improve travel demand models which are employed to predict possible influences of travel demand variations on transportation network.

There is an extensive literature on measuring influences of urban form, accessibility, household income on individuals' travel behavior (Kitamura, 1984; Steiner, 1994; Cervero and Gorham, 1995; Handy, 1996; Ewing et al., 1996; Cervero and Kockelman, 1997; Crane and Crepeau, 1998; Crane, 2000; Cervero, 2001) and most of them argue that land-use factors have significant influence on travel behavior and they add that the effect of those factors varies in time and space.

As it was stated before, travel demand analysis, in a scientific manner, has began in 1950s. Mitchell and Rapkin (1954) provided a framework for travel demand analysis and their research findings have been used in various methods and simulation models. Then, researchers focused on analyzing individual's travel behavior and predicting travel demand including various factors. Recent studies attempt to understand how travel behavior might be influenced by land use, individual characteristics, accessibility, mobility and congestion (Handy, 1996). In the last four decades various models have been developed in order to obtain realistic travel demand predictions (Baty, 1994).

In the recent decade the influence of a variety of factors on individuals' travel behavior are examined through case studies. Handy (1996) and Waddell et al (2001) provided comprehensive evaluation of the literature on travel demand analysis and modeling. Giuliano and Small (1993) investigated the role of land use on travel frequencies. Cervero and Gorham (1995) and Boarnet and Sacrimento (1998) investigated the role of residential density on commuting.

Calthorpe (1993) criticized urban sprawl in American cities and argued that accessibility and urban form play significant roles in individuals' mode choice. Similarly, Newman and Kenwothy (1999) argued that urban sprawl forces people to drive longer distances and put emphasis on the influence of urban form on transportation costs. They put emphasis on urban compactness and discussed sustainable urban form. Levison and Kumar (1994) developed a methodology to measure accessibility. Ewing et al (1996) specified accessibility measures and investigated the role of accessibility in individual's mode choice. Steiner at al. (2003) found that accessibility, a reflection of the "connectivity of a street network", has significant influence on individuals travel making.

Cervero (2001) carried out a sound analysis on induced traffic and argued that, transportation improvements result in increased mobility and therefore additional travel demand increases. Hence congested roads necessitate additional transportation investments. That study addressed efficient and sustainable solutions for urban traffic problems. Recently Parthasarathi et al (2003) investigated the role of induced traffic and their research outcomes confirm the stated arguments on induced traffic.

Most of the researchers emphasize the complexity of the relationship between land use and transportation. Handy (1996) criticized the studies on urban travel, and argued that specified parameters not always represent actual situation in dynamic and complex urban environments. According to Handy interdependent relation between land use and urban travel can not be reduced to deterministic regressions. Handy add that specified parameters that are used in travel demand analysis may not always represent actual situation in dynamic urban environments. Cervero and Kockelman (1997) developed a method of multi-dimensional analysis to explore the major factors influencing individuals' travel behaviors.

The role of congestion in travelers' route choice (or even in mode and destination choices) is investigated by many researchers who focused on dynamic network assignment. Further information about those studies can be found in Chapter 3 and Appendix A. Specific findings of studies dealing with urban travel are:

-Socio economic characteristics of travelers and travel costs are the most influential factors of travel demand.

-Urban sprawl has significant impacts on travel pattern, especially on mode choice.

-Land use mix and residential density have significant impacts on travel frequencies of individuals.

-Road network characteristics determine accessibility and travelers' route choice.

-Road expansion that results in induced traffic is not a sustainable solution traffic planning.

-Congestion (travel cost variations) has a significant impact on individuals' travel behaviors especially on drivers' route choice.

-Due to complexity of the problem and uncertain feature of travel demand it is hard to obtain reliable results from estimations.

-Further studies analyzing impact of uncertainty in travel demand models will have valuable contributions in the field of urban transportation.

Since travel behaviors are dependent upon various factors, simplification (in representation) of travelers' behaviors leads to model uncertainties. Complexity of travel choice is presented in Figure 2.1.

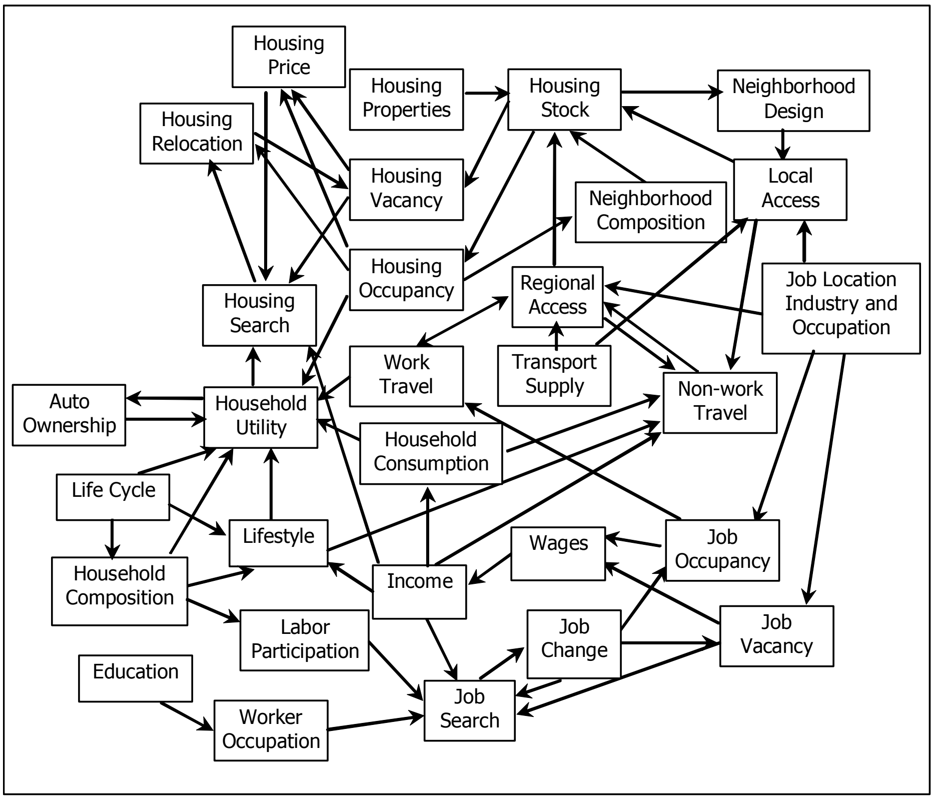



**Figure 2.1: Complexity of individual's travel demand and behaviors.**
Source: Waddel et al, 2001.

### 2.3. Research on Travel Demand Models

Travel demand models are extensively used to assess performances of projects and evaluate scenarios and proposals. Among them synthetic models (i.e. four staged model) are commonly used in urban transportation planning (Meyer and Miller, 1984; Batty, 1994; Ortuzar and Williumsen, 1994; Bell et all, 1997; Black, 2003). Urban transportation models can be classified according to their approach, structure, scope, purpose and knowledge processing:

> -Descriptive, normative and evolutionary models,
> -Predictive and prescriptive models,
> -Econometric, heuristic and simulation models,
> -Macroscopic, microscopic and mezo-scopic models,
> -Long term (static) and short term (dynamic) models,
> -Mathematical, statistical and synthetic models,
> -Aggregate, disaggregate and combined.
> (After Dickey, 1983; Meyer and Miller, 1984; Batty, 1994; Ortuzar and Willumsen, 1994; Ran and Boyce, 1994; Oppenheim, 1995, Black, 2003; Bell et all, 1997).

In transportation planning practice statistical, econometric, mathematical and synthetic models are extensively used both in analysis and project evaluation stages. Conventional four stage model, consists of trip generation, trip distribution, modal split and trip assignment, is widely used to predict the performances alternative transportation projects.

Meyer and Miler (1984) presented a conceptual analysis of the interaction between transportation planning and travel demand models. Batty (1994) provided a historiography of modeling approaches and underlined major critics aroused against those approaches. Recently Boyce (2002) presented a systematic summary of critics on model structures (for further information see literature summary table in appendix A).

Those critics principally focus on insufficiency of four stage model (Batty, 1994). Boyce (2002) argued that model stages are usually not integrated in practice.

Zhao and Kockelman (2001) and Pradhan and Kockelman (2002) investigated the role of uncertainty in travel demand models and stated that structure of four stage model result in propagation of uncertainty through sequential stages. This sequential approach is frequently criticized in the literature. Literature survey showed that as far as uncertainty is concerned, the sequential approach has weaknesses in predicting short term variations of travel pattern. Due to this fact, periodic analyses of sensitivity, reliability and validity are necessary for accurate predictions (Kann, 1998; Rothmans and van Asselt, 1999).

According to Oppenheim (1995), "these models have not been behavioral in nature, because they do not approach to traveler as a consumer". Oppenheim argues that in order to understand and cope with congestion in urban traffic, models must develop more realistic representation methods for individual preferences.

Since 1970's several feedback algorithms, combined models and elastic model structures are developed but conventional structure of the four stage model is conserved and widely used in practice (some are referred in Appendix A). Recently researchers have conducted several studies on elastic and behavioral prediction methods. Since these methods are developed in order to estimate very short term travel behaviors, their "microscopic" structure of solution algorithms does not provide evaluating long term proposals. Hence, further investigation is necessary for realistic models in response to both short term and long term variations in travel demand.

On the other hand, integrated models are developed to provide better estimations of travel demand both for long termed and short termed predictions (Ben-Akiva et.al, 1996). However most of them are tested in hypothetic networks. Therefore their validity and reliability in transforming networks are under question.

This study discusses possible strategies to cope with uncertainty which has significant role in decision making in transportation planning. In the following part the concept of uncertainty and its impacts on travel demand estimation and decision making processes are presented.

## 2.3. The Uncertainty Problem in Urban Transportation Models

### 2.3.1. Definition of the Concept of Uncertainty

In this part, the concept of "uncertainty" is investigated in order to explore its impacts on the performances of travel demand models. Van Greenhuizen and Nijkamp (2003) argued that coping with uncertainty is essentially the most critical element in decision making problem. This problem is also concerned in urban transportation planning. Understanding uncertainty is necessary to reduce the cost of biased predictions. Meanwhile, it can be a challenging contribution to urban transportation planning.

The problem of uncertainty is emphasized by researchers who deal with decision problems. Van Asselt (1999) provided a comprehensive analysis of uncertainty and argued that "knowledge is not equivalent with truth and certainty…, uncertainty is not simply the absence of knowledge. It can still prevail in situations where a lot of information is available". After broad explanations van Asselt grounds the problem of uncertainty on "variability" (of systems) and "imperfect information". Understanding the sources of uncertainty and providing taxonomy of those sources can be valuable for both researchers and decision makers. Furthermore, various forms of flexibility, which is regarded as a strategy to cope with uncertainty in transportation planning, can be associated with corresponding sources of uncertainty.

Morgan and Henrion (1990) investigated the role of uncertainty and risk management in policy development. Their study provided a valuable methodology for planning.

Van Greenhuizen and Nijkamp (2003) discuss the role of uncertainty in adoption of new transport technology in policy making, and Zhao and Kockelman (2001) investigated the source of uncertainty both in imperfect information and methodology of modeling. They conducted a case study in Austin and found that three forms of uncertainty have significant impact on model estimates: "input uncertainty", "inherent uncertainty" and "propagated uncertainty". These studies suggest that lack of knowledge may be of even greater importance than variability in many urban transportation planning studies.

Van Asselt (1999) grounds his idea on the complexity of real world with reference to three main factors: increase in the scale of entity, technological developments and acceleration of processes. In recent years the role of uncertainty in modeling and decision making has been emphasized by many researchers. Funtowitcz, and Ravetz (1990), Van Asselt (1999), van Geeenhıizen and Nijkamp (2003), Zhao and Kokkelman (2001) investigated the sources of uncertainty and come up with six sources:

-uncertainty in the method of experimentation,
-variability of human behavior,
-conceptualization of real world,
-differences in value judgments,
-advancements in technology, and
-extrapolation of current knowledge to the future.

Funtowitcz and Ravetz (1990) and van Asselt (1999) noted problems of understanding and describing complex systems and discussed three forms of uncertainty: technical uncertainties, methodological uncertainties and epistemological uncertainties. Van Asselt provided a typology of the sources of uncertainty and distinguished those sources into two categories: variability and lack of knowledge.

According to van Asselt (1999) technical uncertainties arise due to reliability problems of gathered data, which may be incomplete or insignificant. This type of uncertainty is sometimes called "input uncertainty" (Zhao and Kockelman, 2001). According to van Geenhuizen and Nijkamp (2003) technical uncertainty arise due to lack of appropriateness of analytical tools.

While "inherent uncertainty", is regarded as a consequence of incomplete structure of methodology, "epistemic uncertainty" is associated with inadequateness of knowledge (Van Asselt, 1999; Zhao and Kockelman, 2001; van Geenhuizen and Nijkamp, 2003). These definitions suggest that models dealing with complex systems may not have sufficient capability in formulating realistic representations. This type of uncertainty can be regarded as a part of inherent uncertainty. In Table 2.2 major sources of uncertainty and forms of uncertainty are summarized.

**Table 2.2: Sources and forms of uncertainty**

| Categories of uncertainty | Variability | Inadequate knowledge | | Total uncertainty |
|---|---|---|---|---|
| Epistemological definition of uncertainty. | Objective uncertainty | Subjective uncertainty | | |
| Uncertainty with reference to the subject of study. | Stochastic uncertainty | Conceptual | | |
| Value of uncertainty | Primary uncertainty | Secondary uncertainty | | |
| Form of uncertainty | Random uncertainty | Informative uncertainty | | |
| Type of uncertainty | Aleviatory uncertainty | Epistemic uncertainty | | |
| Location uncertainty | External uncertainty | Internal uncertainty | | |
| Source of uncertainty | Input | Inherent Uncertainty | | Propagated Uncertainty |
| | | Types of Internal (Inherent Uncertainty) | | |
| | | Due to experimentation method | Due to complexity of the problem (or subject) | |
| | | Partial | Structural | Aggregated |
| | | Temporal | Systematic | Accumulated |
| | | Technical | Epistemic | |
| | | | | |

Source: (After Meyer and Miller, 1984; Funtowitcz and Ravetz, 1990; Morgan and Henrion, 1990 van Asselt, 1999; Zhao and Kokkelmann, 2001; van Geenhuizen and Nijkamp, 2003).

Briefly, variability is an attribute of individuals' behaviors; whereas, lack of knowledge is the matter of researchers who may not have perfect information about the system or process that they deal with (van Asselt, 1999). "Metrical uncertainty", as a typical example of lack of knowledge emerges due to lack of observations, practical obstacles, conflicting evidence in data, ignorance and indeterminacy (van Asselt 1999). In the case of transportation planning, van Geeenhıizen and Nijkamp (2003) argued that "assembling proper information may be too costly, but human ability to digest all relevant information is also limited".

### 2.3.2. Uncertainty in Transportation Planning

The problem of uncertainty is regarded as a major problem that resulted in a paradigm shift in urban transportation planning. Meyer and Miller (1984) argued that increased awareness of an uncertain future led transportation planners to searching alternative planning methods.

> The gasoline shortages in the United States during the last decade were a serious shock to many transportation planners who had assumed in their planning methodology and plans that gasoline would continue to be cheap and easily obtained. Whereas planners had once confidently forecasted future land use and then predicted the travel demand resulting from this spatial configuration, unexpected trends and developments in terms of energy availability, economic stability, and transportation technologies served to highlight how uncertain the future really is. This increased uncertainty influenced transportation planning into two major ways. First, new methods were developed to deal with the uncertainty of planning forecasts and the predicted impacts of alternative projects…. Second, project implementation began to be considered in stages, where only the first stage was fully detailed because of the greater certainty of the project characteristics. Later stages were designed with less detail to allow flexibility in responding to future circumstances. (Meyer and Miller, 1984:3)

Meyer and Miller put emphasis on input uncertainty that is usually associated with external data (land use, household characteristics and transportation services). Travel demand simulation models are principally dependent on associated parameters that are accounted in model specification and model calibration processes. In these processes "model uncertainty" may arise due to structures and assumptions of models. Epistemic uncertainty can be associated with specified equations and algorithms while "parametric uncertainty" may emerge in the selection of parameters that are necessarily used in equations. In addition "input uncertainty" is associated with external data.

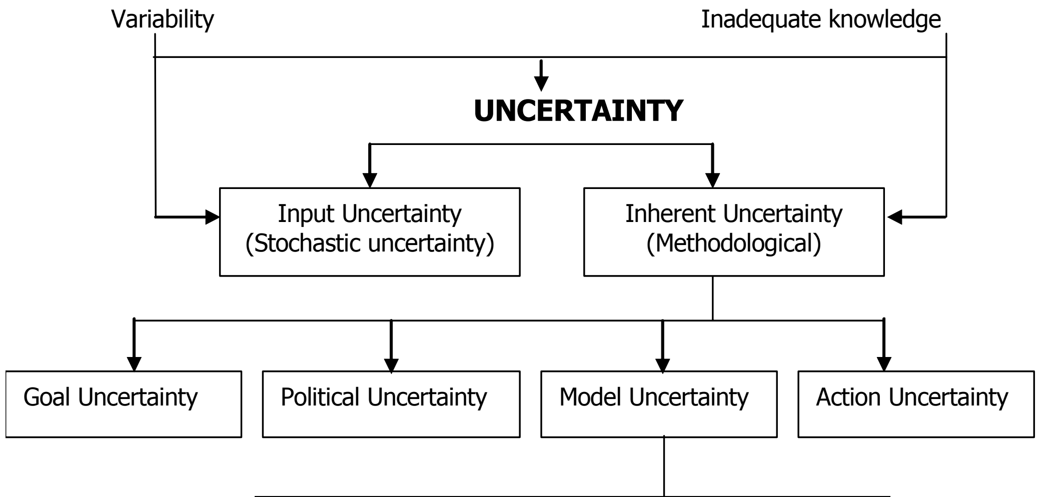
Van Geeenhuizen and Nijkamp (2003) discussed the role of uncertainty in the case of transportation technology and put emphasis on randomness in individuals' decision making in changing circumstances. They argued that "there is some evidence that travel decisions are not exclusively governed by rational cost-minimizing, utility maximizing or profit maximizing-behavior". In other words, variability is regarded as a product of "stochastic behavior", and the accurate characterization of this stochastic behavior is supposed to be possible. Researchers noted the problems of deterministic modeling approach and addressed probabilistic interpretations of social issues to cope with uncertainty.

Walpole et al, (2002) discussed reliability of models and "statistical uncertainty" that refers to significance of distribution of observed data associated to a specific equation. They confirmed that field survey and sampling accomodate statistical errors. This type of uncertainty, measured by standard deviation and correlation coefficient is sometimes called "metric uncertainty" (van Geenhuizen and Nijkamp, 2003).

"Stochastic uncertainty" is associated with structures of models (Geenhuizen and Nijkamp, 2003). In this form of uncertainty constants and parameters that are specified in the equations vary in time that leads to "parametric uncertainty" which is a specific type of epistemic uncertainty. On the other hand, "aleatory uncertainty" which can be eliminated through modeling process, is regarded as a secondary type of uncertainty. In this study this type of uncertainty refers to hidden errors that, a negative error may reduce positive errors in estimations. For instance sometimes total population may be overestimated while car ownership may be underestimated. In that case the result (travel demand) may be almost accurate, however due to "aleatory uncertainty" reliability of further predictions will be weakened.

Since travel demand models are abstract representations of real world, it is impossible to specify all individual movements. This problem motivated researchers around microscopic and behavioral approaches. In the literature "programmatic uncertainties" and "subjective uncertainty" refer to unexpected changes in priorities, standards, and timing in project implementation due to changing political preferences or monetary shortage. Briefly, in travel demand models that are commonly used in urban transportation planning uncertainty may arise due to lack of knowledge (insufficient data), lack of accuracy or lack of confidence (statistical analysis).

Epistemic uncertainty shall be investigated in model structure; that is, methodological uncertainties can be identified in post planning analysis (validation). However, it may not possible to include all factors influencing individual behavior. In this manner this type of uncertainty may fall into a separate category: "unidentified (permanent) uncertainties" that van Asselt (1999) calls "radical uncertainties". In such cases, the researchers may realize the existence of uncertainty, but they may not detect the specific source of the uncertainty. In the following figure the hierarchy of uncertainty is presented in order to associate corresponding sources with specific problems of transportation planning.




| **Types of model uncertainties** | **source/ of uncertainty** |
|---|---|
| Uncertainty in model quantities | parameters, inputs, initial states. |
| Uncertainty about model form/structure | functional relationships, structure of algorithms. |
| Uncertainty due to adequacy of the model | testing model performance, validation approach. |
| Uncertainty in Model operation | hidden flaws, numerical errors, coding errors. |
| Accumulated Uncertainty | propagated uncertainties through the model. |

**Figure 2.2: Hierarchy of Uncertainty**
Source: After Funtowitcz, and Ravetz, 1990; van Asselt, 1999; van Geenhuizen and Nijkamp, 2003; Zhao and Kokkelmann, 2001.

This study is concerned with external (input) uncertainty (variability of socio-economic pattern), internal (inherent) uncertainty, "propagated uncertainty" and attempts to investigate and measure other forms (i.e. programmatic, permanent) of uncertainty to be concerned in traffic flow estimation. In travel demand estimation process, uncertainty sometimes is ignored; however, this problem weakens the reliability of models (Zhao and

Kockelman, 2001). Amekudzi and McNeil (2000) pay attention to the problem of uncertainty (input and model uncertainties) in highway performance estimation. Stepwise analysis and post-planning (Zhao and Kockelman, 2001) analysis are commonly used methods which can be used to understand uncertainty.

In the case of extreme uncertainty (due to dramatic variations) predictability may be problematic however that problem may be an opportunity to propose alternative solutions. In that case minimization/reduction of uncertainty is also necessary to improve reliability of models otherwise evaluation of alternative projects may not sit on rational grounds. In other words "uncertainty in decision-making rises due to the lack of adequate knowledge or capability of choosing the rational alternative" (van Asselt, 1999).

Meyer and Miller (1984) manifested a broader definition of the problem of uncertainty in the process of transportation planning which is commonly a prediction based decision making process. In this process uncertainty at one stage is an input uncertainty for next stages, that accumulation of uncertainty which is called "propagated uncertainty" weakens reliability of proposed systems (Zhao and Kockelman, 2001). This problem was investigated by Zhao and Kockelman in the case of four staged models.

### 2.3.3. Measuring Uncertainty

Van Asselt (1999) draws a typology of methods to deal with (explanation and measuring) uncertainty. Those methods are distinguished into two categories: qualitative methods (hypothetical scenario building against possible states, events, actions or consequences) and quantitative methods (measures, tests and criteria). A broad classification and description of quantitative methods can be found in Walpole et al. (2002). Quantitative methods (integrated assessment models) may be used to understand, measure, and reduce uncertainty (Morgan and Henrion, 1990; van Asselt, 1999). Nijkamp and Rietveld (1987), Morgan and Henrion (1990), and Funtowitcz and Ravetz (1990) presented a taxonomy of qualitative methods.

Uncertainty in modeling and planning may weaken confidence and reliability, therefore decisions dependent upon these models may not be consistent (Zhao and Kockelman, 2001). As long as uncertainties are identified, specified and quantified reliability of travel demand models can be improved. In practice it is hard to analyze and quantify uncertainty. In sequential processes (either in modeling or planning) sequential analysis of uncertainty is a practical method. In the literature disaggregate analysis methods are commonly used for this purpose. Root mean square error and coefficient of regression are main statistical measurement tools to quantify uncertainties in modeling process (Walpole et al, 2002).

Literature survey showed that, commonly four analysis methods are used to measure uncertainty: sensitivity analysis, probability based models, scenario analysis, and strategy development method (van Asselt, 1999; Rothmans and van Asselt, 1999). Sensitivity analysis is performed to measure the level of variations in model parameters in model equations. Reliability analysis is performed to measure the level of precision (convergence of samples) in equations. Validation analysis can be performed to assess reliability of the model in time that the model performance is measured in a time period (further information can be found in Rothmans and van Asselt, 1999; Walpole et al., 2002).

On the other hand probability based mathematical models provide a range of outputs to determine strategies so as to cope with uncertainty. In practice it is very hard and time consuming to get probability distributions that include the range of all possibilities. In addition it is necessary to determine reasonable confidence intervals. In this study a probabilistic method is performed to analyze variations in travel demand in order to revise and validate the structure of the travel demand model.

### 2.3.4. Coping with Uncertainty

Van Geenhuizen and Nijkamp (2003) presented a list of approaches and strategies to cope with uncertainty: doing nothing, neglecting uncertainty, identifying and reducing uncertainty, and acting uncertainty. Researchers noted that reduction of uncertainty and coping with uncertainty necessarily requires scenario analysis and strategy development. Scenario analysis, involves assessment of possible states in the future, is based on learning thinking (van Greenhuizen and Nijkamp, 2003). According to this approach both statistical and informative methods are employed to investigate significant variations in future both in terms of constraints and variables. This method implies evaluating probable outputs of related assumptions and comparing with respect to certain criteria that may be either "objective" or "normative".

Strategy development method necessitates integrated assessment models. In this approach alternative strategies are developed and evaluated, and then possible advantages and disadvantages of each strategy are compared with those of others. At each stage of the assessment model sources and levels of uncertainties are specified in order to define new strategies.

This process helps decision-makers understand potential risks (due to overestimated benefits) of service provision and determine the level of flexibility. This approach can be employed in urban transportation planning. According to visionary approach, which is based on future images, some sort of adjustments are necessary in order to cope with uncertainty since urban quality and human well-being is dramatically suffered from increasing rates of motorized transportation (Rabinovitch, 1992). Both approaches (flexible and visionary) necessitate and consist of distinct models and decision making processes. In the following table analysis and decision making methods are presented.

**Table 2.3: Coping With Uncertainty in Urban Transportation Planning**

| | **Flexible Method** | **Visionary Approach** |
|---|---|---|
| **Pre-Planning Stage (Problem Definition) Hypothesis** | Sensitivity Analysis<br>Model Calibration<br>Reliability Analysis<br>Probability Analysis<br>Prediction | Statement of Vision<br>Problem Definition<br>Hypothesis<br>Expectation<br>Assumption |
| **Planning Stage Decision Making** | Scenario Development<br>Strategy Development<br>Classification& Valuation<br>Priorities | Visualization<br>Objectives<br>Principles<br>Priorities |
| **Post-Planning Stage Criticism** | Monitoring<br>Validity Analysis<br>Problem Identification<br>Scenario Analysis<br>Modification | Observation<br>Criticism<br>Problem Statement<br>Scenario Development<br>Revision |

Source: After Nijkamp and Rietveld, 1987; Funtowitcz, and Ravetz, 1990; van Asselt, 1999; van Geenhuizen and Nijkamp, 2003; Zhao and Kokkelmann, 2001.

Van Geeenhıizen and Nijkamp (2003) argued that "from a methodological perspective there is little distinction between explanation and forecasting". They emphasized the role of strategy development and add that, "forecasting cannot be observed empirically, but they can be developed on the basis of acceptable reasoning". Even though empirical approaches are criticized, today, decision makers and professionals require information about the future in order to develop strategies.

In order to overcome the problem of biased estimation more realistic and sophisticated modeling algorithms can be developed and validated. In this sense various studies are conducted to understand the dynamics and factors influencing urban travel and improve model structures. Levinson (1995) developed a dynamic process for transportation planning models. Bly and Webster (1997) provided an overview of interactive land use and transportation models. Ben-Akiva et al (1997) developed a traffic simulation method (simulation laboratory) which is based on scenario development. Related studies concerning scenario development emphasize the concept of flexibility in transportation planning and aimed at coping with uncertainty in traffic flow. The following section discusses the role of flexibility in urban transportation planning.

### 2.4. Flexibility in Transportation Planning

In this part the concept of "flexibility" is reviewed and discussed to explore its role (a strategy to cope with uncertainty) in travel demand estimation, strategy development, and transportation network design.

The concept of "flexibility" is emphasized in various fields, such as in physics, chemistry, civil engineering, computing, operational research, system design, product design, management, policy planning, urban planning, and architecture and so on, with various definitions, such as "elasticity", "changeability", "robustness", "adaptability", "agibility" and "tractability" etc (Webster's Dictionary).

In Webster's Dictionary, "flexible" refers to ability to adapt; "characterized by a ready capability to adapt to new, different, or changing requirements" and flexibility means "the quality of being adaptable or variable" or "the trait of being easily persuaded". Similarly, a general definition; "ability of any material or system to respond changes in time" may satisfy the professions dealing with the term. In industry, flexibility refers to "degree to which a coating after drying is able to conform to movement or deformation of its supporting structure, without cracking or flaking" while in physics "ability of a material to undergo elastic bending without breaking" (Fine and Freund, 1990; van Mieghem, 1998).

The definition of flexibility can be extracted from those fields to be applied in transportation planning. In general terms, "flexibility" refers to the characteristic of a system, which makes it possible to be changed or adapted without too much additional work" (Saleh et al, 2001). System design approach consists of a variety of planning techniques, which can be adopted transportation in order to provide principal references for transportation system planning. In the system design theory flexibility and robustness are used as interchangeable terms that "robust design provides flexible solutions" (Saleh et al. 2001:1).

Sethi and Sethi (1990) proposed eleven types of flexibility types in manufacturing systems. Among them five types of flexibility are relevant to transportation system design. In manufacturing systems, the ability of production system to handle changes in volume (variability) of same product in a certain time period is called "volume flexibility", while the ability of producing a variety of products without any structural modifications on the existing system is called "product mix flexibility" (Sethi and Sethi, 1990). Recently Shi and Daniels (2003) investigated flexibility and classified manufacturing capacity according to two types: "dedicated" and "flexible". They reviewed the literature and conclude with a brief definition: "flexibility is typically defined as an adaptive response to environmental uncertainty (Pujawan, 2004). Flexibility is an effective means by which it is possible to cope against uncertainty in a swiftly changing environment".

Similarly, "product flexibility" refers to the ability of a manufacturing system to produce different products or various product mixes (Sethi and Sethi, 1990, Saleh et al, 2001). In addition, "routing flexibility" refers to the ability of a manufacturing system to produce a product by alternative routes through the system, while "operational flexibility" indicates the ability of a product to be produced in different ways (Sethi and Sethi, 1990, Saleh et al, 2001). These concepts can be adapted to urban transportation planning in three dimensions:

1. Flexibility in travel demand estimation models,
2. Fexibility in policy making and planning,
3. Fexibility in network design and traffic management.

In Figure 2.3 components of dynamic network planning are presented. In this procedure flexibility is regarded as an essential strategy to cope with uncertainty.

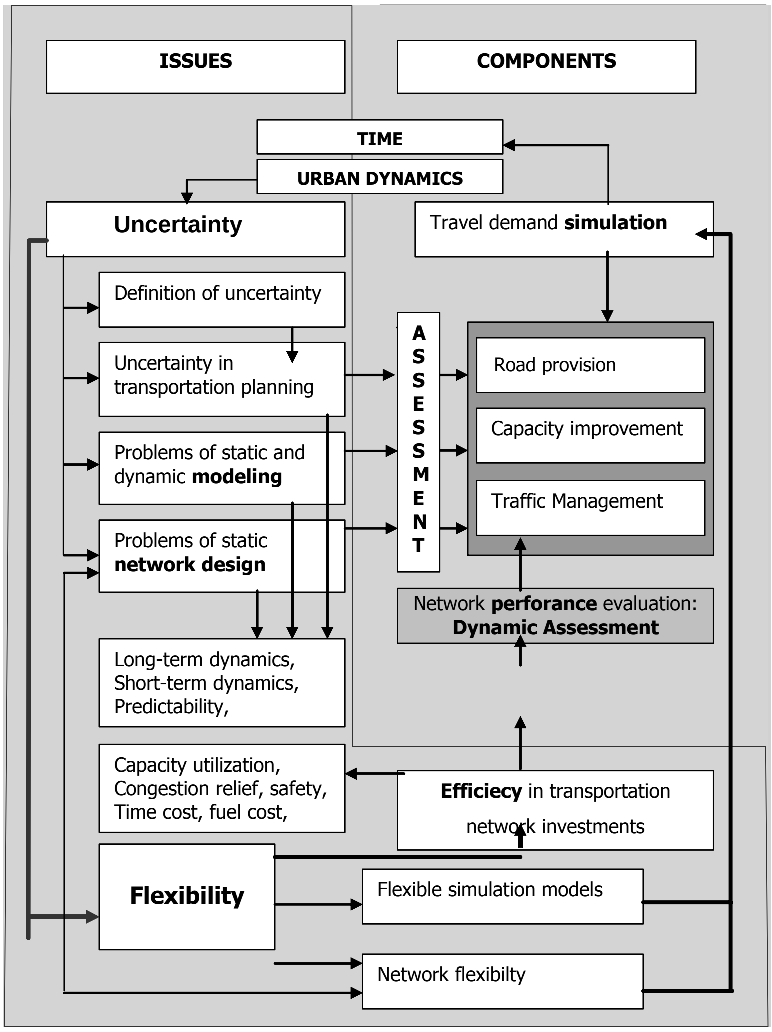



**Figure 2.3: Issues and Components of Dynamic Network Planning Process.**

In the field of transportation planning volume flexibility refers to flexibility in capacity and service provision. Product mix flexibility suggests "flexibility in model outputs" or flexibility in service provision for multi-modal transportation. Product flexibility refers to "flexibility in network design standards". In other words, flexibility refers to ability of adaptation of different design standards on specified components of the road network. Besides, routing flexibility refers to "flexibility in network assignment".

Finally, operational flexibility refers to "flexibility and traffic planning and network operations". Here, managerial flexibility necessitates acting as a response to travel demand variations without any deformation to the physical system.

The ability to handle change (robustness) is a critical issue when built up area does not allow installation of new services. In the hyper-dictionary, robustness refers to "the property of strong in constitution" and in Webster's Online Dictionary it refers to "having or exhibiting strength or vigorous health".

In the case of transportation networks robustness refers to the ability to cope with demand variations. Briefly, robustness requires "operational flexibility". Urban transportation network topology has a critical role in dynamic network assignment and traffic planning. Since dynamic network assignment models are developed in accordance with finding alternative routes to be followed by drivers, efficiency in traffic management systems cannot be achieved unless sufficient numbers of alternative paths are provided (Ran and Boyce 1994; Oppenheim, 1995; Ben Akiva et al, 1996). Ben-Akiva et al (1997) and Waller et al (2001) developed pioneering methods which involve scenario development in order to provide a flexible and robust traffic control system. Ben Akiva et al stated the problem of variability in travel demand as:

> The traffic control system under examination is simulated under a wide range of scenarios. The performance measures obtained are used to generate new scenarios that further challenge the design and eventually refine the initial design. The whole process is repeated until an efficient, effective, and robust design, satisfying the various objectives of the traffic management system, is achieved. Scenarios are used to test the performance of the system under a wide range of traffic conditions. Scenarios are specified according to the following factors: (1) traffic volume by origin-destination pair; (2) time, location, and severity of events; and (3) driver behavior. Each factor consists of a set of variables that can assume a range of values; a scenario is defined by a combination of values across the variables of three factors (Ben Akiva et al. 1997:284).

Feitelson and Salomon (2000) investigated various dimensions of network flexibility. After a specific analysis they concluded that network flexibility implies adaptation to changing circumstances and demands, both in terms of infrastructure and operation.

Feitelson and Salomon (2000) investigated three components of network flexibility: node flexibility, link flexibility and temporal flexibility. Node and link flexibility constitutes spatial flexibility, while temporal flexibility implies flexibility both in traffic management and network design in order to respond traffic demand. In the literature researchers investigate enhancing network flexibility in two main compartments:

-flexible investment strategies are developed in order to reduce possible costs of unexpected circumstances (physical flexibility),

-new technologies are introduced to maximize the network flexibility; network management systems to meet increasing traffic demand (dynamic network assignment and intelligent transportation systems).

Network connectivity, which determines the number of available routes in an underlying network, is a principal factor of network flexibility. Researchers emphasized that network connectivity has crucial role in network performance (Dial, 1971; Ben-Akiva et al, 1997; Boyce et al, 1997; Chien and Schonfield, 1997; Nagel, 2002; Ge et al, 2003; Huang and Zhao, 2004). Connectivity is measured by some basic measures that influence the performance of network in the assignment stage: number of cycles, detour index, network density, alpha index, beta index and gamma index. (Harary, 1969; Henley and Williams, 1973)

These basic properties have substantial influences on network performance. It may not be possible to improve network connectivity in city centers, where adapting traffic management strategies provides operational flexibility (routing, signal control and setting route priorities).

Finally network efficiency which implies "optimal utilization of roads", is measured by the ratio of the total vehicle distance traveled, divided by the total vehicle hours traveled (Sin, 2001; Varaia, 2004). Varaiya (2004), states that the main reason for congestion is not demand exceeding capacity but inefficient use of road space. Varaiya associated congestion with inefficient use of road space:

> People believe congestion occurs because demand exceeds capacity, so they support initiatives to build additional highway capacity or curtail highway travel demand. Politicians work to bring highway construction projects into their districts, and environmentalists support proposals to make transit more attractive or automobile use more costly. Our analysis of the facts does not support the belief that congestion occurs mainly because demand exceeds capacity (pp: 2).

In order to reduce adverse effects of congestion managing and regulating traffic may be more effective than improving physical capacities of few major roads. In this sense, capacity improvement can be obtained by traffic control systems. There are various studies on road capacity improvement and its possible adverse effects on urban traffic (Sin, 2001; Varaia, 2004, Nagel et al, 1996). One of the main concerns is the induced traffic:

> ….induced traffic includes new and longer motor vehicle trips that are made because the highway capacity addition has reduced travel cost, and that induced traffic does not include shifts in the route used to make a trip or shifts in the time of day a trip is made, because such changes generally do not result in a net increase in highway system use. (Sin, 2001: 24).

Measuring induced traffic is beyond the scope of this study; however due to the significance of the problem dynamic travel demand estimation and travel demand monitoring systems are regarded as substantial contributions to the field of transportation planning. Nagel et al. (1996), Ben Akiva et al (1997) and Sin (2001) investigated fluctuating traffic demand and its affects on transportation network planning. They argued that traffic management systems are more flexible and efficient in contrast to capacity improvement.

### 2.5. Concluding Remarks

Literature review showed that most of the recent studies are mainly focused on two major issues: urban travel and specialized models. The issue involves analyzing the impacts of urban growth and the role of household characteristics on individuals' travel making frequencies or other dimensions of travel behavior. The latter issue refers to microscopic (detailed and short termed) travel demand models which include application of information technology in transportation planning. Among them traffic assignment models, intelligent transportation systems, and similar specific methods are introduced to traffic planning recently. However there are few studies on the concept of uncertainty and its possible impacts on various stages of transportation planning. Literature survey suggest that the problem of uncertainty of rises due to imperfect information and variability of human behavior.

A conceptualized summary of studies, which are concerned with travel demand analysis, forecasting models, and emerging problems, is presented in Table 2.4 and Table 2.5.

**Table 2.4: The diversity of researches on the relationship between urban activities and transportation issues.**

| Variety of researches on travel demand / Factors and issues | Trip frequency | Spatial inretaction | Mode choice | Route choice | Urban traffc |
|---|---|---|---|---|---|
| FACTORS | | | | | |
| Demographic characteristics | | | | | |
| Transportation technology | | | | | |
| Urban form and accessibility | | | | | |
| Land use, Density | | | | | |
| Transportation network | | | | | |
| ISSUES | | | | | |
| Uncertainty | | | | | |
| Congestion | | | | | |

Note: Bold marked cells represent higher level of discussions

The figure above indicates that there are fair number of studies that investigated the influences of urban form, land use, accessibility, congestion, transportation network, or socio-economic characteristics of households on individuals' travel behaviors and various models are developed in order to predict both short term traffic demand whereas only a few are concerned with the concept of uncertainty in urban travel and traffic demand prediction.

Researchers have developed various methods to predict benefits and impacts of transportation services. Commonly, in the trip generation stage of four-step modeling process, the individuals' trip making frequencies are predicted by the way of household size, income, and other socio-demographic variables. In addition, these factors are also used to estimate individuals' location, mode and route choices. In this regard researches on travel have great contributions to travel demand models.

**Table 2.5: The level of consistency research outcomes and arguments in urban travel theory.**

| Consistency between research findings in the literature<br><br>Factors and issues | Trip frequency | Spatial inretaction | Mode choice | Route choice | Urban traffc |
|---|---|---|---|---|---|
| FACTORS | | | | | |
| Demographic characteristics | | | | | |
| Transportation technology | | | | | |
| Urban form and accessibility | | | | NA | |
| Land use, Density | | | | NA | |
| Transportation network | | | | | |
| ISSUES | | | | | |
| Uncertainty in travel demand | NA | NA | NA | NA | NA |
| Congestion | NA | | | | |

NA: there are limited studies on this subject therefore it is not applicable
The frame represents the context of the study.
Bold marked cells represent higher levels of significance in related results.

Researchers emphasized that urban transportation planning has evolved into a more complex (in terms of methodology) and microscopic (terms of scope) system. In the recent years more realistic modeling algorithms have been developed. However, these models still have some deficiencies due to uncertain character of urban environment and travel demand. These methods are extensively used by professionals to understand the structure of travel demand and develop scenarios in order to help decision-makers in determining transportation policies and programs. Travel demand analysis methods in which time, distance, safety and pollution are common issues, are used in order to measure possible impacts of transportation projects on urban environment and individual's well-being.

In the next chapter a some of commonly used travel demand models are presented.

# CHAPTER 3

# TRAVEL DEMAND SIMULATION MODELS

## 3.1. Purpose and Scope of Travel Demand Models

In this study reliabilities and relevancies of static and dynamic simulation models (especially network assignment models) are investigated in a dynamic urban structure. Travel demand simulation models are employed in public and private sectors for investment analysis (Weiner, 1997; Black, 2003). At the end of 1950s, the initial forms of these models were developed to understand and predict individuals' movement, passenger and vehicle trips in specific, to assess benefits of transportation investments (Weiner, 1997). In the last two decades, these models are employed in a wide range of application areas, such as consumer behavior analysis and traveler information systems (Lewis et al, 1990; Horowitz and Farmer, 1999; De Lotto and Ferrara, 2002).

Four staged model as a commonly used travel demand (and behavior) simulation method, has shown considerable progress in the last decade, especially in the network assignment. This model is fundamentally based on six phases: spatial representation of urban transportation system (zones, nodes and links), number of trips generated in analysis units (frequency), trips made among units (interaction-distribution), separation of trips according to available modes (modal split) temporal distribution of trips (departure time) and allocation of trips through transportation network (route choice-network assignment) (Meyer and Miller, 1984; Dimitriou, 1992; Ortuzar and Willumsen, 1994; Weiner, 1997; Wright, 1998). Researchers deal with one or more stages depending on specific problems. The final output of the last is passenger volumes (on public transportation network) or traffic volumes (on roadway).

In transportation planning either disaggregated or combined models have been used according to application area (Florian and Nguyen, 1978; Safwat and Magnanti, 1988). In the following part, the structure of conventional four stage model and recent studies are presented.

### 3.2. Trip Generation

In trip generation step of conventional transport model, the numbers of trips made by individuals (the number of trips produced and attracted by each zone) are expressed by equations, which are employed to predict future travel demand (Ortuzar and Williumsen, 1994:113). These equations are commonly obtained through regression analysis (Wiliams, 1982; Meyer and Miller, 1984). Further information about this stage can be found in Ortuzar and Willumsen, 1994; Oppenheim, 1995)

This stage has principally two components: trip production and trip attraction. Trip production and attraction equations assigned to specific trip purposes (work, school, other) are employed to predict future travel demand (Ortuzar and Willumsen, 1994). For instance, for home based shopping trips, trip production rate is a function of income, employment status, household size, car ownership and other socio economic factors. For this purpose, trip attraction rates are estimated as a function of facility size (commercial area), number of employees, and location of activities.

In this stage, productions/attractions are expressed into arrays for all trip purposes, and finally trip generation values are adjusted to balance production and attraction totals and finally, specified equations are calibrated to fit actual trip generation values (Ortuzar and Willumsen, 1994).

In this study, a commonly used multiple regression equation is employed to quantify the factors affecting variations in trip production and attraction. In residential models, this equation is specified for three trip purposes (work trips, school trips, and other trips).

$$P_i^k = \sum_{r=1}^{n} a_r^k \cdot x_r^k \tag{3.1}$$

$$A_j^k = \sum_{s=1}^{m} b_s^k \cdot y_s^k \tag{3.2}$$

where:

$P_i^k$ is the number of trips produced in zone i for trip purpose k;

$A_j^k$ is the number of trips attracted in zone j for trip purpose k;

$a_r^k$ is the trip production coefficient for the $r^{th}$ variable for trip purpose k;

$b_s^k$ is the trip attraction coefficient input for the s$^{th}$ variable for trip purpose k;

$x_r$ $y_s$ are specified independent variables (i.e. population, employment, income)

*k* denotes trip purpose,

*r, s* denote variable names,

*i, j* denote the number of zones,

*m, n* denote the number of variables

(Adapted from Meyer and Miller, 1984: 247; EGO, 1987a:2, Ortuzar and Williumsen, 1994:119; Salter and Hounsell, 1996: 28)

### 3.3. Trip Distribution

In trip distribution stage the interactions among specified units (travel analysis zones) for a given purpose are analyzed and expressed as a function of travel impedance (Ortuzar and Willumsen, 1994). Future interactions according to given scenarios these units are estimated by using this function. Trip distribution methods, which are used to measure interaction (movement of goods or individuals) in geography, have a wide range of application areas (i.e. geography, regional and urban planning and logistics) for various purposes especially in urban environment (Ortuzar and Willumsen, 1994; Oppenheim, 1995; Boarnet, 1998; Black, 2003).

Understanding and predicting of movement of individuals and goods among different geographic locations has been examined in order to determine size and scale of facilities, and benefits and impacts of transportation services (Lewis et al, 1990; Boarnet, 1998; Black, 2003). Researchers stated that, spatial interaction models are extensively employed in order to assess capacity utilization rates, social and financial benefits of urban services, impacts of activity location, and predict consumer behavior analysis in related studies (Black, 2003).

In trip distribution stage, trip production and attraction totals (accounted at trip generation stage) are distributed to the rows and column of an interaction matrix depending on space impedance (travel cots) between each zone pair (Ortuzar and Willumsen, 1994). One of the conventional methods is the "gravity" model, but other sophisticated methods are also employed.

Fundamentally there are two methodological categories on trip distribution stage: growth factor models and synthetic models (Meyer and Miller, 1984; Ortuzar and Willumsen, 1994). Salter and Hounsel (1996:38) subdivide growth factor methods into four: constant growth factor; average growth factor; Fratar method; and Furness method.

**3.3.1 Growth factor models:**

According to this approach, trip distribution, which is represented by trip tables (O/D matrices), is assumed to grow with respect to existing trip distribution rates (Salter and Hounsell, 1996). That is, existing trip rates between O/D pairs are factored up or down to calculate the future trip distribution matrix. Here growth factors are key parameters in the estimation process of future travel pattern. A typical growth method equation is:

$$\sum T_{ij} = \sum t_{ij} * k \qquad (3.3)$$

$t_{ij}$ is the existing trips made between zone i and zone j

$T_{ij}$ is the calculated value of trips to be made between zone i and zone j

$k_{ij}$ is the growth factor to be applied to $t_{ij}$ to calculate $T_{ij}$,.

In this equation, ***k*** is the constant factor derived by dividing the number of predicted trip ends (total trips) by the existing number of trip ends (Adopted from Ortuzar and Williumsen, 1994:154; Salter and Hounsel, 1996:39).

This equation is employed in uniform growth method where the constant factor can also be determined by other factors such as population growth rate. In the average growth method the constant (***k)*** can be obtained according to varying rates of growth of trip making.

In the Fratar Method growth factors of both origin and destination zones are multiplied by existing trips and trip attraction and production totals are adjusted according to these growth factors (Salter and Hounsel, 1996). In the Furness Method first the production trips then attraction trips are balanced according to these growth factors Salter and Hounsel, 1996).

These models are emploed in order to predict short term travel distribution (Meyer and Miller, 1984:250). Since individuals' workplace choices, shopping behaviors, location preferences and other similar travel behaviors are not homogenous, growth models are not able represent actual travel patterns accurately. Moreover, it is not possible to predict possible impacts of urban development (adding new zones) on spatial interaction (Ortuzar and Williumsen, 1994:158).

### 3.3.2 Synthetic models:

These models are based on more complex equations (adapted from Physics, Statistics and Economics) that various interdependent parameters are specified in order to find interaction matrices which "best fit" actual interactions (Batty, 1994; Salter and Hounsel, 1996). According to this approach interactions (trips or movement of goods) among given units (zones) are determined by mostly three independent factors: trips produced by origin zone, trips attracted by destination zone, and travel impedances among specified units (distance, time, or cost) (Salter and Hounsell, 1996:44). In this regard various equations (or different parameters for given equations) may be specified until significant test results are obtained in accordance with application purpose. Necessary data are production and attraction trips (outputs of trip generation stage) and travel impedance factors for studied area obtained through iterations.

In this method, the distinct factor is friction of space which is a generalized function of income per capita, and transportation cost (or service quality) (Salter and Hounsel, 1996). In this stage, like in other stages, actual (observed) trip matrices are obtained from home questionnaires. The algorithm and the number of factors specified in equations determine complexity of model.

According to Ortuzar and Willumsen (1994) trip distribution process is a frequently used method among spatial interaction models. The gravity model is a commonly used method due to its practical advantages (Salter and Hounsell, 1996). They argued that despite its widespread use this model has weakness due to its lack of realistic theoretical basis (pp.251). These critics are rooted in Wilson's model of entropy maximization which is a sound contribution in the development of spatial interaction models (Vries et al, 2000). According to entropy principle (Wilson 1970 and 1974), by maximizing the entropy, which is the measure of the level of disorder in a system, it's possible to obtain a series of interaction matrices. In other words, according to this approach the most probable configuration (best fitting) of the interactions (trip matrix) can be obtained through systematical adjustment in order to improve predictive capabilities of gravity models which have lack of behavioral approaches (Meyer and Miller, 1984:251). Further critics on Gravity Model can be found in Weber and Sen, (1985) and Vries et al, (2000).

Wilson's gravity model, which is a synthesis of statistics and information theory and provided a broader context to spatial interaction issue, is extensively used in transportation planning (Salter and Hounsel, 1996: 251). The simplest (or initial) form of the model, which is adapted from Newton's Gravity Principle, states that the interaction between two units is proportional to the product of the sizes, and inversely determined by the impedance between them.

The interaction (here it refers to trips) $T_{ij}$ from origin ***i*** to destination ***j*** is:

$$T_{ij} = P_i A_j F_{ij} \tag{3.4}$$

where $P_i$ indicates the size of origin (source of movement) i , $A_j$ is the size of destination j , and $F_{ij}$ is the friction of movement between i and j (Adapted from Weiner and Miller, 1984: 250). Friction, as stated above, can be a decreasing function of distance, time or travel cost. Since shares of travel cost in individuals' total income varies according to socioeconomic factors, measurement of friction factor is the most crucial component of synthetic trip distribution models.

After these critics, as stated above, Wilson improved model structure to involve the effects of various factors and provided four stages of the Gravity Model:

-the unconstrained model,
-the production-constrained model,
-the attraction-constrained model and
-the doubly constrained model.

The unconstrained spatial interaction model equation is:

$$\mathrm{T_{ij}} = \left[\mathrm{O_i} * D_j * f_{ij}\right] / \sum_{j=1}^{n} D_j * f_{ij} \tag{3.5}$$

where:

$T_{ij}$ denotes travel between two zones,

$O_i$ denotes number of trip productions from a zone,

$D_j$ denotes the number of trip attractions for a zone,
i is the production zone,
j is the attraction zone,
n denotes number of zones,
$f_{ij}$ is the travel impedance factor (Adapted from Weiner and Miller, 1984: 250).

The model states that, the trip productions in zone i, will be allocated to each destination according to the relative attractiveness of zone j. Here, attractiveness of each destination is determined by product of its attraction and impedance factor between i and j.

The production (origin) constrained and the attraction (destination) constrained model have similar and identical structures in terms of application purpose. In work trips case, if attraction of work places (labor force) are considered attraction constrained model can be employed, whereas allocation of working population trips among residential areas is considered production constrained model can be employed.

In production constrained model, the proportion of employment in zone ***j*** to the total employment determines the production rate of the zone ***i***. Since the total trips from zone ***i*** ($O_i$) is known total number of trips obtained from calculation process should be equal to total origin trips. Here the issue is the allocation of work trips among all destinations.

$$\sum_j T_{ij} = O_i \quad \text{and} \quad \sum_i T_{ij} = D_j \tag{3.6}$$

Then trips from an origin zone to a destination zone are represented as

$$T_{ij} = A_i O_i D_j F_{ij} \tag{3.7}$$

$O_i$ is the number of trips produced in zone i (origin),
$D_j$ is the trips attracted by zone j,
$F_{ij}$ is the friction factor between zone i and j (Wilson, 1974).

Here $A_i$ is the proportionality factor which determines trip production share of each origin zone in total residing employment. $A_i$ can be found from the following equation:

$$A_i = \left[ \sum_j D_j F_{ij} \right]^{-1} \quad (3.8)$$

In destination-constrained (attraction-constrained) case, total residing employment is assumed to be fixed, therefore $D_j$ (total trips to zone ***j***) is a given independent variable. Here the issue is the calculation of work trips (home based work trips) attracted by zones in the studies. Then employment number of each zone proportional to total employment determines the attraction rate of zone ***j.*** In this case the restriction is

$$\sum_i T_{ij} = D_j \quad (3.9)$$

And using proportionality factor $B_j$ trips are calculated (Wilson, 1974) from the following equation:

$$T_{ij} = B_j O_i D_j F_{ij} \quad (3.10)$$

$$B_j = \left[ \sum_i OiF_{ij} \right]^{-1} \quad (3.11)$$

In the production-attraction-constrained, or "doubly constrained" model both $O_i$ and $D_j$ are given, and the allocation of trips is determined by the model is based on two sets of restrictions which are provided in equation 3.13 and equation 3.14.

In doubly constrained model, proportionality factors of both production and attraction $A_i$ , $B_j$ are necessarily calculated recursively. Here in the case of work trips, the equation is:

$$T_{ij} = A_i B_j O_i D_j F_{ij} \quad (3.12)$$

where;

$$A_i = \left[ \sum_j B_j D_j F_{ij} \right]^{-1} \quad (3.13)$$

$$B_j = \left[ \sum_i A_i O_i F_{ij} \right]^{-1} \quad \text{(Wilson, 1974)} \qquad (3.14)$$

In doubly constrained model, recursive calculation process is used to minimize differences in both column sum and row sum. Recalculation of $A_i$ and $B_j$ after each iteration allows substitution on both sides. That is, in attraction constrained model, total production trips may not be equal to observed trips, or in production constrained model, total attraction trips may not be equal to observed trips. In this method both $A_i$ and $B_j$ parameters are adjusted to overcome this problem. The iteration process is repeated until model results converge to observed trip totals.

Iterative process allows minimization of average difference between computed and observed productions/attractions. The iteration process is repeated until significant convergence (minimum error or estimate) between model output and observed trips is obtained. In some cases significant results may not be obtained; that is, friction factor may not be able to represent interactions in the studied area (Salter and Hounsel, 1996). Then it is necessary to recalculate friction factors to balance the row and column totals. In this method, iteration procedure consists of two sub processes: cross comparison of outputs and adjustment of friction parameter.

Therefore the function of friction of space $F_{ij}$ is the critical component of the equation. In this study this function is described by an expression of exponent of time $e^{\beta * t}$, where $\beta$ is the curve factor and $\boldsymbol{t}$ is the travel time.

Since the process comprises of complex equations, computer application is necessary for time saving; in general, computation procedure necessitates a lookup file to process data for the function based upon the friction factors. For further information abut Gravity Models see Ortuzar and Williumsen, 1994 and Salter and Hounsell, 1996)

In this study a double constrained method is employed to estimate trip distribution among all zones for each trip purpose. The form of the doubly constrained trip distribution equation is:

$$T^k_{ij} = a^k_i \cdot b^k_j \cdot G^k_i \cdot A^{k.}_j \cdot (W^k_c \cdot e^{-\beta^k_c \cdot t^c_{ij}} + W^k_t \cdot e^{-\beta^k_t \cdot t^t_{ij}}) \qquad (3.15)$$

where

$T^k_{ij}$ is the estimated number of trips between zone i and zone j for the trip purpose k;

$G^k_i$ is the estimated number of trips generated by zone i for trip purpose k (generators);

$A^{k.}_j$ is the estimated number of trips attracted by zone i for trip purpose k (generators);

$a^k_i$ and $b^k_j$ are row and column factors to ensure that the trips originating in zone i are equal to the total generators in zone i that the trips arriving in zone j are equal to the attractors in zone j for the purpose k, to ensure that $\sum_j T^k_{ij} = G^k_i$ and $\sum_i T^k_{ij} = A^k_J$

$W^k_c$ is the weight given to the travel times by auto mode for trip purpose k;

$\beta^k_c$ is the trip distribution parameter (friction parameter) for the travel time by auto mode for trip purpose k;

$t^c_{ij}$ is the travel time from zone i to zone j by auto;

$W^k_t$ is the weight given to the transit times for trip purpose k;

$\beta^k_t$ is the trip distribution parameter (friction parameter) for the transit times mode for trip purpose k;

$t^t_{ij}$ is the travel time from zone i to zone j by transit;

$W$ and $\beta$ are parameters estimated by the user.

In this equation travel times $t^c_{ij}$ and $t^t_{ij}$ are derived from the shortest paths produced by tree building algorithm (EGO, 1987a:4).

Sometimes it may not be possible to obtain all parameters (transit and auto trip travel times) separately. In that case a generalized cost function may also be used (Ortuzar and Williumsen, 1994:153). The most commonly used trip purposes are "home based work", "home based school" and "home based other" however other purposes may be incorporated in this process. In this procedure non home based trips are also calculated to adjust production and attraction totals. Friction factors for each purpose are specified separately in order to obtain more realistic results. Hence at least three trip distribution matrices are obtained. If the "trip end" method of trip distribution is preferred, at least nine matrices (three modes for three purposes) are obtained. The weaknesses of this method and errors of estimate found in the case study are presented in chapter 5.

### 3.4. Modal Split

The aim of modal split stage is to predict trip distribution by available modes available in the study area (Lewis et al, 1990; Ortuzar and Willumsen, 1994). At the end of this process, trip distribution matrices (for at least three trip purposes) are derived into purpose-mode matrices for all available modes (Lewis et al, 1990). It is assumed that individuals mode choice is mainly determined by three factors; socio-economic status (i.e. income, occupation) of the traveler, service qualities of available transportation modes (i.e. auto, bus, rail, para-transit) and travel cost (i.e. trip length, cost, time) (For further information see Ortuzar and Williumsen, 1994; Bagley and Mokhtarian, 2001; Cervero, 2001). Salter and Hounsell, 1996 stated that the effect of model split is of very considerable significance and it is extensively influenced by transport policy decisions (pp.55).

There are two approaches of modal split: trip end method and trip interchange method. The former one is based on the assumption that "transit ridership" is primarily a function of socio economic variables (Meyer and Miller, 1984:252). According this approach, all riders are assumed to be "captive riders. In trip end method modal split is performed after trip generation; that is, trip destination or travel cost is not encountered but traveler's income, auto ownership, and trip purpose determine individual's mode choice. Hence, in model structure, model split is the second stage of four step model. This method is regarded as a simple process since they require relatively less data for calibration (Meyer and Miller, 1984:252). On the other hand their deterministic assumption is not sensitive to policy changes or technological advancements.

In trip interchange method, travel cost and transportation service characteristics of available modes affect traveler's mode choice (Meyer and Miller, 1984; Salter and Hounsell, 1996). This approach assumes that, the traveler's destination choice is not determined by traveler's socio economic status whereas individual's mode choice mode is determined by a function of travel distance, travel time, and travel cost (or service quality).

In trip distribution stage, friction function is described by an expression of exponent of time $e^{\beta * t}$, where $\beta$ the curve factor, and $t$ is is travel time by specified mode. In trip end method friction factors and travel times for all available modes can be measured separately, therefore the model has advantages in disaggregated analysis. However, when walk trips are excluded from mode choice analysis, distribution function of vehicle trips according to travel distance will not form a exponential form (See Figure 3.1).

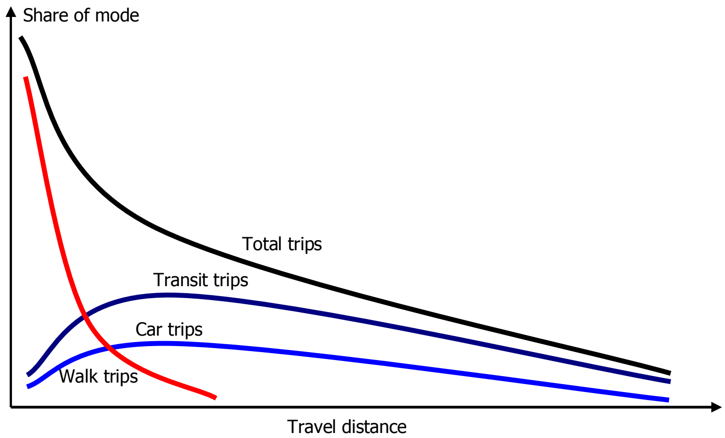



**Figure 3.1: A general function of effect of travel impedance on trips.**
(Shares of travel modes in total trips are influenced by travel distance)

In this case, just walk trips show an exponential distribution; however transit trips and distribution of motorized trips with respect to travel distance (or time) do not fit this function; that is in order to accurately predict the share of a specific mode in total motorized trips some other forms of distribution functions are necessary. Hence in trip end method exponential friction factor cannot be an appropriate expression tool for trip distribution stage. Due to such problems, trip end method is not generally adopted in travel demand estimation (Salter and Hounsell, 1996).

Trip interchange is a widely used method in transportation studies (Salter and Hounsell, 1996). According to this approach travel cost has significant effects on traveler's mode choice for given purposes. In this method total trip matrices are obtained after trip distribution stage, then modal separation of trips is performed with respect to travel costs. Recent studies on dynamic network assignment and mode choice showed that due to congestion car trips may be diverted to public transportation (Cervero and

Gorham, 1995; Oppenheim, 1995; Nagel et al., 1996; Nagel, 2002; Varaia, 2004). Similarly researchers found that road provision and congestion relief result in both diverted and induced traffic (Levinson and Kumar, 1994; Cervero, 2001; Prthasarathi et al, 2003).

Trip interchange method is commonly preferred due to its behavioral and probabilistic assumption (Oppenheim, 1995; Salter and Hounsell, 1996). The first step in this method is to eliminate the walk trip component from the origin destination tables. Walk trips are subtracted from the trip matrix as follows:

$$T_{ij}^{kl} = T_{ij}^{k} .(1 - P_{ij}^{k}) \qquad (3.16)$$

where:

$T_{ij}^{kl}$ is the total number of trips from zone i to zone j by auto and transit modes (excluding walk trips);

$T_{ij}^{k}$ is the total number of trips from zone i to zone j as determined in trip distribution;

$P_{ij}^{k}$ is the proportion of walk trips for purpose k as a function of distance between zone i and zone j and can be expressed as an inverse exponential function ($e^{-\beta d}$) of travel distance and curve factor $\beta$ (EGO, 1987a).

There are two identical calculation procedures of trip interchange method modal split: the fixed modal split method and diversion curves method (EGO, 1987a; Salter and Hounsell, 1996). The former one multiplies vehicle trips by (matrix cells) by given transit and car factors. The latter one uses "diversion curves" in which a relationship is derived from relative weights of car and transit travel costs and express this relationship is expressed by an identical equation (EGO, 1987a:5).

In "diversion curves" method, travel time differences or travel time ratios between zones are obtained from field surveys (EGO, 1987a; Salter and Hounsell, 1996). For each trip purpose a set of diversion curves is specified in order to predict trip distribution by modes. The equations are:

$$T_{ij}^{kt} = T_{ij}^{kl} \cdot m_t^k (t_{ij}^{c/t}, V2) \tag{3.17}$$

$$T_{ij}^{kc} = T_{ij}^{kl} - T_{ij}^{kt} \tag{3.18}$$

where

$T_{ij}^{kt}$ is the number of transit trips from zone i to zone j for tip purpose k;

$T_{ij}^{kc}$ is the number of trips by car from zone i to zone j for tip purpose k;

$t_{ij}^{c/t}$ is the travel time ratio (auto time/transit time) from zone i to zone j;

$V2$ is the second variable that affects auto-transit mode choice. Here car ownership or average zonal income could be used;

$m_t^k$ is the percent transit trips as determined from the "diversion curves by interpolation for each trip purpose (EGO, 1987e:5).

The calibration of diversion curves is performed by cross comparison of model outputs with questionnaire survey results (EGO, 1987a; Ortuzar and Williumsen, 1994). In the recent years neural network methods are applied in trip distribution models (See Appendix A).

### 3.5. Network Assignment

Network assignment is the final stage of conventional four staged transport model. Network assignment models are used in a range of application areas both in public and private sectors (Ben Akiva et al, 1991; Ran and Boyce, 1994; Ben Akiva et al; 1997; Levinson, 2003). By using these models researchers aimed at predicting passenger or vehicular flows, for a specific time interval, on the underlying network of the studied area. Principally there are two components of this stage: trips assignment and traffic assignment (highway assignment). The former one aims at predicting allocation of passenger trips on underlying public transportation network; latter one predicts vehicular flow on underlying road network.

Signalization, junction design, road section design, routing and traveler information systems, traffic management and other similar activities in traffic planning necessitate traffic flow estimates. Besides, facility assessment, route planning and similar services in public transportation necessitate estimation passenger flows (For further information see Memmot, 1983; Ben-Akiva and Lerman, 1985; Ran and Boyce, 1994; Ortuzar and Williumsen, 1994; Oppenheim 1995; Salter and Hounsell, 1996; Lundqvist et al., 1998; Rilett and Park, 1999; Ziliaskopoulos and Waller, 2000; Waller and Ziliaskopoulos, 2001; Levinson, 2003).

In this stage complex sub models are used: network establishment, shortest path analysis and allocation of tips. Principally after trip distribution and modal split stages trips are assigned to appropriate paths established in transportation network which is composed of nodes and links. Roads are represented by links and link properties such as, distance, width, capacity, free flow speed, link class, and traffic control measures (Ran and Boyce, 1994). An appropriate combination of these properties is used to determine individuals' travel cost (disutility) which is regarded as a key factor in traveler's route choice (Oppenheim, 1995).

Network assignment models are commonly employed in order to evaluate urban transportation network performances; that is, passenger demand for specific routes or vehicle volumes on certain road sections can be estimated through this process (Lin et al, 2003). Basically, movements between each origin/destination pair are assigned to least cost route/s. In this process, passenger or vehicle flows obtained from simulation model are compared with traffic counts. If significant convergence between simulated and observed traffic volumes is achieved the model can be applied in further predictions. Then capacity utilization rates of public transportation services and demand for road usage in transportation system can be assessed by model estimates. Traffic assignment is an essential component of following issues:

-to evaluate and assess benefits and impacts of transportation projects;
-to provide travel demand for specific public transportation routes,
-to evaluate impacts of major urban facilities on transportation system,
-to establish implementation phases and priorities for transportation services;
-to analyze alternative locations for urban facilities;
-to provide necessary input and feedback for land use planning proposals and
-to establish capacity utilization rates on traffic network (Safwat and Magnanti, 1988; Roess et al., 1990 Ortuzar and Willumsen, 1994; Ran and Boyce, 1994; Weiner 1997; Weisbrood and Weisbrood, 1997).

There are two identical categories of passenger/vehicle volume estimation methods: statistical methods and mathematical models. Statistical models basically depend on passenger or vehicular traffic trends (Williams and Ortuzar, 1982; Meyer and Miller, 1994; Roess et al., 1990; Ortuzar and Willumsen, 1994). These are:

1-Time series forecasting method,
2-Growth factor method, and
3-Regression method

Time series forecasting methods assume that past trends in traffic volume will continue into the future with respect to volume variations in time. Average annual daily traffic or average daily traffic in any time period is the variable in the equation. Annual volume variation (or growth) rate is the trend parameter. Therefore the equation is:

$$V_t^l = V_{t-n}^l rn \qquad (3.19)$$

Here, $V_t^l$ is the volume on link l at time t,

$V_{t-n}^l$ is the volume on link l at time t-n

***r*** is the variation factor of the average annual daily traffic volume
***n*** is the time period (years) between two time segments (www.fhwa.dot.gov)

It is obvious that this approach assumes static trends in traffic volumes. In this model, traffic volumes for proposed roads cannot be predicted. Due to this fact time series method can not be used in post-planning evaluation.

Growth factor method is another simple and static method, which assumes that past trends in percent increase will continue in the future. In this method, annual increase rates of traffic volumes are obtained from historical data; that is, consistency of the model is analyzed by past trends. In this method the following equation is used:

$$V_t^l = V_{t-n}^l (1+g)^n \qquad (3.20)$$

Here, $V_t^l$ is the volume on link l at time t,

$V_{t-n}^l$ is the volume on link l at time t-n

$g$ is the annual growth factor

***n*** is the time period (years) between two time segments (www.fhwa.dot.gov).

This model fails in predicting variations in travelers' behavior. On the other hand traffic volumes for newly constructed or subject to improvement cannot be obtained through this method.

In regression methods, past trends in average annual daily traffic on transportation network are extrapolated to a target year. In addition the relationships between demographic characteristics, spatial variables and traffic volumes are expressed by regression equations. Then the equation results are compared with actual traffic volumes in order to test reliability of equations. Like other conventional statistical methods weight of each variable is determined in order to establish a hypothesis for future predictions. Traffic volume for a specific road section is predicted by the following equation:

$$V_t^l = a + b_1 x_1 + b_2 x_2 \cdots\cdots b_n x_n \tag{3.21}$$

Here, $V_t^l$ is the volume on link l at time t,

$a$ is the constant term (or present volume),

$b_i$ is the regression coefficient of independent variable ***i***, for the year ***t***,

$x_i$ is the value of independent variable ***i*** for the year ***t*** (www.fhwa.dot.gov).

This model, like other statistical models, does not take into account transformation of road network in the future. Therefore it is not possible to predict possible impact of additional transportation services. This method is employed to understand past trends so as to be taken into account in pre-planning stage. In general statistical methods models may be used in pre-planning stage. Since individuals' travel behaviors are not represented in statistical methods they are not able to predict actual traffic volumes in the future. Due to this fact statistical methods are not preferred in traffic estimation (Ortuzar and Willumsen, 1994; Roess et al., 1998).

Mathematical models fall into the second category of the traffic estimation methods. Among them three methods of traffic assignment are commonly used in transportation planning (Meyer and Miller, 1984; Ortuzar and Williumsen, 1994; Ran and Boyce, 1994; Oppenheim, 1995; Salter and Hounsell, 1996; Rilett, and Park, 1999):

1. All or nothing (minimum path),
2. Capacity restrained (equilibrium), and
3. Stochastic and dynamic assignment models.

These mathematical models are differentiated according to methodology based on assumptions about traveler's route choice. These models are motivated around finding least cost path/s in un-congested or congested networks. There is an extensive literature on model development, network design problems and application of network assignment models. Ben Akiva et al (1978), Ben Akiva and Lerman (1985), Ben-Akiva et al. (1986), Ran and Boyce (1994), Oppenheim (1995), Rilett and Park (1999) and Levinson (2003) investigated solution algorithms for this problem and these researchers have substantial theoretical contributions to this field.

The researches are categorized into four groups in terms of purse and scope:

1. Comparative analysis of shortest path methods,
2. Improvement of specific shortest path algorithms,
3. Application of information and communication technology, and
4. Application of models on real networks.

Among mathematical assignment methods, all or nothing (minimum path) method, the simplest form of network assignment, is based on the assumption that all travelers follow the route that have minimum cost (in terms of monetary cost or time) between origin destination pairs (Salter and Hounsel, 1996).

This approach assumes that all travelers have similar perceptions of travel time and travel cost. Initially minimum paths are found then trips that are represented by a trip distribution matrix are allocated to the specified paths. All trips between a given origin and destination are loaded on a single shortest path (See Figure 3.2). Then, all trips (or vehicles) are allocated on the underlying network. Specific link volumes can be obtained at the end of this process. Since shortest paths are extremely dependent on link costs some links are assigned with more traffic volumes than their capacity others may not be assigned (Salter and Hounsell, 1996).

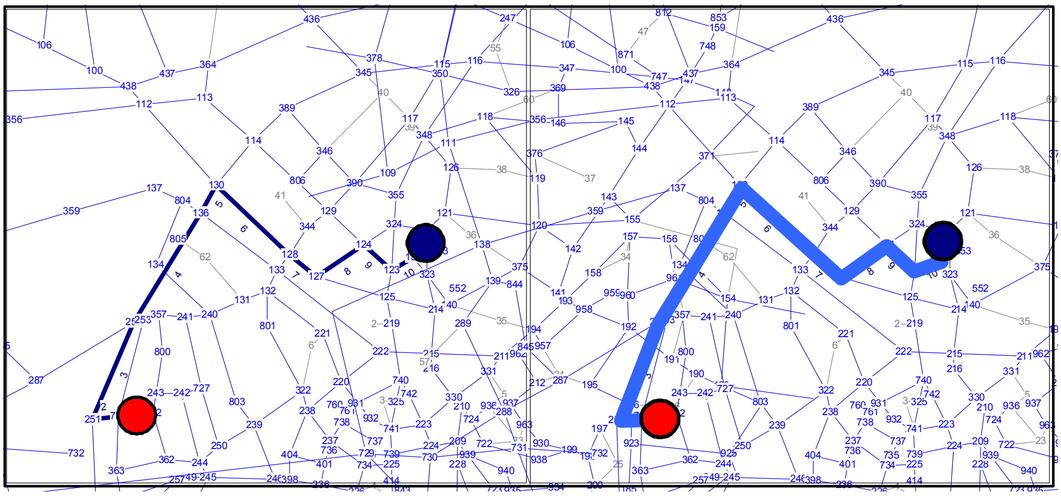


**Figure 3.2: A shortest path and traffic assignment example in "all or nothing assignment" method**

Capacity restraint method is based on the principle that as traffic volume increases on a specific link travel speed at corresponding link decreases (Ortuzar and Willumsen, 1994). In this traffic assignment method, the trips are assigned to least cost paths that are found in an iterative process. After initial iteration travel speeds are recalculated until an equilibrium distribution is achieved. Finally, the traffic volumes on the underlying networks are obtained. This method has been commonly applied in transportation network design and traffic management (Ortuzar and Willumsen, 1994; Salter and Hounsell, 1996; Boyce et al, 1997; Ziliaskopoulos and Waller, 2000).

According to this method there is a direct relationship between volume/capacity rate and travel speed (Ortuzar and Willumsen, 1994). In this method travel speed and travel time is recalculated through iterations, therefore shortest path between each origin destination pair is determined according to travel time. Meyer and Miller (1984), Ran and Boyce (1994) and Ortuzar and Willumsen (1994) claimed that this process was developed to take into account travel time in congested networks, especially in peak hours. In such cases as links on the initial shortest path (p1) between zone i and zone j are assigned with traffic volumes the level of service which is determined by traffic speed, decreases. In the second iteration congested links are not preferred if a second best route (p2) is available. Then all trips between corresponding origin destination pair are assigned to the second least cost path, and this process continues until all trips are loaded on the network (See Figure 3.3).

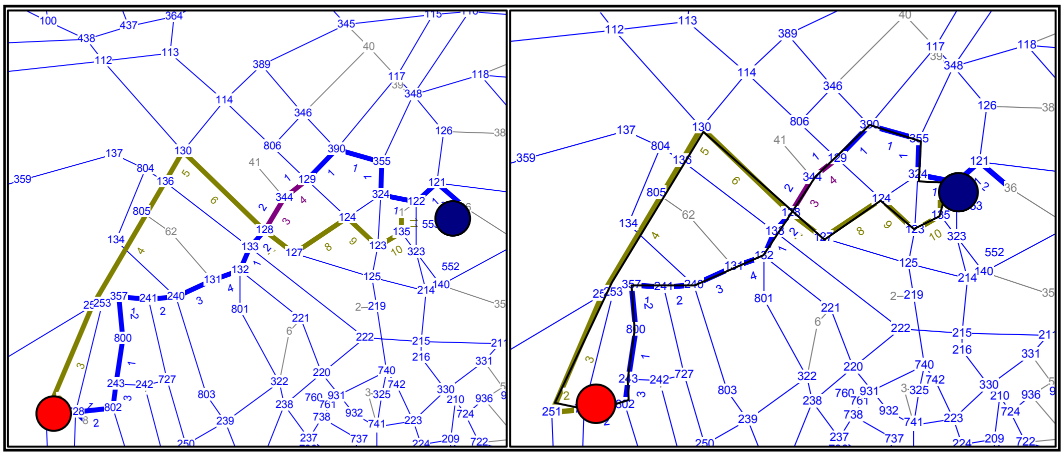


**Figure 3.3: Shortest paths and traffic volumes in the conventional type of capacity restraint assignment method**

In this process commonly traditional BPR function (U.S. Bureau of Public Roads developed a function, based on volume/capacity ratio that is used in order to calculate travel time in congested links) is used:

$$T_C = T_0 * (1 + \alpha * (V / C)^{\beta}) \qquad (3.22)$$

where

$T_C$ is the actual flow time in loaded network (or congestion) at volume V,

$T_0$ is the free flow time (in terms of design speed),

$V$ is the actual link volume

$C$ is the link capacity

$\alpha$ and $\beta$ are parameters of calibration. Commonly these values are assumed to be 0.15 and 4 are respectively (Ortuzar and Willumsen, 1994; Salter and Hounsell, 1996).

Another method is proportional assignment which assumes that all travelers do not follow same routes especially in congestion. In this method, trips between each origin-destination pair are allocated and assigned to two or more paths in terms of proportions determined according to link capacities. In next iterations, speeds are recalculated in terms of volume and capacity ratios in order to determine new paths. Finally all trips are allocated on the network until equilibrium is obtained. The proportional type of capacity restraint assignment model is mainly path based.

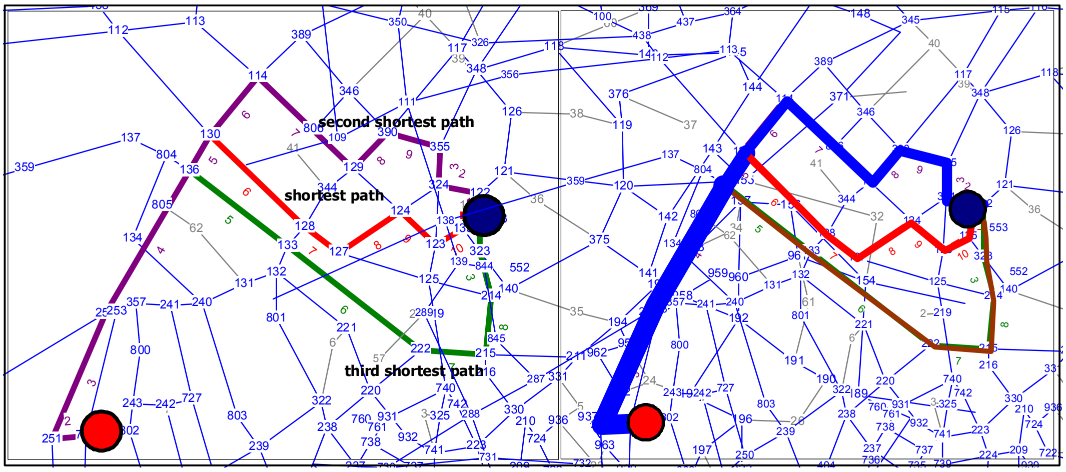



**Figure 3.4: Shortest paths and traffic volumes in the proportional type of capacity restraint assignment method**
(trips are allocated proportionally in terms of capacity or speed)

The third method is Dynamic Traffic Assignment which assumes that travelers may follow alternative routes depending on departure time, actual travel speed, and varying travel cost factors. This method has not been applied in transit networks yet. These methods are developed in order to predict varying traffic flow in congested networks under assumption that travel time and travel cost of any link varies in time depending on density. Sometimes they are called "multi-route" and "link based" (Ran and Boyce, 1994, Oppenheim, 1995).

In this method when an initial shortest path is occupied by vehicles other travelers seek alternative shortest paths (Ran and Boyce, 1994). After a period of time, some travelers leave a link and enter to an un-congested link, and then others follow them until corresponding link is congested. This principle is called "first in first out" (Ran and Boyce, 1994).

This method assumes that a traveler may not have perfect information about shortest paths at departure time; therefore they seek alternative links by trial and error method. In dynamic assignment method, trips are assigned to all possible paths between zones as a function of travel time which is influenced by flow, density, and actual speed. Here, paths may not have equal costs then, the probability that a traveler will prefer path ***i*** is determined by a function of total travel cost (Oppenheim, 1995).

This method assumes the probability of choosing alternative paths which depends on departure times that even longer routes (of travel distance) may be followed by some individuals when roadway is congested (See Figure 3.5). In dynamic network assignment method departure time, density, flow, travel speed and travel time are necessary factors in order to determine individuals route choice (Ran and Boyce, Oppenheim, 1995).

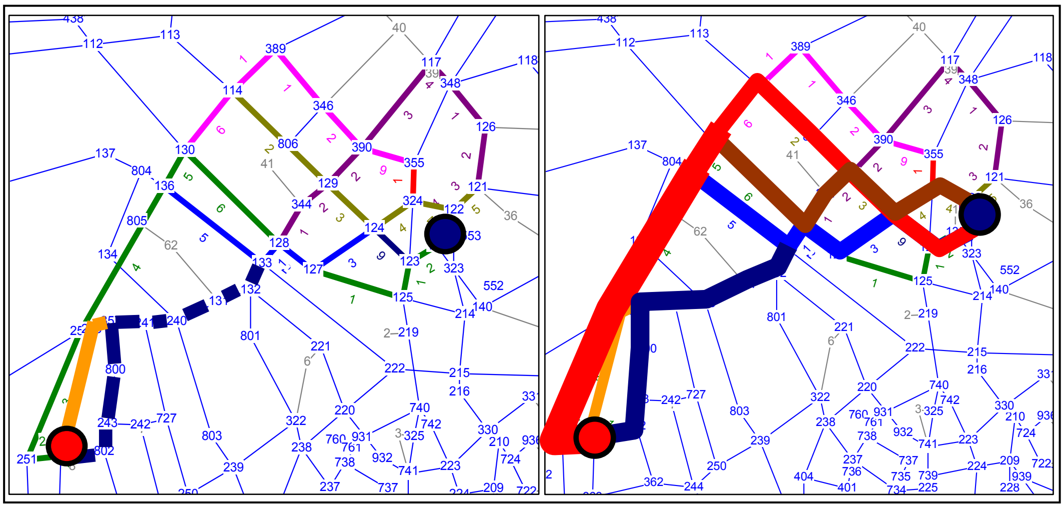


**Figure 3.5: Departure time dependent routes and traffic volumes in dynamic network assignment model**

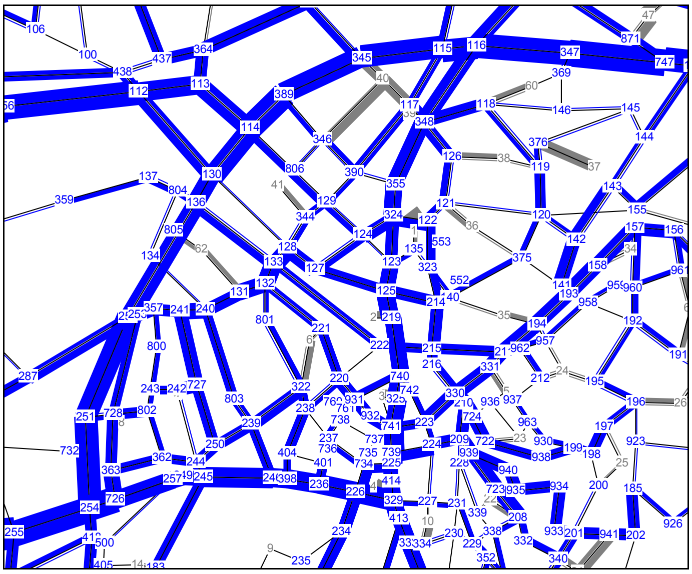


**Figure 3.6: Traffic volumes obtained by network assignment model.**

In class based models (Ran and Boyce, 1994; Oppenheim, 1995; Lo and Szeto, 2003; Yang and Huang) traveler's income (or utility) is also encountered as a significant factor of travelers' route choice since "travel cost" has relative effects on travelers' budgets. Oppenheim (1995) provided a comprehensive analysis of the relationship between utility and travel behavior.

### 3.5.1. Foundations of Dynamic Traffic Assignment Models

There is an extensive literature on dynamic network assignment problem. A broad literature review on network assignment is provided by Peeta and Ziliaskopoulos (2001). In this part, a summary of approaches and model structures developed by the pioneers of this field (Ben Akiva et al, 1978; Florian and Nguyen, 1978; Ben-Akiva and Lerman 1985; Ran and Boyce, 1994; Oppenheim, 1995) are presented. Ran and Boyce (1994) investigated the foundations of traffic assignment models and put special emphasis on Wardrop's principle, a pioneering contribution to network assignment modeling theory:

> First Principle: The travel times of all routes actually used are equal, and less than those, which would be experienced by a single vehicle on any route.
>
> Second Principle: The average travel time is minimum.
>
> The first principle is known as the user equilibrium (UE) rule, which can be further explained as the follows: the UE rule is that no user can improve his/her travel time by unilaterally switching routes, and consequently any unused route has a higher cost than the used one (between a given O-D pair).
>
> The second principle is referred to system optimal (SO), under which users select their routes according to what is optimum from a society point of view. Under the SO the total travel cost in the system is minimized. This principle does not necessarily generate an equilibrium flow, where the users are able to improve their individual travel time by using other routes. Thereby, in most cases, the SO solution produces a non-stable system which is not realistic, unless users are "forced" to use the designated paths. (cited Ran and Boyce, 1994).

According to Ran and Boyce (1994) "elastic demand traffic assignment problem" constitutes theoretical grounds of dynamic assignment models. According to this method number of flows on any route between a given origin-destination (O-D) pair is a function of the travel time (or cost). Dial (1971 cited in Ran and Boyce, 1994) developed a probabilistic multi-path traffic assignment algorithm that constitutes the ground of recently developed models.

Ran and Boyce (1994) and Oppenheim (1995) stated that congestion is also a significant factor in travelers' destination, mode and route choice. Among them, especially utility based route choice models, in which travel is a disutility, are developed depending on realistic assumption of travelers' behavior in congestion (Oppenheim, 1995). Oppenheim (1995) argued that "the user equilibrium", which is the principal assumption in most static assignment models. According to this approach individuals are assumed to be rational decision makers and have perfect information about traffic flow. Hence, traffic flow is predicted based on the idea that drivers always prefer predetermined shortest paths.

Dynamic network assignment models are based on defining temporal (and varying) least cost routes in congestion to achieve minimum travel time. Therefore such models are called "system-optimal" (Ran and Boyce, 1994, Oppenheim, 1995). According to dynamic route choice assumption, drivers' route choice is a dependent factor of socio economic characteristics of traveler and varying traffic flow. Besides destination, mode, departure time and route cost have significant influence on route choice (Ran and Boyce, 1994; Oppenheim, 1995). In this sense these models are called "probabilistic and behavioral".

Literature survey showed that these models are developed for various purposes, such as traffic management, central signalization systems, travel route guidance systems, and vehicle operation systems. Peeta and Ziliaskopoulos (2001) argued that although such models are applicable to the congested networks, in which drivers have tendency in the selection of alternative routes, there is a great deal of uncertainty in travel demand. They summarized of recent studies concerned with development of probabilistic methods and provided a framework for predicting varying travel in order to overcome uncertainty problem. A similar methodlogy can be found in Ben Akiva et al (1997).

Ran and Boyce (1994) presented a family of assignment models which aim responding varying travel demand. Ben-Akiva et al. (1997) developed a simulation method which can be applied in dynamic travel demand conditions. Waller et al. (2001) provided a methodology for dynamic network assignment problems under uncertainty. These models encounter probability based trip distribution tables and model outputs are redistributed into departure times. Briefly, in model algorithms following criteria are necessarily taken into account:

1- Varying travel demand (probabilistic prediction),
2- Disequilibrium in traffic flow,
2- Fluid (continuous) departure time (or short time intervals),
3- Variations in travel speeds in congestion,
4- Variations in travel times in congestion,
5- Probability of alternative routes, and
6- Travelers' perceptions at any instant of time
(After Ben Akiva et al, 1997; Ran and Boyce, 1994; Peeta and Ziliaskopoulos, 2001).

Ben-Akiva et al. (1997) and Waller et al (2001) take into account the role of uncertainty (or variation) in dynamic assignment modeling framework. According to Waller et al. (2001) essential variables vary in short time intervals. In this regard they proposed a model that includes trip distribution, mode choice, departure time, and route choice components. This framework aims at providing additional information to policy-makers (Waller et al. 2001). In the recent years, neural networks models have been applied in network assignment (Lam and Xu, 2000). These methods are based on the assumption that the relations among identical parts of a system (neurons) provide understanding general interaction within a system.

### 3.5.2. Dynamic Network Assignment Model Structure

In this study a dynamic assignment model developed by Ran and Boyce (1994) is employed to simulate vehicle flows on an underlying network. This process is carried out to compare performances of static and dynamic assignment models under uncertainty. Then relative advantages and disadvantages/limitations of dynamic assignment models are presented in the case study.

Boyce and Bin (1994) developed a family of dynamic models in which, vehicle flows are calculated in certain time intervals recursively. Therefore, trip assignment is regarded as a method of representation of dynamic flow. This assumption distinguishes dynamic models from deterministic models. Dynamic traffic algorithm, adapted from the literature is presented in Figure 3.7 (Ran and Boyce,1994; Oppenheim, 1995).

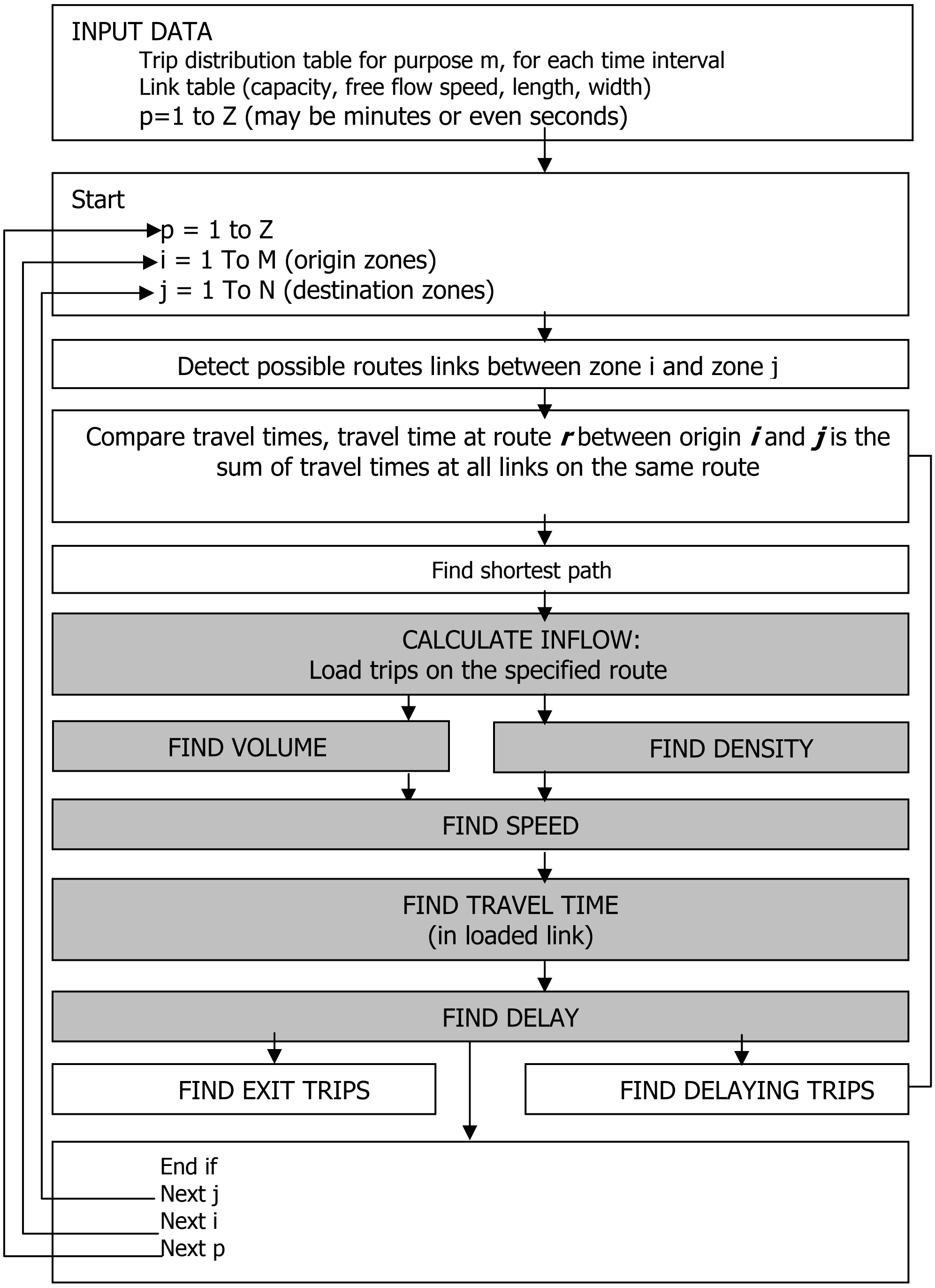



**Figure 3.7: A typical dynamic network assignment algorithm.**
(Adapted from Ran and Boyce, 1994; Oppenheim,1995; Ben Akiva et al, 1997)

Departing from this algorithm, calculation process is model concretized by constraints and necessary equations. In this algorithm, at each instance of time departures from each origin destination pairs are allocated simultaneously. In instantaneous dynamic assignment algorithms departure times are assumed to be random factors. This requires more complex computation environments.

In the case study, a simultaneous type of family of dynamic models is employed. In this method, basic principle is the probability of deciding on a route among all possible routes. That is, the probability that an individual, traveling between origin ***i*** and destination ***j*** is will follow route ***r*** is:

$$P_r = \frac{e^{\beta(g)}}{\sum_i e^{\beta(g)}} \tag{3.23}$$

Where,

$P_r$ is the probability of route ***r*** ,

measured by travel impedance factor,

$\beta$ is travel cost coefficient (measured by observation)

$g$ is the generalized travel cost; a combination of travel time and distance (Oppenheim, 1994, 77).

Sometimes, a project evaluation method may necessitate assessment of travel time and travel distance separately. In such cases one or more appropriate factors are used in order to obtain travel cost factor.

It is obvious that more complex equations and algorithms may be developed; however, the aim of this study is to discuss principles, assumptions and problems of travel demand models especially assignment models. Therefore, in this part, fundamental principles and necessary equations are presented.

Dynamic models assume that each travel has negative impacts on network properties; flow, density travel speed, travel time and volume and all these factors are inter-dependent. Following necessary constraints and equations are adapted from Ran and Boyce (1994).

1-The number of vehicles on link ***l*** (density of link ***l*** can also be measured) at any time ***t*** is:

$$v_{lr}^{ij}(t) = \int_0^t (i_{lr}^{ij}(t) - \chi_{lr}^{ij}(t))d(t) \qquad \forall a, p, r, s \qquad (3.24)$$

Where;

$v_{lr}^{ij}(t)$ is the number of vehicles traveling on link ***l*** over route ***r*** with origin ***i*** and destination ***j*** at time ***t***. Where, $v_l(t)$ is the number of vehicles traveling on link ***l*** at time ***t*** between all o-d pairs;

$i_{lr}^{ij}(t)$ is the number of vehicles entering to link ***l*** on route ***r*** between origin ***i*** and destination ***j,*** then $i_l(t)$ is the inflow rate (vehicles/ hour or vehicles/minute) on link ***l*** at time ***t*** and between all o-d pairs;

$\chi_{lr}^{ij}(t)$ is the number of vehicles leaving link ***l*** on route ***r*** between origin ***i*** and destination ***j***. then $\chi_l(t)$ is the exit flow rate (vehicles/ hour or vehicles/minute) on link ***l*** at time ***t;***

2-At the initial stage, the number of vehicles on link ***a*** at an initial time ***t***=0 is assumed to be 0 (at the beginning of the traffic flow):

$$v_{lp}^{ij}(0) = 0 \qquad \forall i, j, l, r \qquad (3.25)$$

4-Then, the number of vehicles on link ***a*** at any time ***t*** is given by

$$v_{lr}^{ij}(t) = v_{lr}^{ij}(0) + \int_0^t \{i_{lr}^{ij}(t) - \chi_{lr}^{ij}(t)\}d(t) \qquad \forall a, p, r, s \qquad (3.26)$$

In computation stage of most assignment models, all variables must be non negative at all times:

$$\chi_{ap}^{rs}(0) \geq 0, \quad i_{ap}^{rs}(0) \geq 0, \quad \chi_{ap}^{rs}(0) \geq 0 \qquad \forall a, p, r, s \qquad (3.27)$$

(Ran and Boyce, 1994)

Flow propagation on underling network (links) is presented in the following figure:

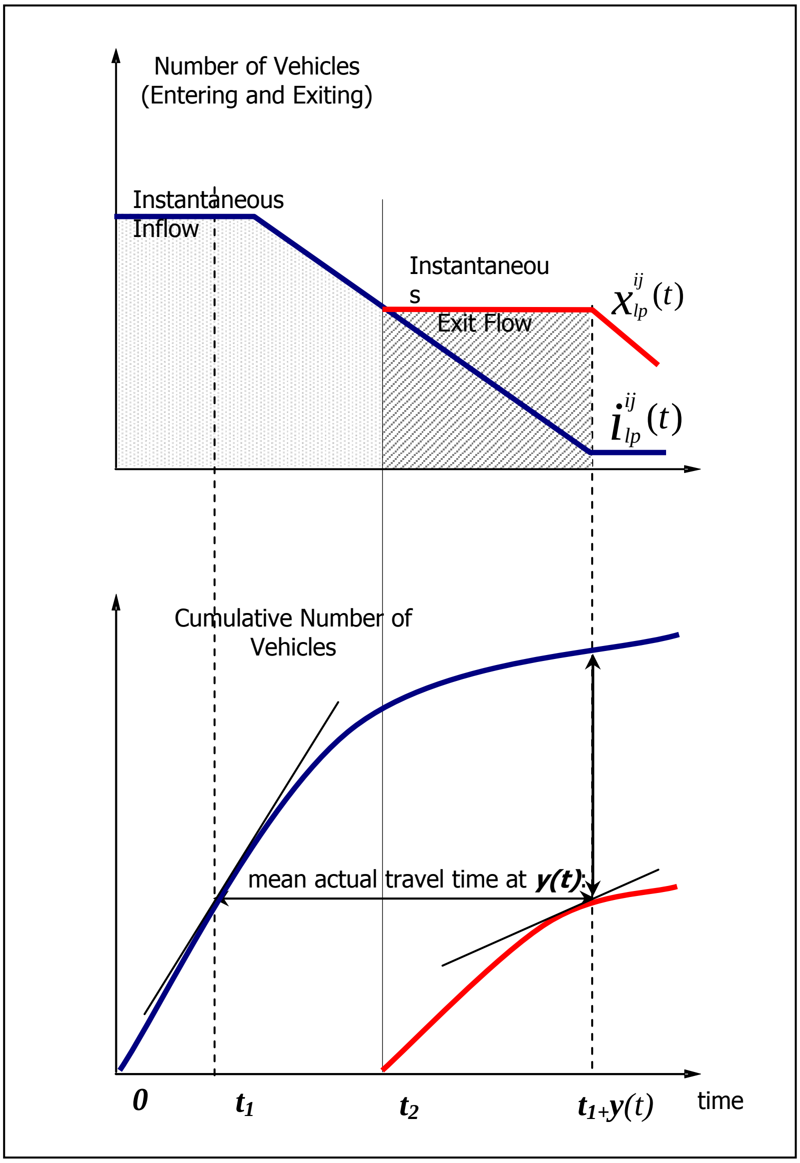



**Figure 3.8: Flow propagation on link l**
(Source: Ran and Boyce, 1994)

Due to increasing flow rate, free flow speed (initial design speed) decreases (Figure 3.9). In the following figure **A** denotes under-saturated flow, **B** denotes forced flow and **C** denotes oversaturated flow.

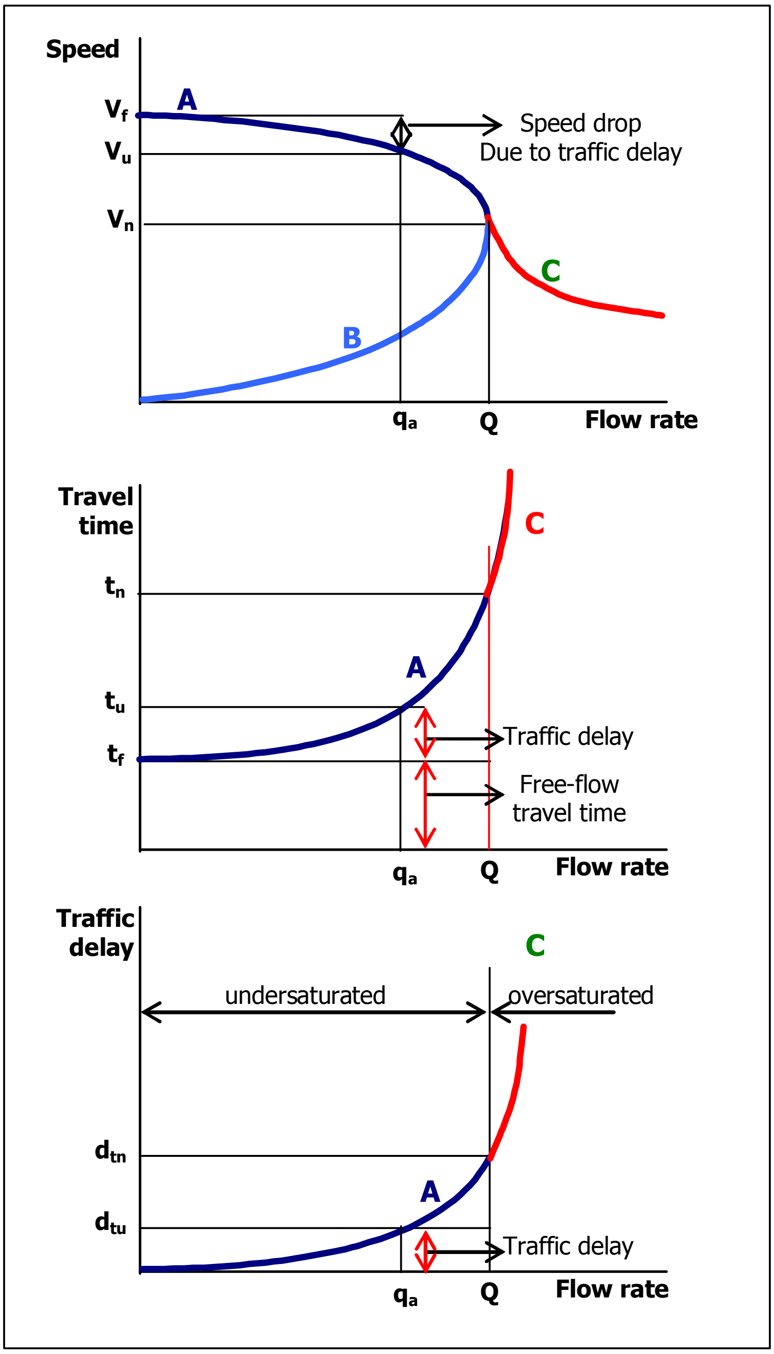



**Figure 3.9: Speed, travel time and delay as functions of flow rate in continuous**

**traffic streams**
(Source: Akçelik, 2003)

Principally dynamic models assume trip departure as a continuous movement (fluid), and in this process each factor has influence on other corresponding factors. Speed, travel time, delay, density and flow are regarded as interdependent factors in route choice stage. These relationships are described in the following equations:

$$V_u = 3600 / t_u = 3600 /(t_f + d_{tu}) \qquad (3.28)$$

(Roess, 1990; Akçelik 1991; Salter and Hounsell, 1996; Akçelik 2003)

$V_u$ is the travel speed at given flow rate (km/h) and

$t_u$ is the travel time per unit distance at a given flow rate (seconds/km),

In this equation:

$$d_{tu} = (t_u - t_f) = (3600 / V_u - 3600 / V_f) \qquad (3.29)$$

Where

$d_{tu}$ is the traffic delay per unit distance (seconds/km),

$t_u$ is the travel time per unit distance at a given flow rate (seconds/km),

$t_f$ is the free flow travel time per unit distance (seconds/km),

$V_u$ is the travel speed at given flow rate (km/h) and

$V_f$ is the free flow speed (km/h)

Here travel speed and delay are mutually dependent variables ($V_u$ and $d_{tu}$).

(Roess, 1990; Akçelik 1991; Salter and Hounsell, 1996; Akçelik 2003)

In dynamic assignment methods density is a factor of speed drop in congested networks. Travel speed at given flow rate can be obtained from density (the number of vehicles traveling over per unit distance) for given flow rate. Hence travel speed is equal to:

$$V_u = C \ln\left(\frac{D_j}{D}\right) \qquad (3.30)$$

Where;

$V_u$ is the travel speed at given flow rate (km/h),

$D_j$ is the jam density (commonly this value is determined by link properties like capacity obtained from observations),

$D$ is the density at given flow rate and

$C$ is the curve factor determined by link properties obtained from observations.
(Source: Salter and Hounsel, 1996:122)

Density can be obtained from volume-density relationship. Then travel speed at given density can be calculated through iterations. The process recursively calculates delay and actual travel time from speed drops. This relationship is presented in the following figure:

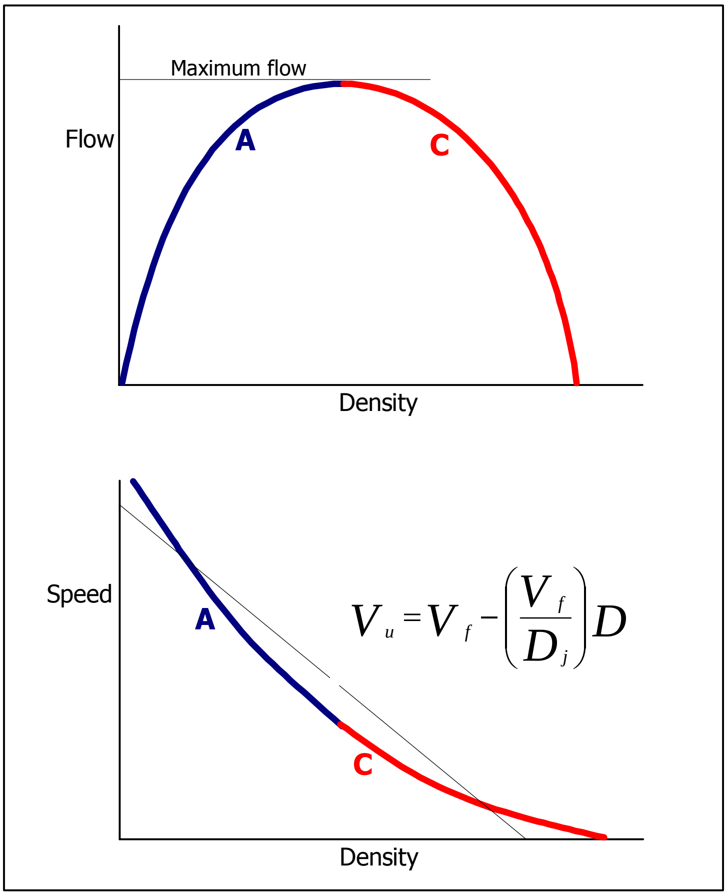



**Figure 3.10: Volume-Density relationship**
(Source: Salter and Hounsel, 1996:122)

### 3.5.3 Measuring Travel Time and Travel Distance in Network Assignment

Travel time and travel cost factors are commonly encountered in transportation project assessment procedures. Conventionally, in project evaluation process, travel assignment models are employed in order to measure possible impacts of transportation projects on individuals' travel time and fuel cost. These factors are sometimes called "travel disutility factors" (Oppenheim, 1995). Total travel time, travel time savings, and total distance travelled are some measures calculated at final stages of network assignment model applications. Typical outputs of assignment models are traffic volumes, average travel distance, average delay, level of service and average travel time.

According to Oppenheim "traditional approach" which is based on descriptive modeling. Oppenheim (1995) adds that individual travelers are assumed to make travel choices which are "the best" for them, whereas in "behavioral approach" individuals prefer routes among alternatives in terms of their travel cost (disutility) perceptions.

Travelers' utility may be measured either in terms of time or distance. In deterministic models individuals travel cost (in terms of time) is equal to

$$t = \sum_a t_a v_a = \sum_i \sum_j \sum_r t_{ijr} T_{ijr} \tag{3.31}$$

(Oppenheim 1994:70), where;

$t$ is the total travel time
$t_a$ is the total travel time on all routes between all origin-destination pairs,
$v_a$ is on all routes between all origin-destination pairs, and
$t_{ijr}$ denotes travel time on route $r$ between origin $i$ and destination $j$ and
$T_{ijr}$ denotes trips on the route $r$ between origin $i$ and destination $j$,

In transportation planning practice, the travelers' monetary surplus is measured as a function of time (and cost) through "before and after" impact assessment studies carried out for transportation projects. Total surplus is a function of time and/ or distance:

$$TS_R = -\sum_i \sum_j T_{ij} g_{ij} = -\sum_i \sum_j \sum_r T_{ijr} g_{ijr} \tag{3.32}$$

(Oppenheim1994:77); where,

$T_{ijr}$ denotes trips on the route $r$ between origin $i$ and destination $j$,

$g$ is the generalized travel cost; a combination of travel time and distance. In general following equation is preferred;

$$g = a(t_n - t_0) + b(d_n - d_0) \qquad (3.33)$$

$t_0$ is travel time before project implementation,

$t_n$ is travel time after project implementation,

$d_0$ is travel distance before project implementation,

$d_n$ is travel distance after project implementation,

***a*** and ***b*** are time and distance coefficients. In general these coefficients are measured in field survey.

In the probabilistic case, if routes are found in terms of travel time, the route demands are equal to

$$T_{ijr} = T_{ij} P_{r/ij} = T_{ij} \frac{e^{-\beta_r (t_{ijr})}}{\sum_r e^{-\beta_r (t_{ijr})}} \qquad (3.34)$$

(Oppenheim 1994:79). Where;

$\boldsymbol{T_{ijr}}$ denotes trips on the route *r* between origin *i* and destination *j*,

$\boldsymbol{P_{r/ij}}$ denotes probability of route *r* to be preferred among other alternatives, by the individuals traveling between origin *i* and destination *j*

$\boldsymbol{t}_{ijr}$ denotes travel time on route *r* between origin *i* and destination *j* and

The $\boldsymbol{T_{ij}}$'s are input trips from observed or estimated data. In general case, $\boldsymbol{\beta_r}$ is the travel time coefficient (measured in observations) (Oppenheim 1994:80).

In this assumption, the traveler surplus in the probabilistic route choice case is equal to:

$$TS_R = \sum_i \sum_j T_{ij} \ln \sum_r e^{-\beta_r g_{ijr}} \qquad (3.35)$$

(Oppenheim 1994:81).

$\boldsymbol{T}_{ijr}$ denotes trips on the route *r* between origin *i* and destination *j*,

$g$ is the generalized travel cost factor (a combination of travel time and distance), which was specified in equation 3.33. (Oppenheim 1994:81)

**Concluding Remarks**

In this part, travel demand models and their structures are presented. In order to evaluate any transportation investment or a traffic management scheme, professionals employ necessary components of a model or a combination of them. Transportation project assessment processes need prediction of total travel demand, benefits and costs of any proposed facilities. Total travel time cost or other monetary costs are key issues in impact assessment.

Static models assume "steady state conditions", therefore, such models are more suitable for longer time horizons and larger networks; however, less attention is paid for short term variations. Dynamic models (as in network assignment) are developed in order to respond travel behaviors and predict short term variations in the traffic flow. Hence dynamic models are more suitable for short termed that is individual travel behavior in the network is assumed to be varying in time.

In the case study, merits and drawbacks of such models are analyzed, and then the role of uncertainty in modeling process is discussed.

# CHAPTER 4

# RESEARCH PROPOSAL AND METHODOLOGY:

## 4.1. Objectives of the research

In recent years information technologies are extensively employed both in urban travel demand simulation and traffic management, in order to cope with transportation problems under "dynamic" and "uncertain" properties of travel demand. Traffic assignment models aim to achieve high accuracy in traffic flow in order to develop appropriate traffic management strategies.

Literature survey showed that recently developed model algorithms (especially dynamic network assignment models) have great contributions to transportation and traffic planning. Most of the recent studies, which aim at predicting traffic flows in short term, are conducted in North American and European countries where urban physical structures are almost fixed. In this regard, dynamic network assignment algorithms are developed in order to facilitate well-organized traffic planning by dynamic control systems.

On the other hand in developing countries, both urban structures and travel demand are dynamic and travel demand is continuously growing. In this study the validity of static and dynamic models in a transforming network under dynamic urban travel patterns are investigated. In this study the evaluation process involves three stages:

1- Application of a conventional static model in Ankara case study: In this stage urban development and transformation of transportation network are analyzed to identify "dynamic city". Then, static assignment models are performed in order to understand deficiencies of these models under uncertainty. Since network assignment is principally dependent on a priori knowledge about travel demand, conventional four stage model is performed in order to obtain time dependent trip distribution matrices for auto trips.

2- Application of static and dynamic model structures in a transforming network: In this stage both static and dynamic network assignment models are employed to assess performance of road network, therefore in this step the following issues are concerned:

- How do trip generation, distribution and traveler route choice vary in a large congested network and what are possible impacts of a congested network on individual travel demand?

- How do static and dynamic network assignment models perform under dynamic travel demand, and what kinds of uncertainty are faced through traffic flow prediction process.

- What kind of prediction methods can be developed in order to improve reliability of travel demand models under uncertainty and what kind of principles and specifications can be involved in model development?

- What kind of planning strategies could be formulated in order to cope with uncertainty in transforming networks?

- What are the deficiencies of conventional methods in predicting dynamic traffic flow and its influence on network performance?

3- Evaluation of model structures and recommendations for further studies: In this part spatial and temporal variation of travel demand (both in short term and long term) is investigated.

This study investigates possible strategies to cope with uncertainty in travel demand. Transportation planning proposals aiming efficient use of road space and to cope with congestion necessitate as much as accurate travel demand estimation methods to achieve specified goals. Performance of networks in different travel demand conditions may be affected by uncertainties which may exist in both demand side and supply side of transportation system:

-travel demand variables (frequency, spatial distribution, variation in departure times, temporal distribution in day or even within the peak period) and behavioral responses of drivers in congested networks (instantaneous behavioral response, route choice, estimation of travel time etc),

-network configuration (physical capacity, connectivity-flexibility and robustness of the system etc.), congested traffic assignment variables (v/c, congestion, level of service, speed etc) and network performance variables (speed, total travel vehicle/km, and vehicle/h, travel costs, etc.) (Ran and Boyce, 1994).

### 4.2. Research and evaluation method of the study

Reliability and validity of assignment models are investigated in a case study by post-planning method. Case study is conducted in Ankara, the capital city of Turkey, to evaluate network performance under uncertainty. It is argued that Ankara exhibits a dynamic urban development and dynamic travel pattern. Further information about the city is provided in chapter 5. The case study analysis consists of three stages:

1-Evaluation of "IBI Model": Ankara Transportation Study was carried out in 1985. In that study travel demand estimation model was developed by IBI Group (IBIMOD). Model estimates for target year 2004 are compared with actual states. At the end of this stage sources and types of uncertainty are detected. To do this, model estimates are compared with actual data and observed traffic volumes. The structure of IBI Model is mainly based on the classical structure of four stage model, described in chapter 3.

In trip generation stage a multiple regression model is employed (see equations 3.1 and 3.2. in chapter 3). Model outputs and estimations are in presented in chapter 5. In trip distribution stage a doubly constrained spatial interaction model is employed (see equations 3.12 and 3.15). Further evaluation of model performance is presented in chapter 5. In modal split stage, trip interchange method is employed (see equations 3.17 and 3.18). In network assignment stage conventional type of capacity restrained model is employed (see equation 3.22 and figure 3.3).

2-Evaluation of "Validated IBI Model": In the second stage model inputs are updated. In this stage zonal population, employment, school enrollment, and hospital capacities are obtained from four disaggregate data sets. The first data set, which comprises of sub-district populations, is obtained from the State Institute of Statistic and Greater Ankara Municipality for the year 2000 and corresponding values are extrapolated to the year 2004. The second data set comprises of student enrollment by schools which is obtained from the Ministry of Education and universities. The third data set involves employment numbers which are obtained from the Chamber of Commerce and Greater Ankara Municipality. Finally, hospital bed capacities are obtained from the Ministry of Health.

Aggregate data involves car ownership which is obtained from Governorship of Ankara. In addition road network data and traffic counts are obtained from Greater Ankara Municipality.

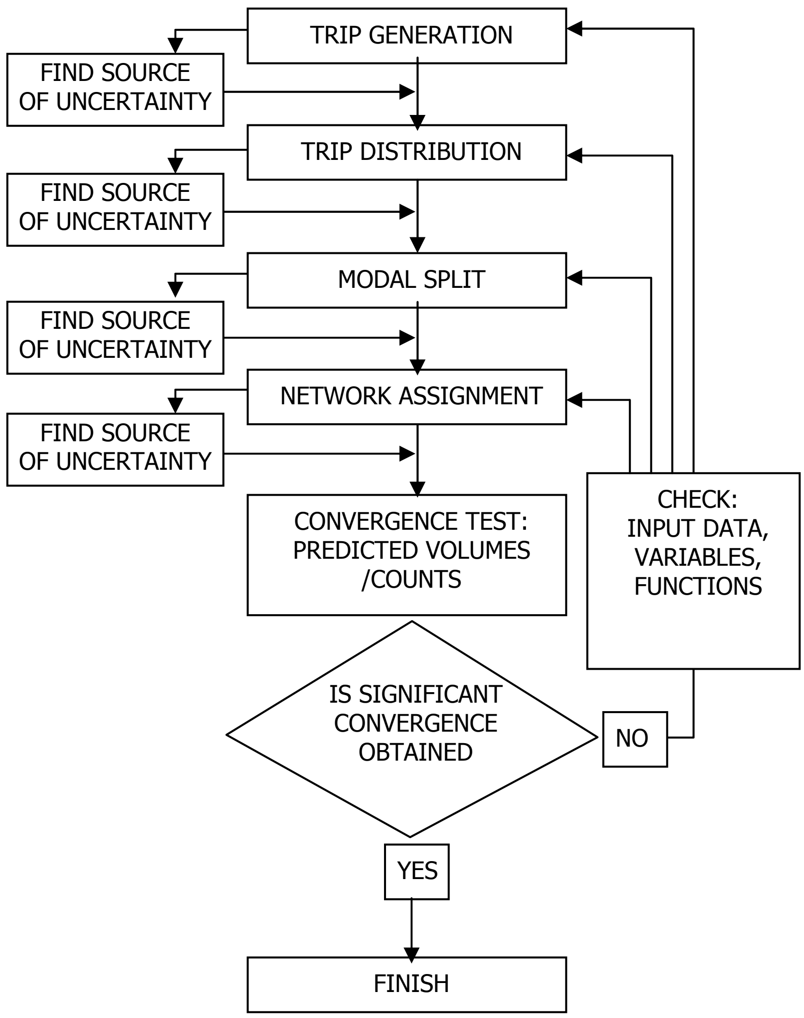



**Figure 4.1: Uncertainty Analysis Procedure in Model Structure (stage 1)**

Input data are updated in order to perform calibration process. In this stage the validity of the model for the current state (for the year 2004) is analyzed. "Validated IBI Model" comprises conventional four stages of travel demand estimation. Model variables are updated in order to obtain trip distribution matrix for car trips. Then model equations are validated. This process takes into account "variations" in travel demand; that is, parameters which are specified in model equations are checked and validated. Validity of model is tested by using cordon counts and questionnaire survey conducted in a specific zone. In this stage model outputs are compared with actual data and a feedback process is performed in order to calibrate model parameters in a sequential process. Model results are also compared with those of stage 1 in order to find input and inherent uncertainties.

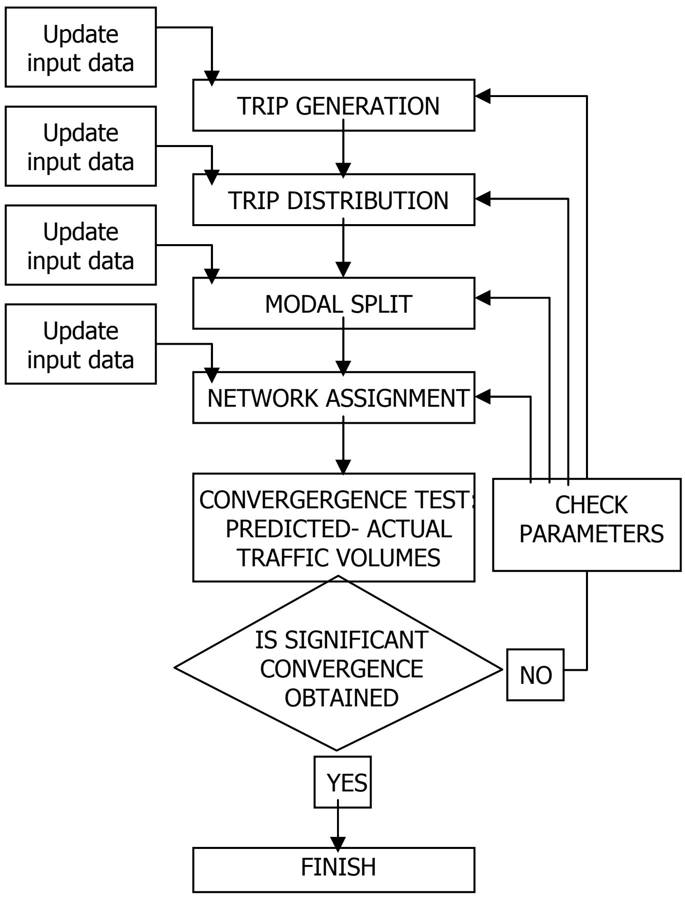



**Figure 4.2: Model Validation Procedure (stage 2)**

Then static network assignment outputs of validated IBI Model are compared with those of dynamic network assignment which is performed in the third stage.

3-Evaluation of dynamic and static assignment models: At this stage travel demand model structure of IBI Model is conserved but a dynamic assignment method is integrated to the model structure. At the end of this stage static and dynamic model outputs are compared in order to evaluate performances of these models.

In this stage a scenario based probabilistic assumption is elaborated. Since travel demand (individuals' travel behavior) varies in time, scenario based estimation method allows understanding these variations. A similar probabilistic assumption is introduced by Ben-Akiva et al:

> Traffic demand determines the amount and composition of traffic present on the roadway. Travel demand is specified by time-dependent origin-destination (OD) matrices. Different combinations of time dependent OD demands represent a wide range of possible travel demand patterns (Ben-Akiva et al., 1997:284).

In the proposed model, simulation is based on the definition of possible variations in model parameters. Each scenario comprises of minimum and maximum deviations from predicted values of corresponding stages. Conventionally model calibration is based on significance tests, and precise model outputs are compared with observed data for current state. However after a period model equations may not respond to actual travel pattern. Then model periodical validation becomes necessary. In this study in order to overcome such problems a scenario based prediction method is developed. Hence model estimates are principally based upon assumptions rather than precise predictions. Model outputs for specified scenarios are compared with actual traffic flow to understand variations.

Conventionally the significance of relations between land use data and travel behavior are expressed by equations and reliability of specified equations are measured after calibration process. In this study scenario based estimation process implies "possible" outputs in order to reduce uncertainty. In the proposed procedure (probabilistic and dynamic assignment), traffic volumes (intervals) are specified in order to evaluate scenarios. In the sequential model structure two possible cases (minimum and maximum) are determined. In this context, scenarios not refer to infinite alternatives.

In trip generation stage inputs data involves socioeconomic and spatial variables. Input data are assumed to be varying due to urban development, economic development and physical transformation. Hence minimum and maximum values of input data can be specified according to variation ranges (less or more than prediction).

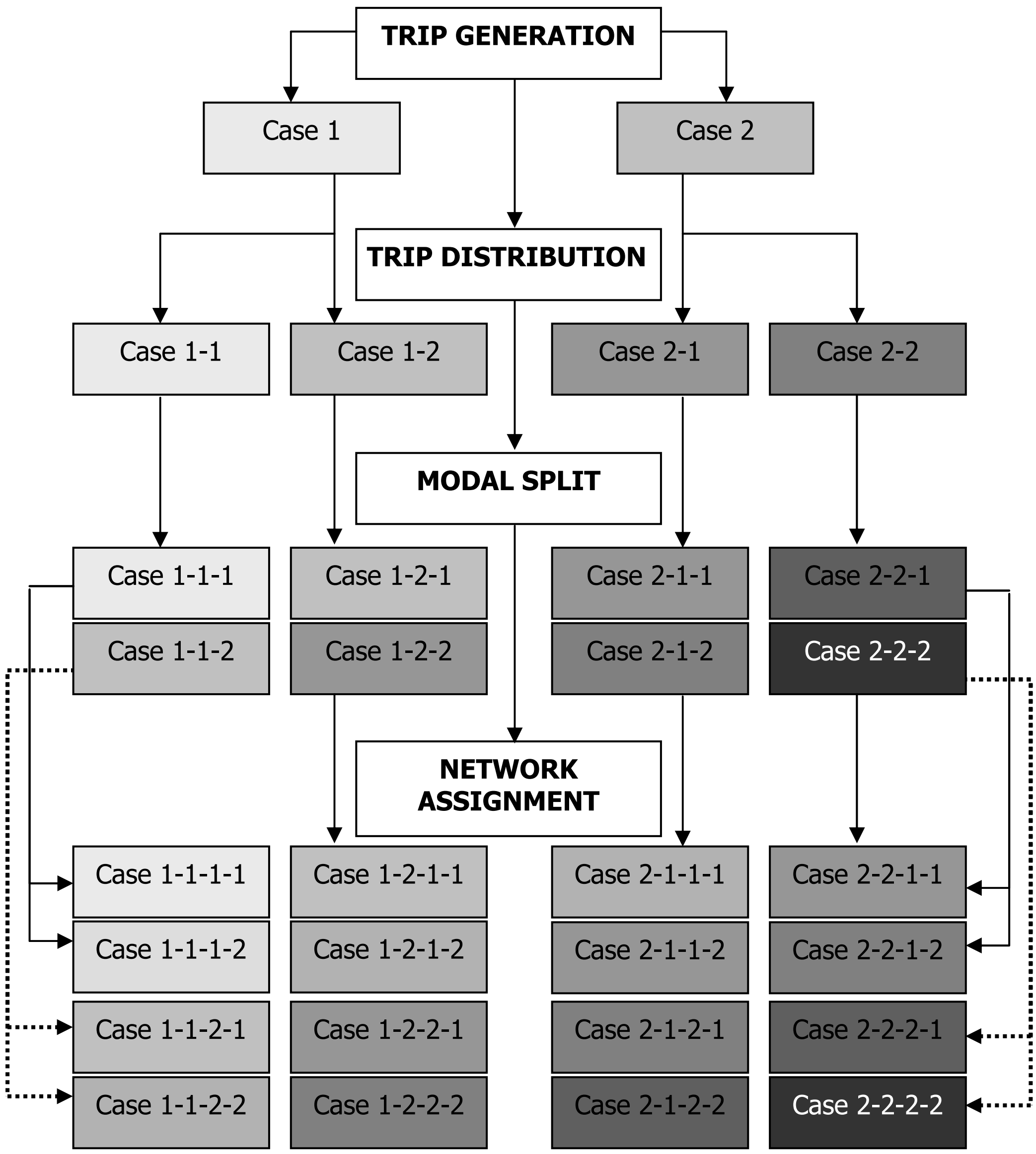



**Figure 4.3: Scenarios to be considered in urban travel demand simulation.**

In trip generation stage variables that are specified in equations may be less or more than predicted. In the figure above "case 1" represents minimum value of trip generation (production and attraction); that is, trip production is assumed to be less than predicted whereas "case 2" is assumed to represent maximum range of predicted value for given trip purpose. Deviations are determined according to standard deviations which are measured for specified trip production equations.

In trip distribution stage minimum case identifies minimum interaction (inter-zonal) among travel analysis zones. In other words, individuals are assumed to travel in shorter times due to higher travel impedance. Here, interaction is measured by travel time and travel impedance (beta parameter) enforces individuals to prefer nearest destinations to reduce their travel times. On the other hand maximum case identifies lowest limit of beta parameter which implies longer travel times. Hence travel interaction pattern influences individuals' mode choices and may result in higher traffic volumes on the underlying transportation network. In the figures 4.3 case 1.2 and case 2.2 represent minimum levels of travel impedance.

In modal split stage minimum case means lowest share of car trips. It is assumed that individuals' mode choices are extremely dependent on socio-economic characteristics of individuals and also influenced by external factors. Scenario based method is employed in order to respond to temporal variations in mode choice. According to this method maximum cases (cases1.1.2, 1.2.2, 2.1.2 and 2.2.2) refer to highest value for the share of car trips in total trips. Hence after network assignment stage 16 possible results (volumes) are obtained instead of "precise" estimates.

In transportation travel demand analysis the final outcome of four stage model is traffic (or passenger) volumes. In this stage departure times influences peak hour factor. According to scenario based method minimum cases identify lowest value of peak hour factor whereas maximum cases are determined according to highest value. In conventional methods, road links are assumed to be loaded with precise traffic volumes, whereas probabilistic method implies a range of outputs. In the calibration stage, mean volumes can be compared with actual traffic volumes. Road network design and traffic management necessitate traffic volumes that can be predicted through network assignment models.  Biased prediction result in capital losses weakens reliability of such models. Since travel demand models are extremely influenced by external factors model reliability may not be guaranteed for longer time periods. In this study a scenario based method is employed in order to improve reliability of dynamic network assignment. Since this stage is dependent on former stages dynamic network assignment methods may not be reliable under uncertainty. In the planning and design stage, predicted volumes may be associated with appropriate probability distribution functions which can be specified for each road section (link). The probability of each case can be found as a function of mean predicted volume, standard deviation and volume for a specific case (Figure 4.4).

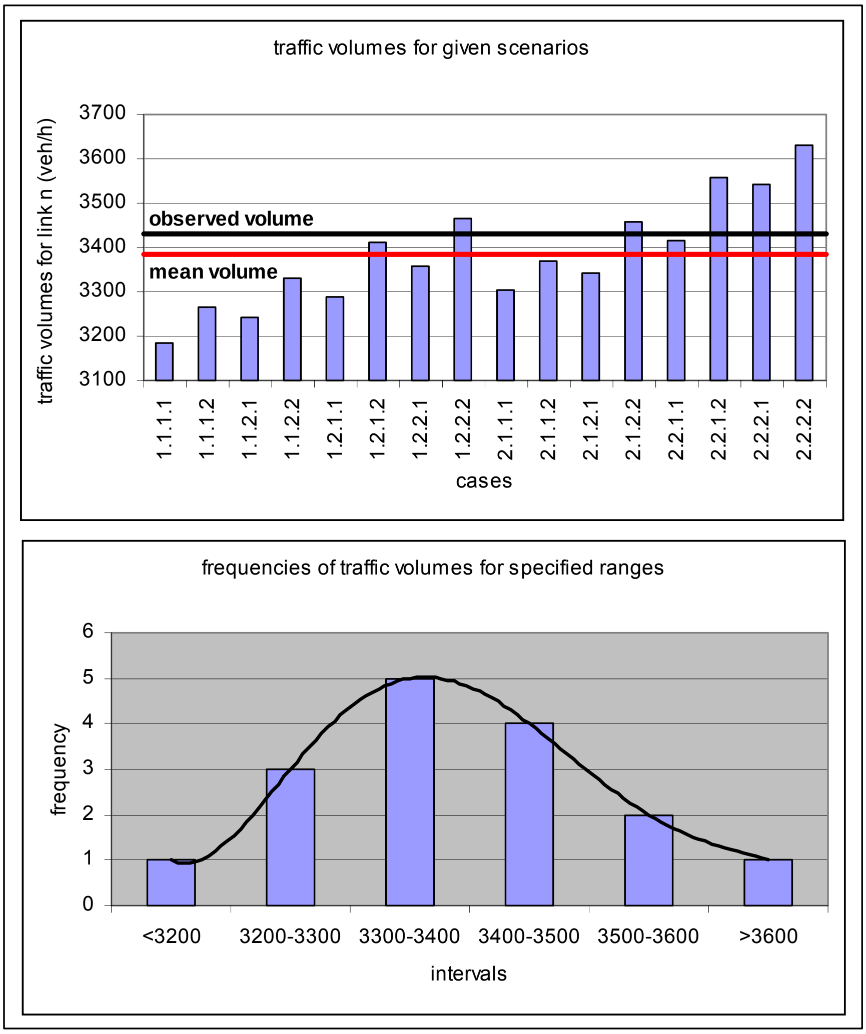



**Figure 4.4: Final outputs (traffic volumes) of probabilistic estimation method**
(Traffic volumes are assigned to specific links based on given scenarios)

The reliability of this method can be assessed by co-linearity analysis between mean volumes and observed ones. In planning stage, probability distribution functions can be assigned to specified road sections in order to determine road capacities. In this study 16 cases are determined. These cases may be multiplied by including input variables or for each stage more than two cases may be determined, then total number of cases would be multiplied. When outputs exhibit normal distribution then following equation can express frequency distribution:

$$f(x,\mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\left[\frac{(x-\mu)^2}{2\sigma}\right]} \tag{4.1}$$

Where:

$f(x,\mu,\sigma)$ is the probability distribution function for case $x$ (estimated volume for link n case for in case x), mean $\mu$ (mean volume) and standard deviation $\sigma$ .

In this function, probability of a specific range can be calculated:

$$P\chi_i = f(\chi_i,\mu,\sigma) / \sum_i^n f(\chi_i,\mu,\sigma) \tag{4.2}$$

(Walpole et al, 2002)

Where, $P\chi_i$ is the probability of range ***i*** among ***n*** intervals, and $\chi_i$ is the predicted volume for case ***i***.

In the case study 16 possible cases are determined. For each road section mean volumes and standard deviations are found to determine corresponding intervals for predicted traffic volumes. Mean volumes are compared with available observed volumes for specific links. Finally outputs of dynamic assignment are compared with those of static assignment.

If model outputs converge to counts (convergence test) the procedure can be applied in future estimates. This method provides possibilities to be considered in planning stage. Therefore alternative solutions may be investigated in transportation service provision.

Otherwise, uncertainties may be neglected; therefore unexpected variations may result biased predictions.

In the proposed method probability distribution functions for specified intervals are assigned to each link. In each function, probability of mean volume (case i) is expected to be higher than other possible cases. Since network assignment is dependent on other stages of the four stage model, network assignment outputs bear accumulated uncertainty. In the proposed model, frequency distribution of specified intervals are expressed by probability distribution functions. In the figure 4.5 right and left sides of the curve represent minimum and maximum ranges of predicted values. Due to the fact that probabilities of extreme minimum (case 1.1.1.1) and extreme maximum cases (2.2.2.2) are lower than averages uncertainty is assumed to be higher.

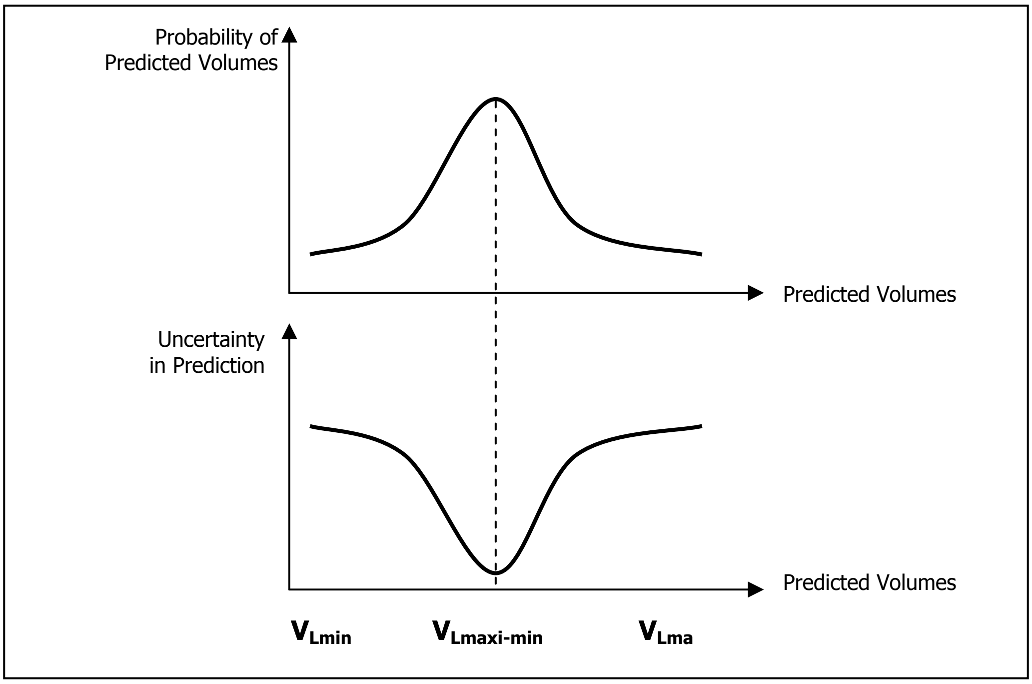



**Figure 4.5: Probability and uncertainty in predicted volumes.**

### 4.3. Model Calibration

#### 4.3.1. Data

Travel prediction models are used to analyze travel demand in order to estimate future travel behavior, which is a function of socio-economic characteristics of individuals and also associated to the transportation network of the city. In this process, particular simulation methods are used in calibration of model parameters. Hence simulated travel behavior is compared with real travel behavior in order to justify the reliability of the model.

In this procedure commonly four data sets are necessitated (Meyer and Miller, 1984; Salter and Hounsell, 1996). The first group, which is gathered from population census and questionnaire surveys, includes population, households, employment, and similar socio-economic characteristics of the transportation analysis zones in the study area. The second data set includes transportation network characteristics which are road width, road length, lanes, capacity, design speed, transit usage, parking and junctions. The third data source, which is also obtained from questionnaires, includes individuals' trip making characteristics. These characteristics are trip per capita, destination choice, mode choice and route choice. Finally passenger and traffic volumes are obtained from cordon and screen-line counts.

Literature survey showed that travel demand models are extremely dependent on the four data sets and uncertainty can emerge due to variations in these data sets (Meyer and Miller, 1984; Ortuzar and Willumsen, 1994; Zhao and Kockelman, 2001). Therefore the accuracy in the estimation of socioeconomic data has considerable impacts on the performances of models. A reliable for a specific time may not guarantee reliable simulations under dynamic urban environments. In the second stage of the model application transportation network data and socio-economic data sets are updated, and then model parameters are calibrated. Otherwise estimation may accommodate accumulated errors. Then research findings are used to update variables and validate travel demand model (IBI Model).

In the calibration stage, model outputs are compared with household questionnaire results and traffic counts. Parallel to simulation process, a household questionnaire is conducted in 2004, (628 individuals in Koru Sitesi neighborhood with 13.315 population in 2000) to investigate individuals' travel behaviors. In this study a random sampling (4.9 %) method is used. In the questionnaire survey involves is carried out on 37 streets (74 households) and 17 community houses (136 households).

In the questionnaire survey, drivers travel behaviors of are investigated. Among them special emphasis is put for route choice. In the first part, socio-economic characteristics; in the second part trip making frequencies, destinations for three purposes (work, school and other) and travel modes are investigated. The third part of the questionnaire is concerned with drivers' route preferences and behaviors in traffic. For specified origin destination pairs individuals are asked to express his/her preferences among 11 possible paths. Then individual preferences are analyzed under following issues:

1-The influence of departure time on individuals' route choice in order to understand the influence of congestion on departure time,
2-The role of socio-economic status in route choice in order to understand the roles of time and distance,
3-The influence of congestion on route choice in order to find temporal variations in route choice. The questionnaire results are presented in chapter 5.

### 4.3.2. Model Structure

In the first stage of the case study four stage travel demand model, which is developed in Ankara Urban Transportation Study, in 1985 by IBI Group Toronto-Canada, is performed. This model is based on traditional four-step modeling process consisting of trip generation, trip distribution, modal split and network assignment (EGO, 1987a). The model is also employed in Ankara Transportation Study in 1992. In this study, TP+ and Viper (Visual Planning Environment) (UAG, 2000) are also employed to compare model performances. In both models similar parameters are used. In the second step these parameters and variables are updated.

Model structures of IBIMOD and TP+ are similar, that is, both programs perform four major functions (See Chapter 3). Model structure of IBIMOD and necessary parameters, which are used in Ankara Transportation Study in 1985, are described in the following part.

In the trip generation stage, the program calculates the number of trips originating and ending in each zone as linear functions of the values of land use activity variables in each zone (see equation 3.1 and 3.2, EGO, 1987a:2).

In trip distribution, a doubly constrained method is employed (see equations 3.12 and 3.15), taking into account travel times and the friction of space, trips originating in each zone are distributed among all possible destinations (EGO, 1987a:4). In the modal split stage trip interchange method (equations 3.17 and 3.18) is employed, in which the proportion of trips assigned to walk, private car and public transit for each O-D pair is calculated (EGO, 1987a:5).

In the network assignment stage a capacity restrained technique (equation 3.22 and figure 3.3) is used in Ankara Transportation Study-1985. In this method, which involves iterations, travel volumes between each O-D pair are redistributed from congested links to less congested links of the road network (EGO, 1987a:37). In the proposed approach, a dynamic assignment model (see figure 3.5 and equations 3.23-3.30) is applied in order to understand advantages and disadvantages of dynamic assignment models under uncertain character of travel demand. As it was mentioned before, travelers' route choice in congestion is one of main concerns of network assignment models, in which travel flow is seen as an "inverse demand function" which implies decreasing travel demand with respect to increasing cost (Ran and Boyce 1994, Oppenheim, 1995). But, in reality, the most influential instances of congestion result from network configuration (limited number of alternative routes).

Network file development process is an essential component of the network assignment stage. In this process transportation system is coded and represented by nodes, links and attributes associated to corresponding links. Dynamic network assignment stage requires detailed data about network geometry and link properties. These are:

1-Time dependent trip distribution matrices,

2-Link attributes:

- link group/ category/class
- number of lanes,
- link length;

-design speed (or free flow speed);

-link capacity and maximum density

3- Actual speeds,

4-Traffic counts.

Functional classification of the road system plays an important role in network assignment. Including all streets in a large urban area requires excessive time in the network processing stage. If all local streets are included in the system, major arterials may be loaded with less traffic volumes. Link properties should accurately represent real network in terms of functional classification. In addition to physical classification observation is necessary to determine functional classification. Sometimes local streets may function like local distributors. When they are not included in the network major roads may be overloaded due to reduced number of alternative paths. Taking into account these factors an optimal network is developed to represent actual road network and traffic flow

#### 4.3.3. Model Calibration and Validation

In the fist stage of model application the structure of model developed for Ankara transportation study in 1985 is conserved in order to find out model deficiencies. Travel demand predictions made in 1985 Study for the target year 2004 (target year estimations are interpolated between 2000 and 2005 values) are compared with actual data obtained in 2004. Then model simulations are evaluated according to inputs and model parameters.

In the second stage travel demand model developed in 1985 (IBI Model) is validated for the year 2004. Validation process took two years (from 2002 to 2004). In this stage, as it was mentioned in section 4.3.1, input data and variables are updated. Then model estimation is repeated by using updated data for the year 2004. Then model outputs are compared with actual state and estimation errors are analyzed. Hence the factors influencing model performance are investigated. In this regard the structure of the current model is criticized on the basis of assumptions and methodology. Proposed model is developed to take into account possible uncertainties. For easier computation procedure TP+ and Viper computer packages are employed to analyze reliability of the IBI Model.

At the final stage a probabilistic model structure is developed in order to cope with problems emerged due to uncertainty. Principally the analysis focused on two sources and forms of uncertainty. External uncertainties (land use, network data and urban development) and internal uncertainties (due to limited parameters) are regarded as major sources of uncertainty. In addition specification and computation errors (limited confidence due to processing) and accumulated (propagated) errors (due to model structure) result in different forms of uncertainty.

In Ankara two major transportation studies were carried out since 1985: "Ankara Transportation Study", which was finalized in 1985 and approved in 1987, and "Ankara Transportation Plan". The former one is conducted by a work group (Greater Ankara Municipality, Canadian Consortium and Kutlutaş) organized by Greater Ankara Municipality Directorate of EGO.  That study was motivated around rail transit projects and transportation master plan. The latter one was conducted by EGO and finalized in 1993. In both studies IBI Model was employed in travel demand prediction process.

This study focuses on performances of network assignment models under uncertainty. In both transportation studies (1985 and 1992) static network assignment methods are employed. In the initial stage of static network assignment shortest paths for each origin-destination pair are built and trips are assigned to those paths. After all trips from all origin zones have been processed, link costs (commonly based of travel time) are calculated in order to measure congestion. In this method trips between all origin-destination pairs are loaded simultaneously. On the other hand, in the dynamic network assignment method, shortest paths are found for shorter time intervals (minutes). In this process trips between all origin-destination pairs are allocated to numerous paths.

Then, traffic volumes on each link are summed up. In the adjustment stage travel times are computed and the link time values are revised in order to be used in the next iteration. For each time interval travel times are computed depending on volume, density and delay. After each step all possible routes are scanned and appropriate shortest paths are selected depending on minimum time. Shortest path processing is the most time consuming task of network assignment. In recent years more complex path selection methods are investigated through geographic information systems (see appendix A).

After network development, observed trips are assigned to the network. Then the evaluation takes place at several different levels; observation of traffic across the network is compared to traffic assigned by travel demand model (count volume versus simulated volume). Co-linearity between observed and simulated trips is a commonly used measurement method to understand model reliability. If these results appear reasonable ($R^2$ >0.90), then the assignment model is accepted as generally realistic and reliable.

In this study validation is performed in order to reduce both external and internal uncertainties. Since variations results in external uncertainties, input data bear errors. Sources of external errors (underestimation/ overestimation) may emerge due to:

1-External factors: Sometimes, model inputs may not be measured accurately therefore input data results in inaccurate simulation. Mostly, major changes in urban development cause estimation errors. In addition development in transportation technology, new modes, oil prices, economic decline are other possible factors of external errors.

2-Structural errors: Model structure may not provide disaggregate (separate) analysis of errors, therefore, simulation errors are multiplied in final outputs (Zhao and Kockelman (2001) called "propagation of uncertainty"). In addition model equations may not provide significant representation of actual condition.

3-Parametric errors: Model parameters and variables may not represent actual travel behavior. In addition some parameters may be neglected in model equations.

4-Sampling and measurement errors: In a post planning evaluation study it is hard to analyze sampling and measurement; therefore, it is beyond the scope of this study.

5-Unidentified (un-specified) errors: It may not be possible to find all sources of errors, that is, a significant model may accommodate an amount of errors that are called "permanent uncertainty". For instance, in regression methods simulated values may not always fit observed ones. Since this type of errors may not be measured, the proposed model is developed in order to encounter possible effects of such errors.

### 4.3.4 Evaluation Measures

In this study sources and effects of uncertainty are investigated in travel demand analysis and planning process especially in network assignment models. Detection of simulation errors, which reflect to model uncertainties, is necessary to cope with uncertainty in future estimates. Validity and reliability checks are necessary to reduce uncertainty through travel demand simulation. There are various methods of validation checks (sensitivity checks, mean error, moot mean square error, correlation coefficient, variance, standard deviation) (Walpole et al., 2002). There are various statistical methods to measure error that can be used in the evaluation stage.

Absolute Percentage Error is used to measure specific differences between predicted and actual values of travel demand. Root Mean Square Error Percentage Root Mean Square Error is used to evaluate general errors of estimate in model application. Correlation Coefficient ($R^2$) provides understanding co-linearity between predicted and observed traffic volumes. Standard Deviation, a measure of reliability analysis is used to understand confidence of regression outputs.

## CHAPTER 5

## CASE STUDY AND EVALUATION OF RESEARCH OUTCOMES

In this part, urban development and transportation network of Ankara are investigated in order to find out dynamic properties of the city. Then the planning objectives, predictions, urban development, and evolution of transportation network are associated with travel demand characteristics. Such an analysis provides background information to evaluate transportation plans, prediction methods, infrastructure provision and implementation processes. Case study particularly focuses on the problems of network assignment models under dynamic travel demand conditions.

### 5.1. Urban Development in Ankara

In the last two decades Ankara experienced a gradual development and transformation. Literature survey suggests that land use, population and socio-economic characteristics of individuals have significant influence on travel demand. The following table shows urban development and its influence on travel demand in distinct periods.

**Table 5.1: Urban development and travel demand in Ankara.**

| | Urban Area (hectares) | Population | Vehicle Trips (Daily) | Number of autos | Vehicle trip per capita |
|---|---|---|---|---|---|
| 1927 | 300 | 74,553 | | | |
| 1956 | 3,650 | 455,000 | | | |
| 1970 | 14,000 | 1,236,152 | | | |
| 1985 | 27,000 | 2,304,166 | 2.695.000 | 84.384 | 1,16 |
| 1990 | 56,000 | 2,584,594 | 3.159.000* | 207.000* | 1,17* |
| 2000 | 66,000 | 3,237,679 | 4.350.000** | 433.758 | 1.34 |
| 2004 | 71,000 | 3,481.522 | 4.803.000** | 536.074 | 1.38** |

*1992 values, **projected

Sources: Greater Ankara Municipality, State Institute of Statistics, 2000 Ankara Transportation Studies (1985, 1993), Çalışkan, 2004: 188

This part of the study focuses on last three decades of urban development in Ankara. Since 1970's the city of Ankara has shown considerable progress both in urban planning and major transportation investments. Urban population was over 1.2 million and urban lands covered 14.000 hectares (see Figure 5.1). In 1969 Ankara Metropolitan Area Master Plan Office (AMANPB) prepared a master plan, which envisaged a new structure of urban development (Altaban, 1998). Planning group estimated 3.6 million populations for 1990. South-western and north-western parts of the city were regarded as major development corridors (Figure 5.2). That plan was prepared in a manner that structural planning approach manifested new growth directions (Altaban, 1998).

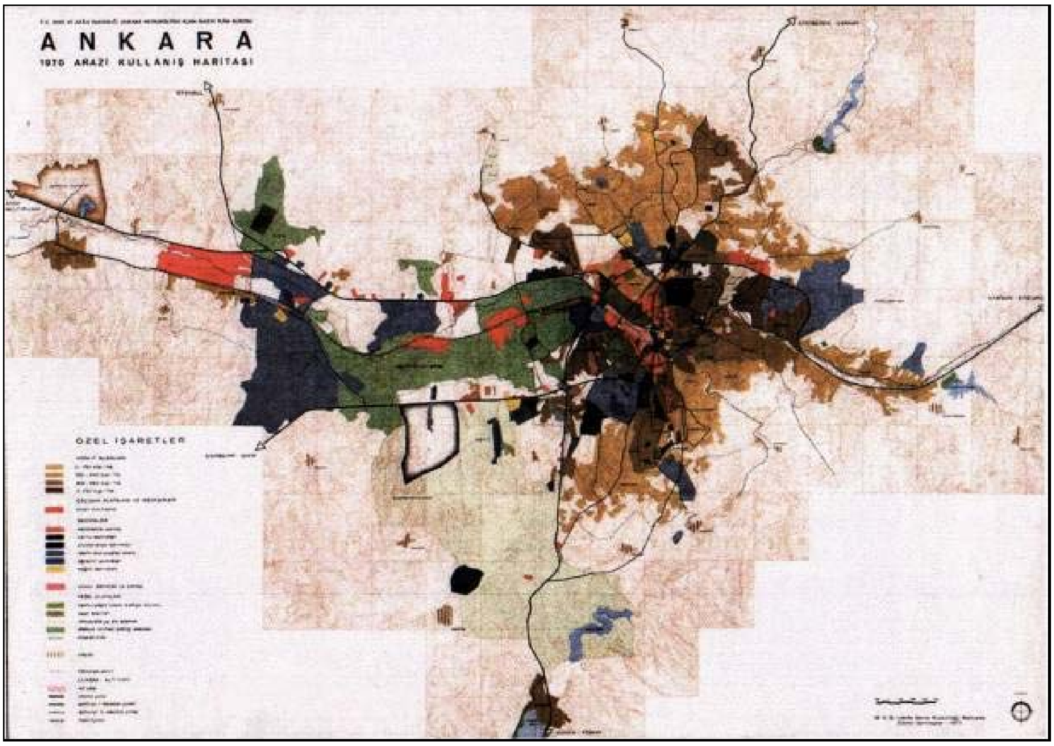



**Figure 5.1: Land Use Map of Ankara (1970)**
(Source: Ankara Greater Metropolitan Municipality)

Parallel to urban planning studies the first transportation planning study of Ankara was conducted in 1969. This study was motivated to assess the feasibility of a possible transit system, 14 km in length, between Kavaklıdere-Dışkapı districts (north south corridor) and Dikimevi-Beşevler districts (east-west corridor) (EGOb). However this project was not realized due to financial problems.

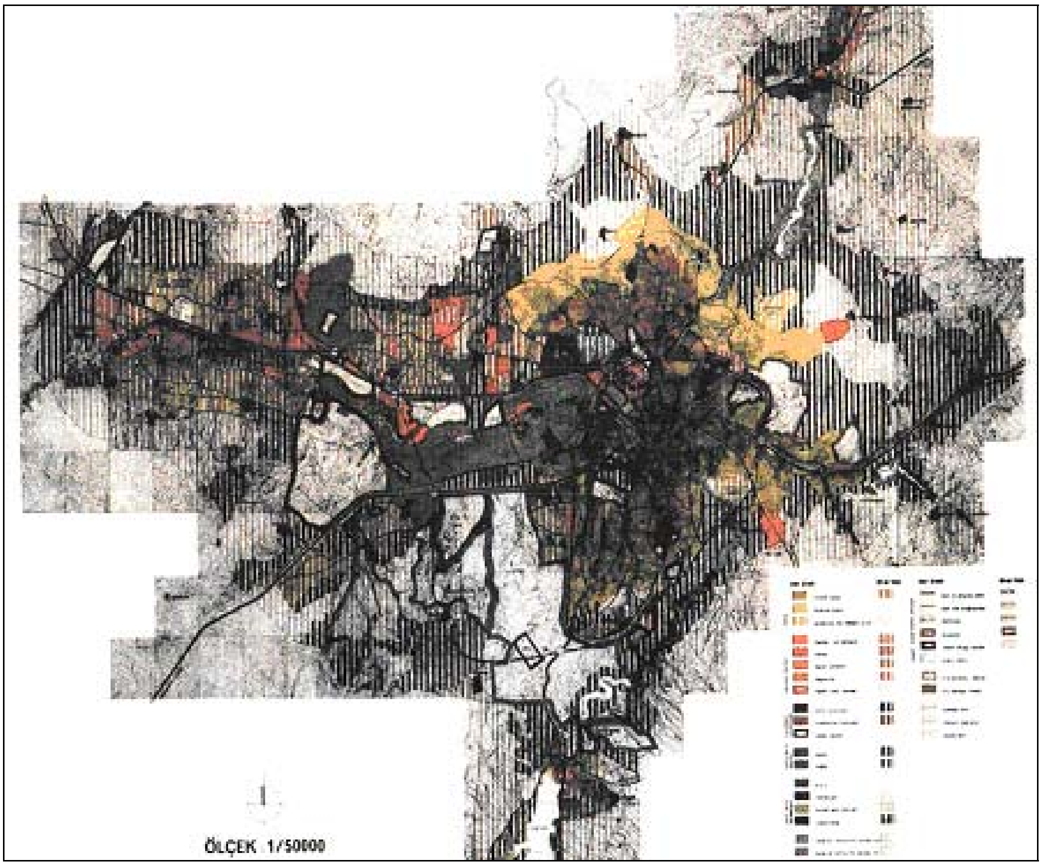



**Figure 5.2: Ankara Master Plan for 1990**
(Source: Ankara Greater Metropolitan Municipality)

In 1985 a study group at Middle East Technical University was charged to prepare an urban macro-form analysis and provide a basis for the investment of new transit system (Altaban, 1998). At that time the city population exceeded 2.3 millions and urbanized area covered approximately 27.000 hectares. The city was in a compact form with high dense residential areas (Figure 5.3).

The planning group aimed providing a policy set with a structural plan in order to promote urban development toward western corridors. In 1985 total vehicle trips generated in the city have exceeded 2.5 millions and the city was suffering from traffic congestion and air pollution problems.

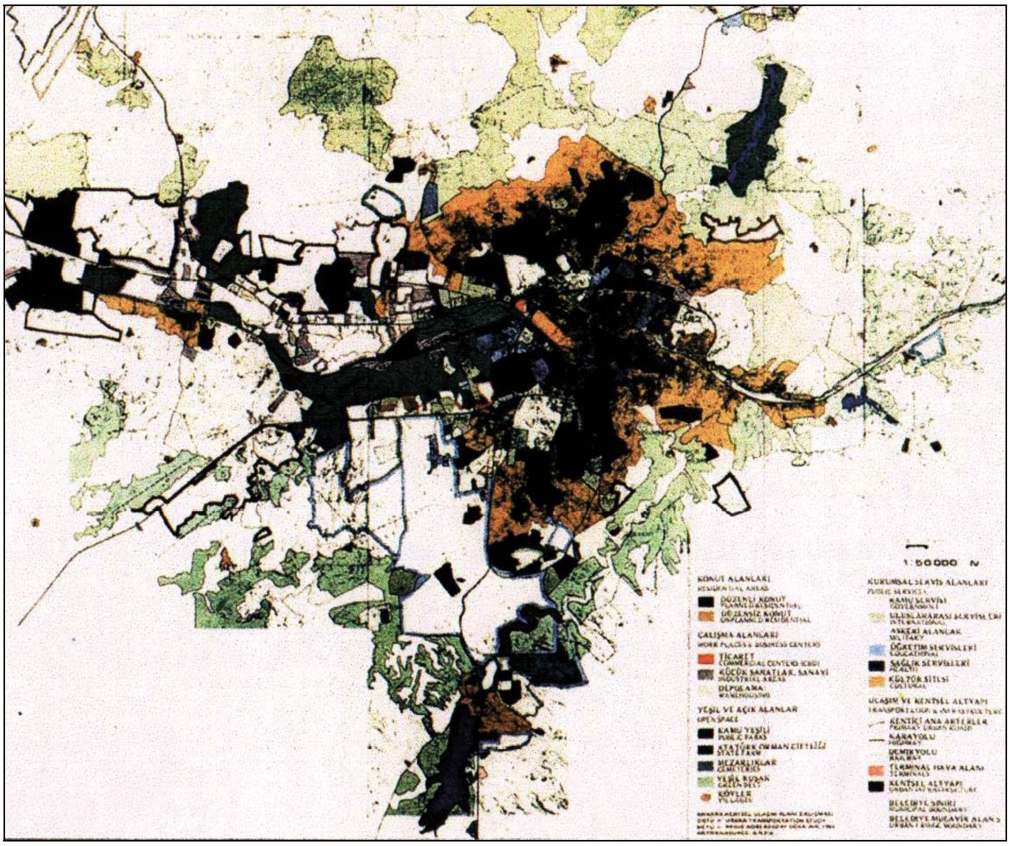



**Figure 5.3: Urban development in Ankara (1985).**
Source: Greater Ankara Municipality

The motivation of the planning study was developing a new structural approach for an intended transit investment (EGO, 1987b). "The population of the city was expected to reach nearly 5 million in 2015, with a twofold increase in 25 years," (METU Study Group, 1986: 184). The main proposal of the plan was "decentralization". According this strategy, beside existing urban fabric of Ankara, each of those settlements, were regarded as new growth nodes for metropolitan area (Figure 5.4). The main objectives of "Ankara 2015 Structural Plan" were:

-New residential zones should be leaped out from the topographical threshold, which surrounds existing urban fabric, suffering from air-pollution.

-The population of new growth nodes should not exceed 300.000.

-Decentralization scheme should be provided in a ring of 35-40 km by strengthening the existing settlements, rather than development of new towns.

-The allocation of employment opportunities should be regarded as the main factor in decentralization process. Integration of residential and working areas in development nodes should be provided.

- A star-shaped city structure enhanced by public transportation was suggested.

-The urban form would be flexible in order to provide opportunities for prosperous alternatives in the future (METU Study Group, 1986: 184).

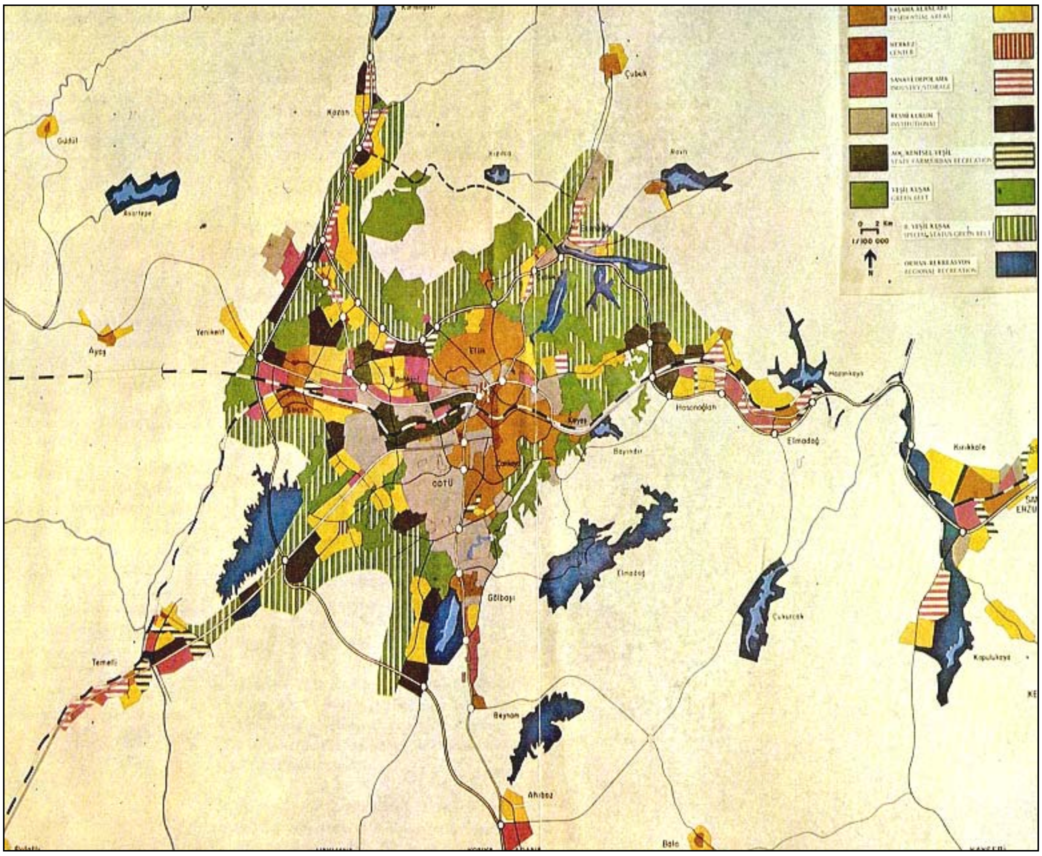



**Figure 5.4: Urban development schema of Ankara 2015.**
Source: Greater Ankara Municipality

Besides, a regional transportation network was proposed in order to enhance decentralization of urban development. One of major projects was a ring road with three by-passes which were included in the investment programs of the General Directorate of State Highways. In addition, a new radial road network was proposed (EGO, 1987a). Another major project was rail transit system in which Heavy Rail System and Suburban Rail Connections were integrated. These rail projects were mainly proposed to enhance urban development toward western corridor (EGO, 1987a, 1987b).

In 1993, Ankara Transportation Master Plan was prepared. That plan was principally based on assumptions of previous study (1985) and envisaged an extensive rail transit system for the year 2015 (EGO, 1993). In that study four rapid rail transit lines were proposed: from the center to the south-west, north-west, north and south directions (Figure 5.5).

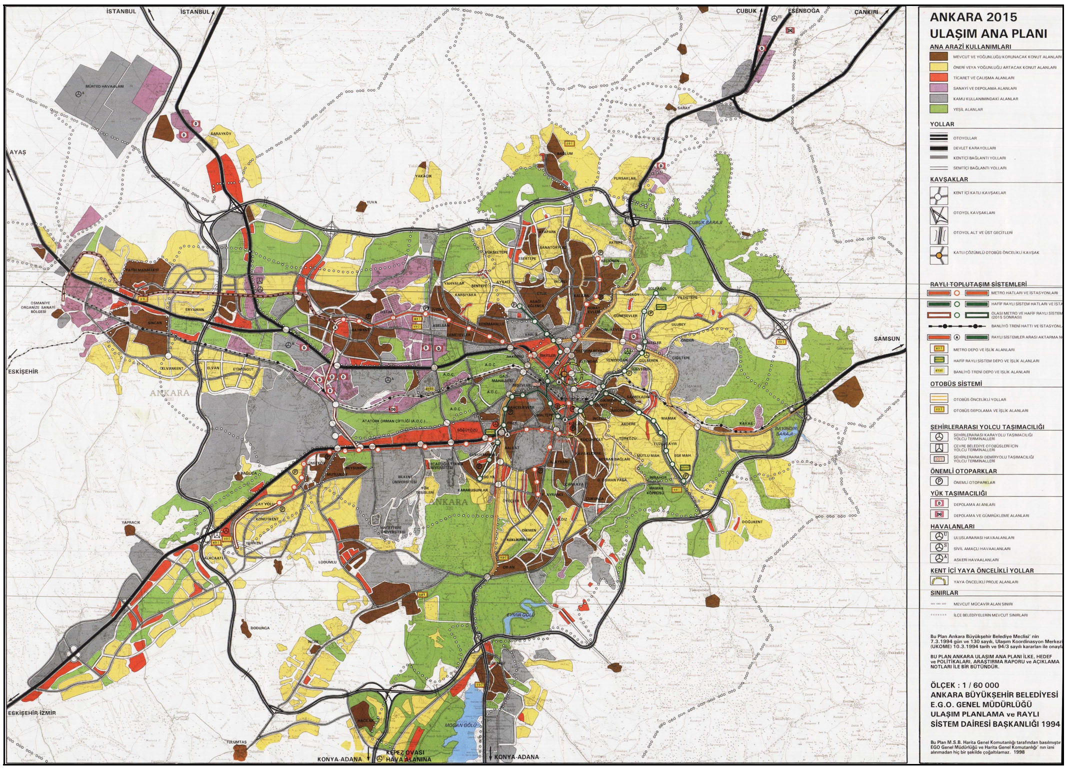



**Figure 5.5: Transportation Master Plan of Ankara 2015**
Source: Greater Ankara Municipality, 1993.

Although urban population has not shown any noteworthy change between 1985 and 1990 a gradual increase is observed in the overall urban land coverage. In 1990 urban population has just exceeded 2.5 millions while overall urban land covered more than 55.000 hectares. In addition vehicle trips generated in the city exceeded 3 millions.

At present, the population of the city has reached to 3.5 millions and total coverage area spread over 70,000 hectares (Çalışkan, 2004: 189). Çalışkan adds that although this form of urban redevelopment has been dominated by planning studies, growth of residential areas at the outskirts of the city is interdependent with increasing car ownership (Figure 5.6).

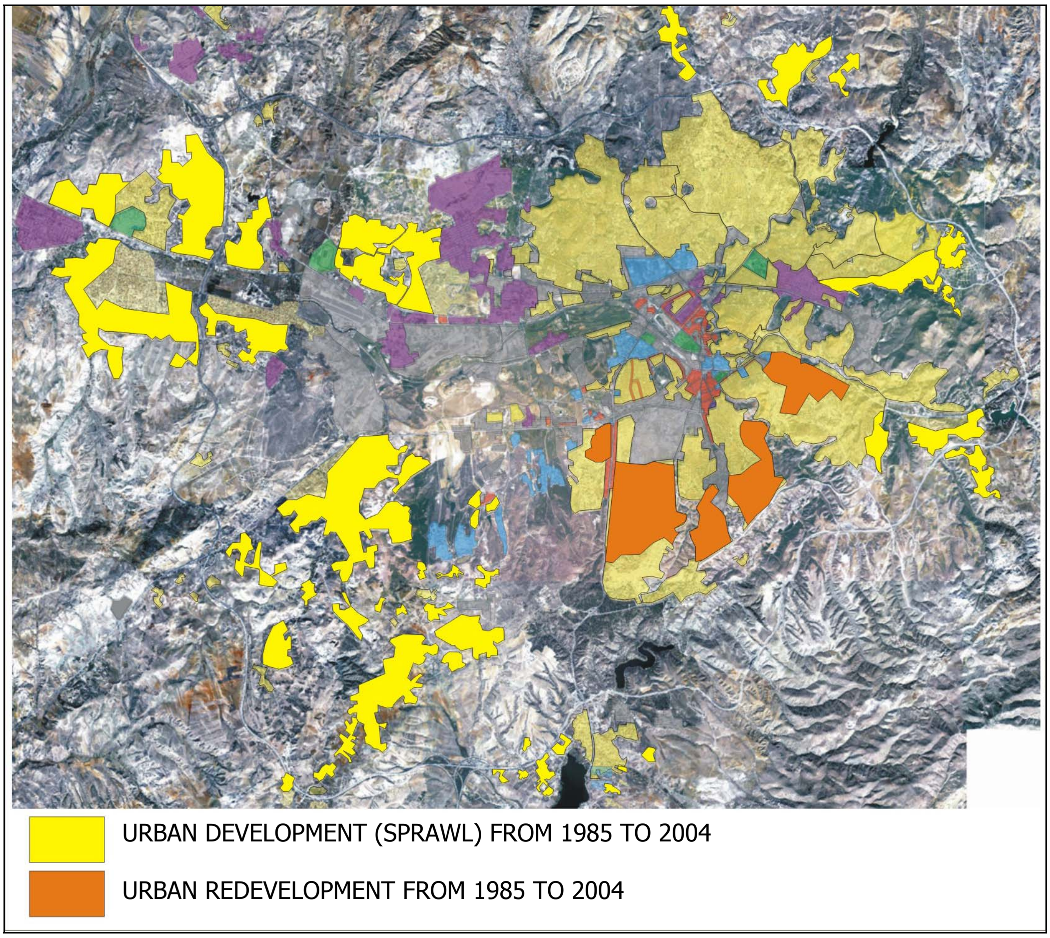



**Figure 5.6: Urban Development from 1985 to 2004**
(Source: Greater Ankara Municipality and personal observations)

Since most of major rail transit projects are not constructed yet, urban sprawl becomes the sole process creating a tendency to modify the concentric urban growth pattern of Ankara. Today, parallel to its growth the city experiences a gradual increase in the share of motorized trips. On the other hand, inadequate public transportation services resulted in high-density urban development that exhibit a concentric form around the center. Urban redevelopment has shown a considerable progress especially on the southern parts of the city. In the last decades this form is modified by an expansion along main arteries eventually leading to a star-shaped urban form.

Parallel to the urban development, transportation network (especially road network) has been transformed (Figure 5.7). The ring-road, major highways and elevated junctions have been major transportation investments since 1985. Hence, urban development and transportation network showed transforming and “dynamic patterns”.

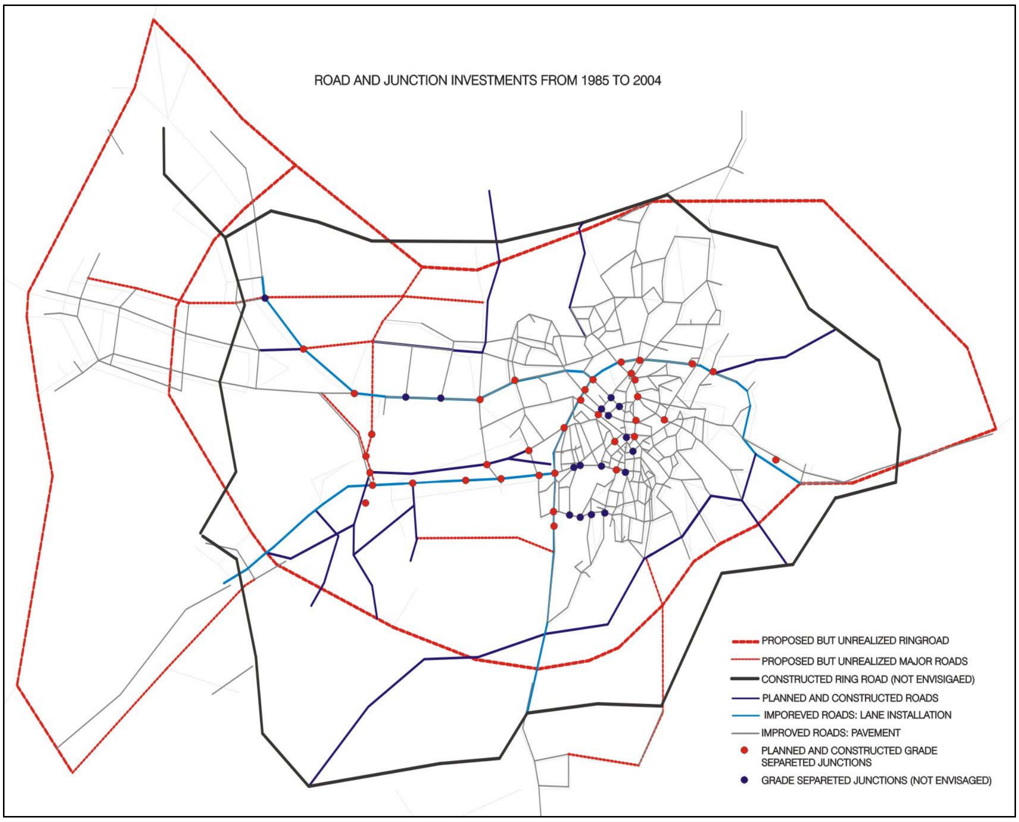



**Figure 5.7: Transformation of Transportation Network from 1985 to 2004**
Source: Greater Ankara Municipality, Department of Public Works

In the last two decades urban form and travel demand in the city of Ankara have shown considerable growth. The following conclusions can be derived from over 19 years of urban land use and transportation planning experiences:

-City’s population has increased from 2.3 millions to 3.5 millions that represent an average annual growth rate of 2,1%.

-Total employment has increased from 681.000 to 1.1 million.

-The city has experienced dramatic physical development and transformation.

-Transportation network has experienced structural transformation.

-Car ownership per 1000 persons has increased from 57 to 138,

-Number of daily vehicle trips has increased from 2.3 millions to 4.8 millions.

## 5.2. Travel Demand Characteristics

According to 1985 survey findings in Ankara Transportation Study, "the average daily trip generation per capita was 1.73, including walk trips, while the number of vehicle trips made per capita was found as 1.16" (EGO, 1987c:9). In 1992 (Ankara Transportation Study, 1993), the average daily trip generation per capita was found as 1.92, and vehicle trips per capita reached to 1.34. By the year 2000 these rates are estimated to be 1,96 and 1,41 respectively (Greater Ankara Municipality, Directorate of EGO). Parallel to Municipality forecasts, in this study these values are estimated by a linear projection method.

In 1985, within vehicle trips, the share of private car in vehicle trips was 20% and of the transit was 80%, whereas in 1992 the share of car increased to 24% (EGO, 1987c; 1993). In the year 2000, this ratio was estimated to be 23% (Greater Ankara Municipality, Directorate of EGO; Çubuk et al, 2001).

Trend analysis showed that the rise in auto ownership, urban growth and economic growth resulted to a gradual increase in total travel demand. Figure 5.8 and Figure 5.9 indicate population growth, car ownership, total vehicle trips and vehicle trips per capita in the last two decades.

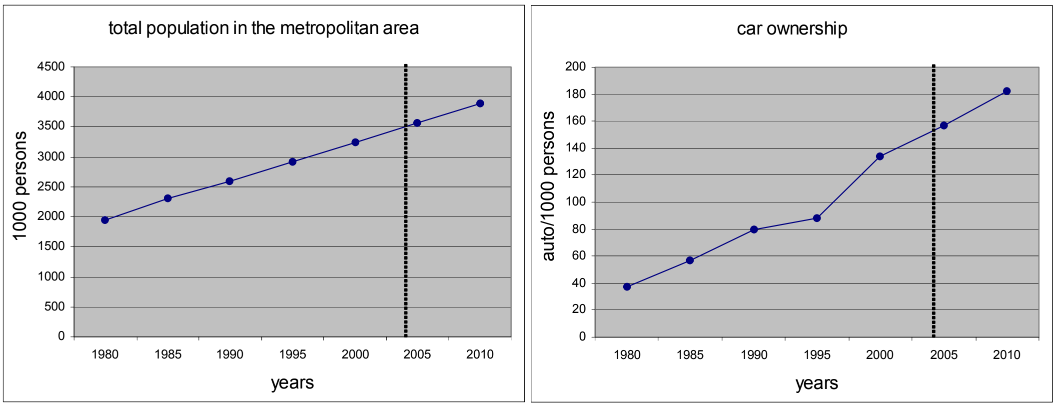



**Figure 5.8: Trends in Total Population and Auto Ownership**
(Sources: Greater Ankara Municipality; Governorship of Ankara)

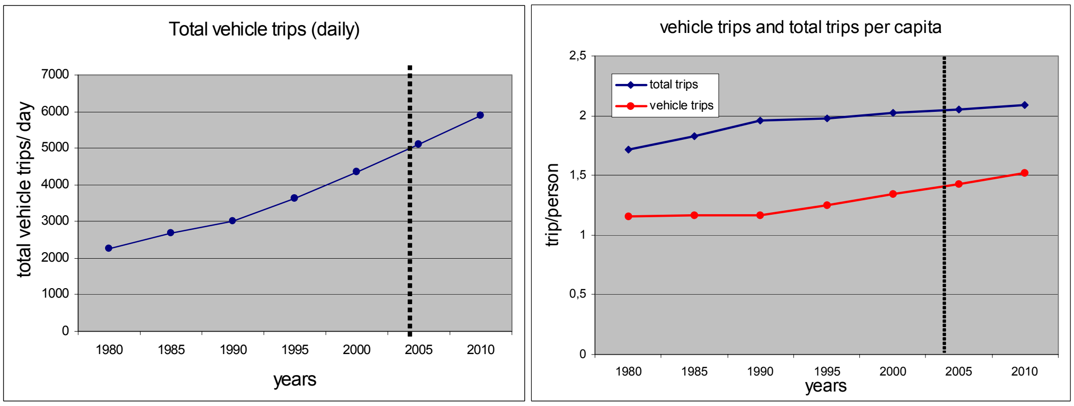



**Figure 5.9: Trends in total daily vehicle trips**
(Source: Greater Ankara municipality, Directorate of EGO; Çubuk et al, 2001)

### 5.2.1. Trips by Purposes

In 1985, the trip generation rates per capita by purpose, including walk trips, were found as 0,57 for work trips, 0,42 for school trips and 0.73 for other trips respectively (EGO, 1987c). In 1992, 0.82 for work trips, 0.60 for school trips and 0.55 for other trips were accounted (EGO, 1993). Corresponding values for these rates that are accounted in 2000 were estimated to be 0.90, 0.69 and 0.88 respectively (Greater Ankara Municipality, Directorate of EGO and trend analysis carried out in this study). In 1985 "the intra-urban distribution of trips by purpose shows wide variations with respect to the urban structure along with the differences in the total number of trips" (EGO, 1987c:10). Similar travel demand pattern was also observed in 1992. In it was claimed that the rates of trips by purpose were mainly influenced by land-use (education-school trips, commerce and business-work trips, etc.). In this concern, in the model validation process a range of variations in trip rates is taken into account to predict traffic volumes.

Both studies (1985 and 1992) showed that the total volume of trips produced by transportation analysis zones vary according to population, socio-economic characteristics of individuals, location of work places, and the extent of commercial, business and social activities (EGO, 1987c:10; 1993). The two analyses of daily number of trips by purpose in Ankara for 1985 and 1992 indicate that the number of daily trips attracted by central business districts (Kızılay and Ulus) is much more than those of other zones (EGO, 1987c; 1993).

In model calibration stage cordon counts, which conducted by Greater Ankara Municipality Directorate of EGO in 2004, are used to predict actual trip attraction rates in a probabilistic manner. Analysis of traffic volumes on central links showed that corresponding values for trip attraction rates have increased gradually. Both studies showed that the distribution of zonal trip production, by purpose was largely determined by zone characteristics that in 1985, Kızılay attracted 202.712 trips (8% of total trips) (EGO, 1987c). In 1992, the corresponding value had increased to 323.144 (270.315 is accounted for vehicle trips) (EGO, 1993). Whereas 266.034 trips (244.520 is accounted for vehicle trips) were attracted by Ulus in 1992 (EGO, 1993). The questionnaire survey, conducted in 2004 showed that in addition to Kızılay and Ulus and workplaces in the southern part of the city center attract noteworthy proportions of work and shopping trips. However, Kızılay and Ulus are still dominant centers of trip attraction. Detailed evaluation of this survey is provided in the next part.

### 5.2.2. Mode Choice

Modal split is another important indicator of travel demand characteristics of a city. Conventionally trips are categorizes into three modes: walk, auto and transit.  In both studies transit trips include those made by EGO buses, minibuses, private buses, service buses and the suburban railway. Since predetermined routes are not assigned to service buses in network assignment stage it is hard to predict trip volumes. To overcome this problem an alternative method is to allocate those trips made by service buses like auto trips.

In both studies conducted in 1985 and 1992, the majority of the intra-urban trips were made by mass transit. In 1985, a very high level of demand for the transit service comprising 54% of the total daily trips (3.832.995 including walk trips) was accounted for transit modes (EGO, 1987c:11). In 1992, the corresponding values have increased to 52%, 16%, and 32% respectively (EGO, 1993). Municipality of Greater Ankara investigated travel distribution by modes in 2000, and found that rail transportation systems have a significant influence on individuals' mode choice (Table 5.2 and Table 5.3).

**Table 5.2: Mode Choice in Ankara-1992**

| **Mode** | **Passengers** | **Share %** |
|---|---|---|
| Buses (private and public) | 875281 | 28.87 |
| Minibuses | 182985 | 6.04 |
| Service Buses/Minibuses | 878331 | 28.97 |
| Suburban Rail Transit | 365971 | 12.07 |
| Metro (Heavy Rail Transit) | 51846 | 1.71 |
| Ankaray (Advanced LRT) | **2354414** | **77.66** |
| **Public Transport** | 152488 | 5.03 |
| Private Car | 515410 | 17 |
| Taxi | 9149 | 0.3 |
| **Individual Transport** | **677047** | **22.33** |
| **Grand Total** | **3031461** | **100** |

(Source: Greater Ankara Municipality, 1993).

**Table 5.3: Mode Choice in Ankara-2000**

| **Mode** | **Passengers** | **Share %** |
|---|---|---|
| Buses (private and public) | 1 315 000 | 27,93 |
| Minibuses | 990 000 | 22,76 |
| Service Buses/Minibuses | 685 000 | 15,75 |
| Suburban Rail Transit | 100 000 | 02,30 |
| Metro (Heavy Rail Transit) | 175 000 | 04,02 |
| Ankaray (Advanced LRT) | 175 000 | 04,02 |
| **Public Transport** | **3 340 000** | **76,78** |
| Private Car | 750 000 | 17,24 |
| Taxi | 260 000 | 05,98 |
| **Individual Transport** | **1 010 000** | **23,22** |
| **Grand Total** | **4 350 000** | **100,00** |

(Source: Greater Ankara Municipality, 1993; Çubuk et al, 2001).

These findings showed that the share of private service trips have increased dramatically. This fact was also observed in the questionnaire survey that the corresponding value was found as 11%. Survey findings in 1985 showed that "the proportion of transit trips was remarkably high in central business district zones, while the densely populated residential areas exhibit a relative dominance of walk trips" (EGO, 1987c:11). While in 1985 transit share was 79.8% this value has slightly decreased to 77.7% in 1992 and estimated to be 76.8% in 2000 (Figure 5.10). The corresponding value in peripheral residential districts decreased dramatically both in 1992 and 2004 (questionnaire survey).

The gradual decline in the share of municipal buses was thought to be resulted from the fact that "some of the travelers who would normally use transit, prefer to shift over to other modes (private services) because of the lack of adequate transit service which lead to considerable time losses" (EGO, 1987:12). This problem has significant influence on travelers' mode choice and car usage is regarded as a major factor of congestion. Studies conducted in the last two decades showed that inadequate transit service provision, deficiencies in transport infrastructure, noise and air pollution caused by heavy traffic as well as other transportation related problems severely affect the well-being of inhabitants of Ankara.

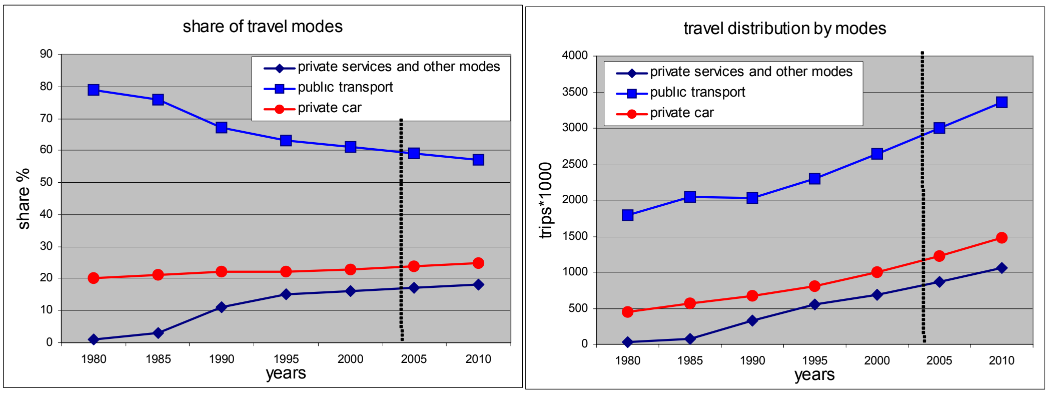



**Figure 5.10: Shares of travel modes and total trips by mode (vehicle trips)**
(Source: Greater Ankara Municipality, 1993; Çubuk et al, 2001).

Ankara faces transportation problems especially during the peak hours. The morning peak period displays larger passenger volumes than the evening peak period. It was notable that CBD zones have shown considerable trip attraction figures during the morning peak period (EGO, 1987b, 1993, Greater Ankara Municipality, questionnaire survey).

### 5.2.3. Travel Times

Historical analysis of transportation network showed that even though major investments are made for road improvement travel times have not been reduced. In 1985 road network capacities of the western districts were higher than those of other areas (EGO, 1987c: 13). It was noted that since future development was intended to take place towards the western part of the metropolitan area (e.g. İsmet İnönü and İstanbul Boulevards) capacities of these roads have been increased. In addition more than forty grade separated junctions have been constructed; however traffic congestion still frustrates travelers.

Average travel time by non-transit vehicle trips in 1992 was accounted as 16 minutes for vehicle trips while it was 12 minutes in 1985. In the model validation average travel time in the city was estimated to be 21 minutes. The corresponding value in the questionnaire survey exceeds 30 minutes since the survey was conducted in a peripheral district. While urban development showed sprawl (mainly directed towards the western and southern parts of the city), travel times have been increasing (Figure 5.11). In addition, congestion results in frustration and outstanding increases in travel times.

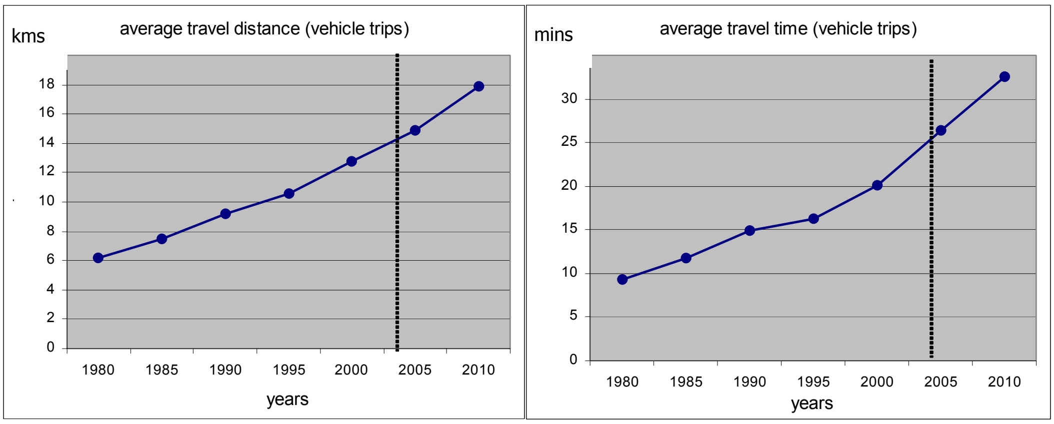



**Figure 5.11: Average travel distance and average travel time (vehicle trips)**

### 5.3. Transportation Network Data and Land-use Variables

#### 5.3.1. Network Data

Transportation network is an essential factor in travel demand analysis. Ankara road network is represented by 625 nodes (99 of them are zone centroids) and 1645 links (each direction is represented by a separate link) (Table 5.4). Centroids represent gravity centers of transportation analysis zones. Each link is associated with an attribute table (see Figure 5.12).

Network attribute tables include number of lanes, link distance, link group code, count volume, free flow travel cost (time), speed class, capacity class. In network building procedure, roads are classified into 12 categories (Table 5.5).

**Table 5.4: Transportation Network Characteristics, 1985**

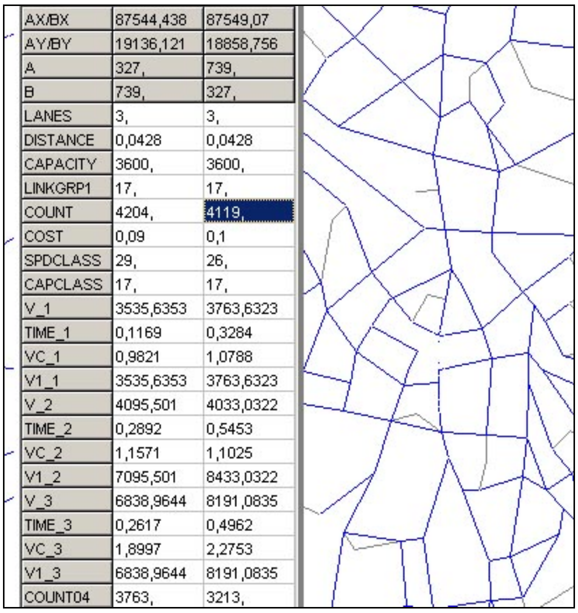
| Road Network | 1985 | 2004 |
|---|---|---|
| Number of Zones | 74+25 | 74+25 |
| Number of Nodes | 413 | 625 |
| Number of Links | 1126 | 1645 |
| Number of Link Classes | 12 | 12 |

Source: EGO, 1987a

**Table 5.5: Link Groups in Ankara Transportation Study**

| Link Type | Roadway Classification | Lanes | Link Class | Roadway Classification | Lanes |
|---|---|---|---|---|---|
| 1 | Centroid Connectors | - | 7 | CBD Artery- Divided | 2 |
| 2 | Residential Street | 1 | 8 | CBD Arteries –Divided | 3 |
| 3 | CBD Artery | 1 | 9 | Urban Expressway- Divided | 3 |
| 4 | CBD Artery | 2 | 10 | Highway- Divided | 3 |
| 5 | Central Artery- Divided | 2 | 11 | CBD Artery- Divided | 4 |
| 6 | Residential Collector- Divided | 2 | 12 | Urban Expressway- Divided | 4 |

Source: EGO, 1987a



| | | |
|---|---|---|
| AX/BX | 87544,438 | 87549,07 |
| AY/BY | 19136,121 | 18858,756 |
| A | 327, | 739, |
| B | 739, | 327, |
| LANES | 3, | 3, |
| DISTANCE | 0,0428 | 0,0428 |
| CAPACITY | 3600, | 3600, |
| LINKGRP1 | 17, | 17, |
| COUNT | 4204, | 4119, |
| COST | 0,09 | 0,1 |
| SPDCLASS | 29, | 26, |
| CAPCLASS | 17, | 17, |
| V_1 | 3535,6353 | 3763,6323 |
| TIME_1 | 0,1169 | 0,3284 |
| VC_1 | 0,9821 | 1,0788 |
| V1_1 | 3535,6353 | 3763,6323 |
| V_2 | 4095,501 | 4033,0322 |
| TIME_2 | 0,2892 | 0,5453 |
| VC_2 | 1,1571 | 1,1025 |
| V1_2 | 7095,501 | 8433,0322 |
| V_3 | 6838,9644 | 8191,0835 |
| TIME_3 | 0,2617 | 0,4962 |
| VC_3 | 1,8997 | 2,2753 |
| V1_3 | 6838,9644 | 8191,0835 |
| COUNT04 | 3763, | 3213, |

**Figure 5.12: Link attribute table.**

In model application traffic volumes and calibrated travel cost (time) are outputs of network assignment process. After the proposed network is constructed it is observed that there are considerable differences between proposed and realized networks (see Figure 5.13). Due to this problem outputs of the IBI Model (1985) can not be compared with observed volumes. However in central parts network configuration has not been modified, therefore the analysis is carried on by examining model outputs for central links. In the second stage (model validation) network building process is repeated in order to represent current road network (Figure 5.14).

**Figure 5.13 Ankara Road Network -2015, Proposed in 1985**
(Source: Greater Ankara Municipality, General Directorate of EGO).

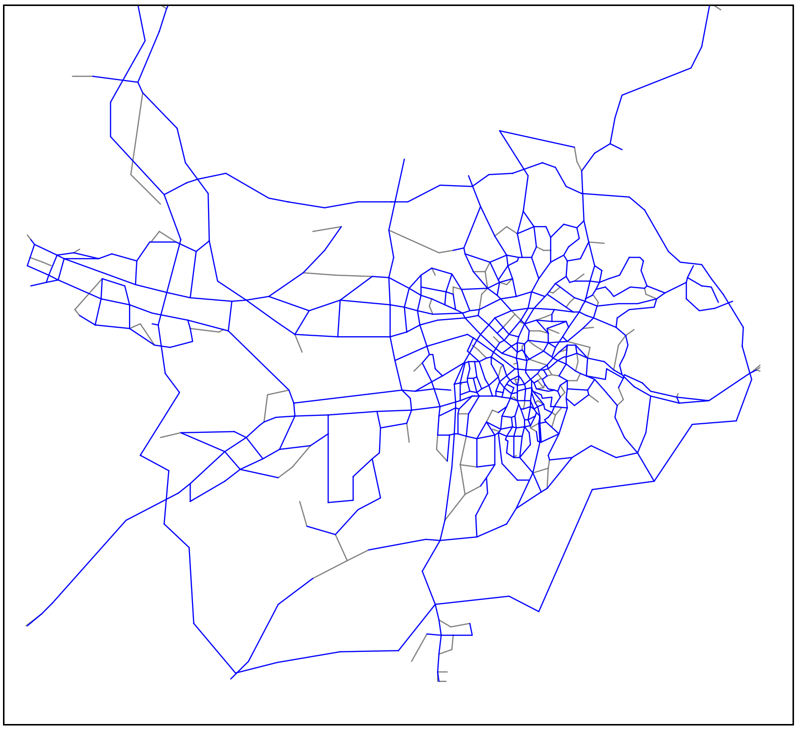


**Figure 5.14: Existing Road Transportation Network.**

### 5.3.2. Demographic Data

Zonal distributions of population, employment, resident bound employment, resident bound student, student enrollment, hospital bed capacity and number of autos are necessary input data in travel demand analysis. In this study four data sets are obtained.

Total population is obtained from population census (aggregate data), State Institute of Statistics in 2000. Zonal population distribution is obtained from Greater Ankara Municipality, Building Registration Office in 2002 and checked by population census values. Zonal employment distribution is obtained from Chamber of Commerce, Ministry of Finance and SSI (Social Security Institution) for the years 2000, 2002, and 2004. Zonal student enrollment in schools is obtained from Ministry of Education in 2002 and 2004 University web sites. Zonal hospital bed capacities are obtained from Ministry of Health in 2002 and 2004. Total auto ownership (aggregate data) is obtained from State Institute of Statistics in 2000 and Governorship of Ankara Directorate of Security in 2004. Aggregate values are redistributed into zones and disaggregate values are obtained. In this stage 1985 and 1992 values are extrapolated and estimated values are compared with current data. Further information is provided in Appendix C. In Table 5.6 socio-economic variables in 1985 are presented. Predicted and residual values are shown in Table 5.7 and Table 5.8.

**Table 5.6: Zonal Distribution of Demographic Variables (1985)**

| zone | population | employment | labor force | school enrolment | resident students | hospital beds | cars |
|---|---|---|---|---|---|---|---|
| **1** | 9484 | 92855 | 2805 | 10417 | 2155 | 195 | 417 |
| **2** | 245 | 14382 | 72 | 11240 | 56 | 3341 | 11 |
| **3** | 11259 | 78148 | 3330 | 8979 | 2559 | 164 | 1464 |
| **4** | 3106 | 29094 | 919 | 4478 | 706 | 0 | 404 |
| **5** | 11758 | 8333 | 3478 | 8503 | 2672 | 200 | 1529 |
| **6** | 41202 | 13358 | 12187 | 7852 | 9363 | 0 | 3173 |
| **......** | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| **99** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **total** | **2303688** | **681395** | **681399** | **523500** | **523500** | **12316** | **87051** |

Source: Ankara Transportation Study 1985 (EGO, 1987e)

**Table 5.7: Demographic Variables for 2004 (Predicted in 1985).**

| zone | population | employment | labor force | student enrolment | resident students | hospital beds | cars |
|---|---|---|---|---|---|---|---|
| **1** | 7219 | 99142 | 2098 | 10484 | 266 | 195 | 898 |
| **2** | 250 | 19028 | 73 | 11312 | 59 | 3341 | 32 |
| **3** | 10538 | 77627 | 3062 | 9036 | 2481 | 164 | 1569 |
| **4** | 3149 | 42870 | 915 | 4515 | 741 | 0 | 470 |
| **5** | 11038 | 12999 | 3207 | 8557 | 2599 | 200 | 1644 |
| **6** | 40060 | 23089 | 11639 | 12492 | 9432 | 0 | 5859 |
| **......** | .... | .... | .... | .... | .... | .... | .... |
| **99** | 919 | 1647 | 267 | 183 | 217 | 0 | 120 |
| **total** | **3997909** | **1158510** | **1158519** | **940081** | **938599** | **18910** | **368646** |

Source: Ankara Transportation Study 1985 (EGO, 1987b)
Values are obtained by interpolation from those of target years 2000 and 2005

**Table 5.8: Zonal Distribution of Demographic Variables (2004)**

| zone | population | employment | labor force | student enrolment | resident students | hospital beds | cars |
|---|---|---|---|---|---|---|---|
| **1** | 1909 | 99984 | 623 | 16446 | 576 | 195 | 302 |
| **2** | 178 | 20099 | 58 | 19300 | 54 | 3900 | 28 |
| **3** | 18413 | 89430 | 6009 | 39456 | 5561 | 420 | 2909 |
| **4** | 230 | 45095 | 75 | 4829 | 69 | 1 | 36 |
| **5** | 9811 | 13647 | 3202 | 9153 | 2963 | 800 | 1550 |
| **6** | 40013 | 24157 | 13058 | 13105 | 12084 | 1 | 6322 |
| **......** | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| **99** | 0 | 644 | 0 | 0 | 0 | 0 | 0 |
| **total** | **3551060** | **1158873** | **1158847** | **1071301** | **1072432** | **20160** | **561080** |

Sources: State Institute of Statistics, 2000
Greater Ankara Municipality, Building Registration Office, 2002
Ministry of Finance, and SSI (Social Security Institution, 2000, 2002, and 2004,
Ministry of Education, 2002 and University web sites, 2004
Governorship of Ankara, Directorate of Security, 2004

### 5.3.3. Traffic Counts

Traffic volumes are obtained from traffic counts conducted in the years 2002 and 2004 by the Greater Ankara Municipality, Department of Public Works. Traffic volumes are encountered in model calibration and validation. In particular in network assignment requires comparing model outputs with observed volumes. Traffic counts were conducted at 48 junctions (15 of them match with cordon counts conducted in 1985) in the morning peak period (Table 5.9).

**Table 5.9: 1985 Count Stations**

| Cordon Stations | | | | Screen-line Stations | |
|---|---|---|---|---|---|
| 1 | İstanbul Highway | 9 | Tıp Fakültesi Street | 17 | Çiftlik Street |
| 2 | İvedik Street | 10 | Kıbrıs Street | 18 | Bahçelerarası Street |
| 3 | Etlik Street | 11 | Libya Street | 19 | Tandoğan Bridge |
| 4 | Fatih Street | 12 | Akay Street | 20 | Sıhhiye Bridge |
| 5 | İ. Baştuğ Street | 13 | Atatürk Boulevard | 21 | Hasırcılar Street |
| 6 | Samsun Highway | 14 | Dikmen Street | 22 | Kurtuluş Bridge |
| 7 | Plevne Street | 15 | İnönü Boulevard | 23 | Dikimevi Bridge |
| 8 | Mamak Street | 16 | Fen Fakültesi Street | 24 | Saimekadın Bridge |

Source: EGO, 1987d

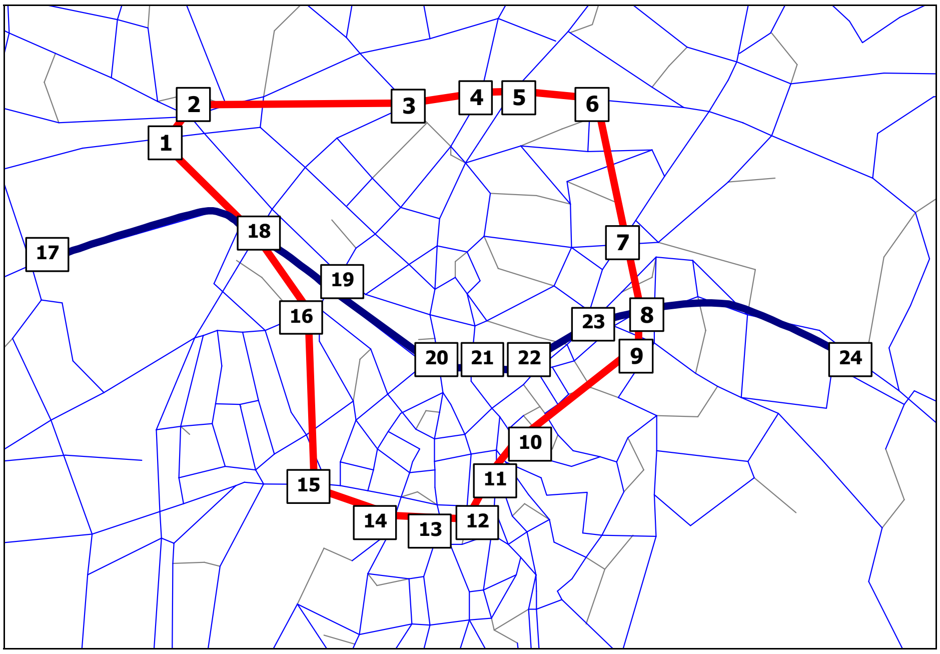



**Figure 5.15: 1985 Count Stations**
Source: EGO, 1987d

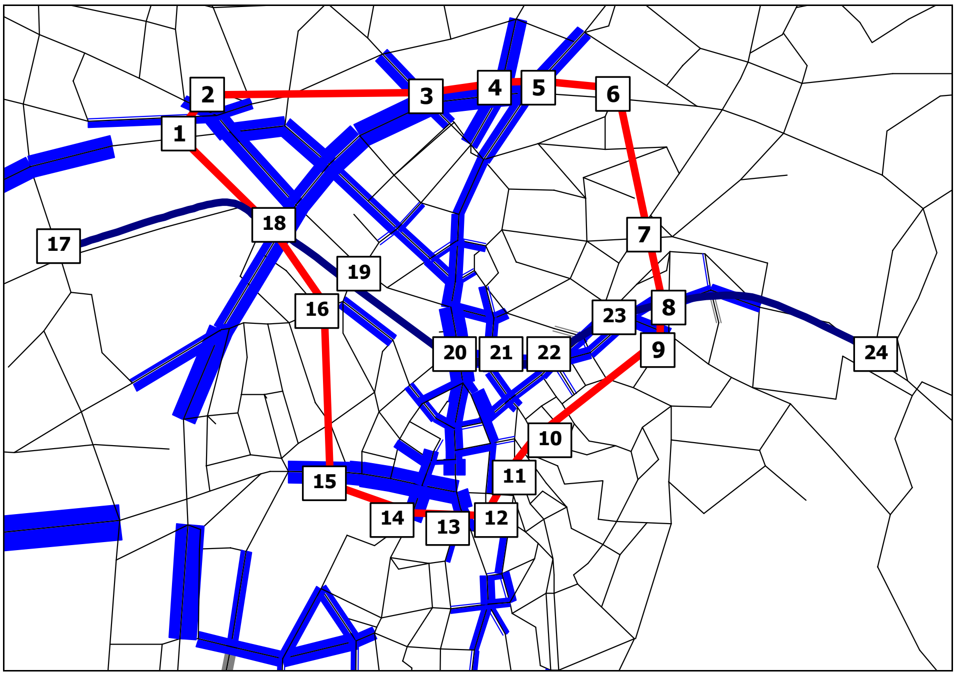



**Figure 5.16: Traffic volumes obtained from count stations (2004)**
Source: Greater Ankara Municipality Department of Public Works, 2004

### 5.3.4. Questionnaire Survey Findings

The household questionnaire is conducted in 2004 in Koru Sitesi neighborhood which is located on the southwestern part of Ankara. This neighborhood, in which upper middle and high income population reside, has been developed in the last two decades. It is commonly accepted that high income individuals make more trips. It is assumed that trip making frequencies of this neighborhood represent highest rank in the whole city. Departing from this fact in probabilistic analysis maximum levels are determined by survey findings. Questionnaire survey has been undertaken by random sampling (4.9%) method. 628 individuals asked for 22 questions to understand their travel behaviors in particular route choice.

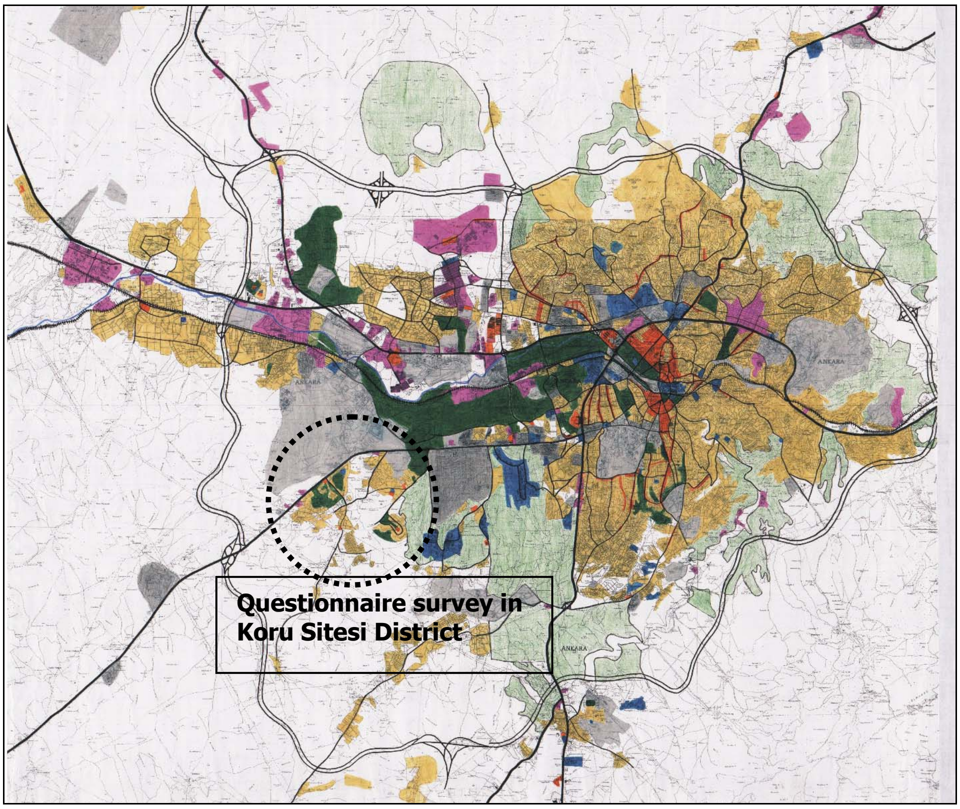



**Figure 5.17: Location of the Survey Area in Ankara**

**Table 5.10: General indicators of travel demand in Koru Sitesi**

| | | | |
|---|---|---|---|
| sample population | 628 | | |
| number households | 212 | | |
| average household size | 2,96 | car owners in particular | |
| number of cars | 251 | car owners | 251 |
| cars per household | 1,18 | car owners who always travel by car (all purposes) | 208 |
| cars per 1000 population | 399 | car passenger | 46 |
| average transportation cost (millions TL per month) per capita (all modes) | 109 | car users (total) | 254 |
| average transportation cost (millions TL per month) per capita (car owners) | 147 | share of other modes (instead of car) | 0,07 |
| average transportation cost (millions TL per month) per capita (drivers) | 177 | public transportation mode preference reasons | parking and fuel cost |
| share of other trips (excluding work, school and shopping trips) | 0,13 | reasons for service car preference | fuel and time cost |

The table above shows that car ownership rate car usage, which is one of major factors influencing travel behavior, is much higher than city average. In the following figure individuals occupations and travel mode choices are presented.

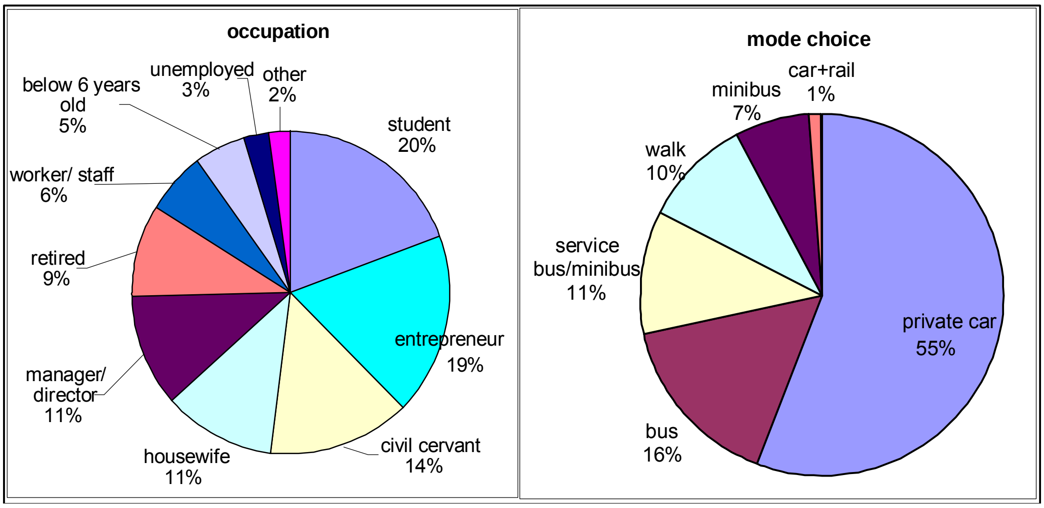



**Figure 5.18: Occupation and Mode Choice**

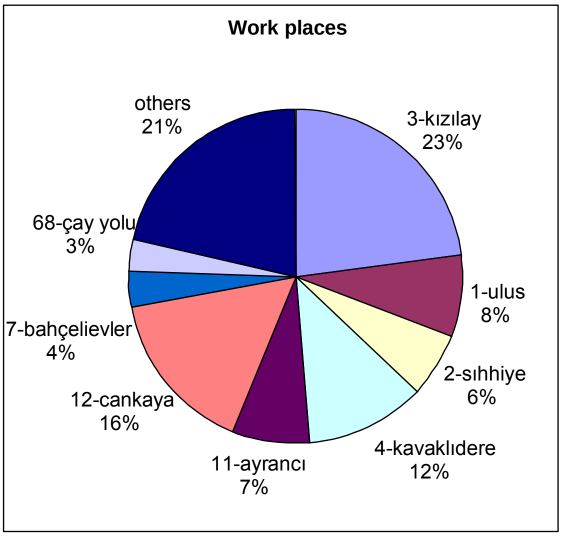



**Figure 5.19: Work Places**

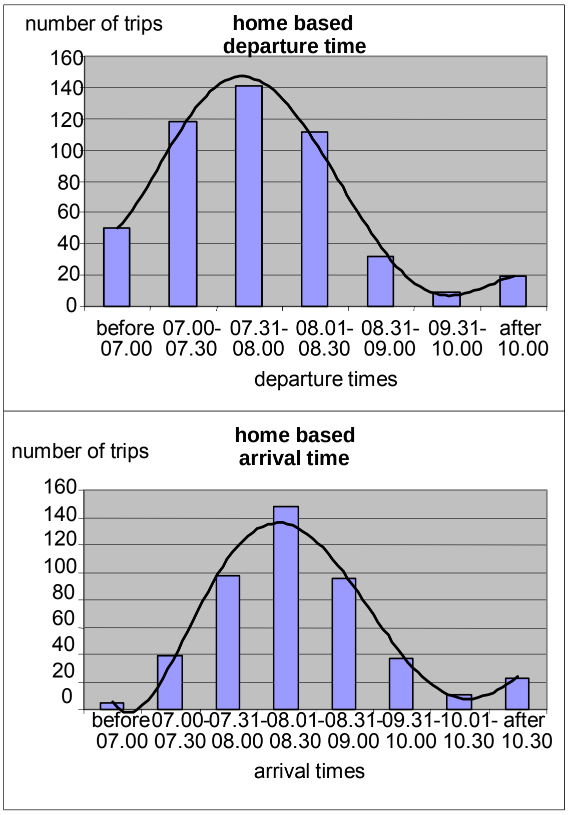



**Figure 5.20: Departure and Arrival Times (Home Based Work Trips)**

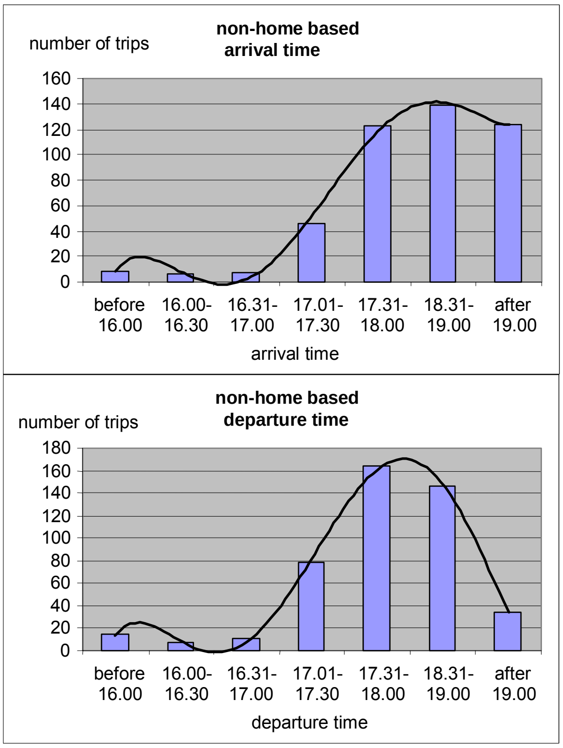



**Figure 5.21: Departure and Arrival Times (non-Home Based Trips)**

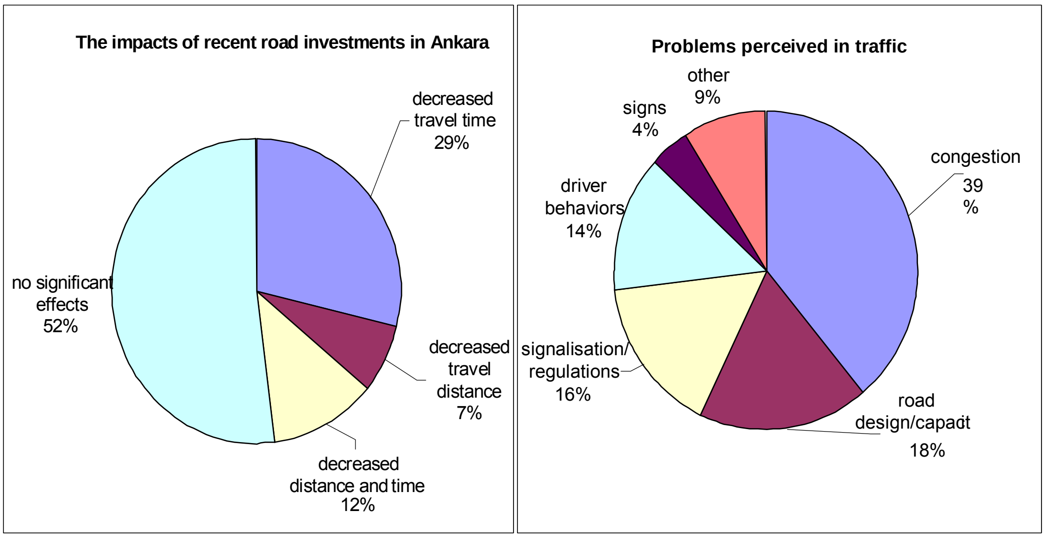



**Figure 5.22: Drivers' Perceptions in Traffic Flow**

| route choice | time | distance | time/dist. optimal | instantaneous | total |
|---|---|---|---|---|---|
| travel cost<100 M.TL | 0,07 | 0,63 | 0,21 | 0,09 | 1,00 |
| travel cost 100-149 M.TL | 0,16 | 0,49 | 0,24 | 0,11 | 1,00 |
| travel cost 150-199 M.TL | 0,33 | 0,34 | 0,16 | 0,17 | 1,00 |
| travel cost 200-249 M.TL | 0,54 | 0,19 | 0,09 | 0,18 | 1,00 |
| travel cost >250 M.TL | 0,61 | 0,14 | 0,11 | 0,14 | 1,00 |
| average | **0,34** | **0,36** | **0,16** | **0,14** | **1,00** |

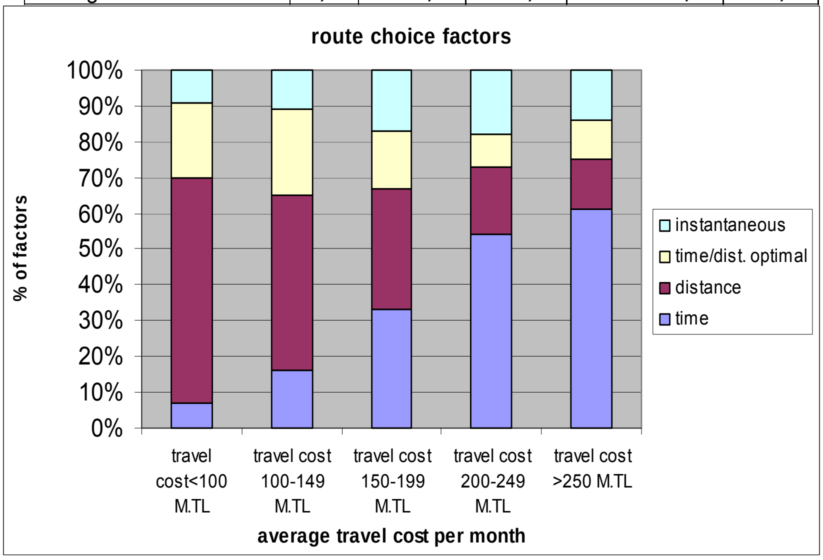



**Figure 5.23: Drivers' Route Choice (All Purposes)**

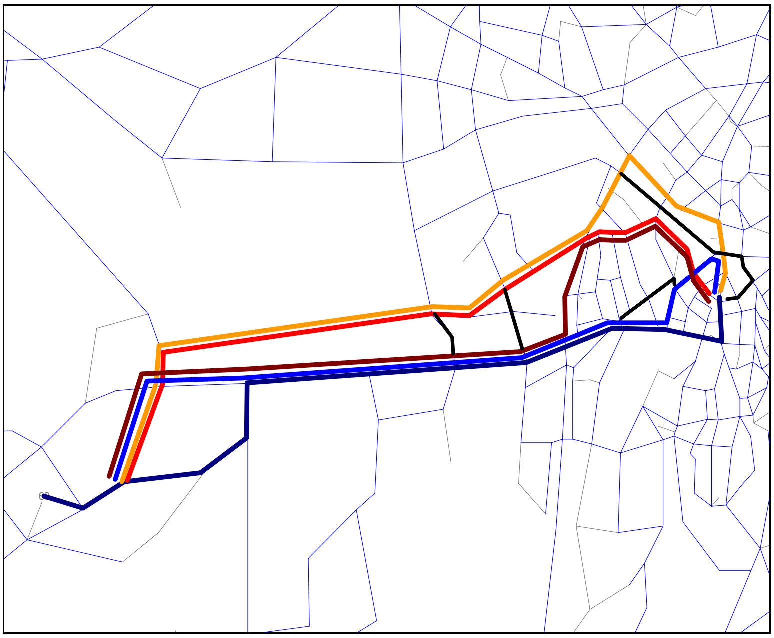


**Figure 5.24: Alternate routes between Koru Sitesi and Kızılay**

These figures suggest that questionnaire survey findings could be used to determine maximum rates of travel behavior: trip generation, trip distribution, mode choice and route choice. Trip making frequencies are high, whereas trip impedance is low. Besides, the share of auto trips and travel costs are much higher than city average. Since travelers are belonging to high income class individuals seek alternative routes in travel in order to reduce travel time. This factor is essential to adopt dynamic traffic assignment. On the other hand travel distance is also a significant factor in route choice. This fact suggests that in dynamic network assignment stage using a generalized cost function could provide realistic results.

## 5.4. Model Applications

In the first stage of this section, estimates of the model developed in 1985 by IBI Group (called IBI Model) in Ankara Transportation Study, are compared with current state. This procedure is conducted to detect errors of estimate and analyze sources of uncertainty. In the second stage the model is calibrated and validated. In the third stage, the validated model is restructured; the static assignment model is replaced by a dynamic assignment component. Finally, a comparative evaluation is conducted to identify differences among model outputs.

### 5.4.1 Stage 1: Application of IBI Model

In Ankara Transportation Study (EGO, 1987a), a multiple regression analysis is carried out for the calibration of the trip generation equations. In trip generation stage trip rates are specified for three trip purposes: home based work, home based school and home based other. Thus, in that study, six trip production and attraction equations have been developed for each category of trip purposes. The independent variables of these equations are derived from the land-use data set and other home interview survey. In that study (EGO, 1987a) 7 variables were specified:

1.POP : Residential Population (person)
2. LF : Resident-bound Workers (person)
3.RS : Resident bound Students (person)
4.CAR : Number of Cars per 1000 population
5.EMP : Employment at Work Places (person)
6.SCH : Enrolment at Places of School (person)
7.HOS : Number of Hospital beds

These variables are also used in this study in order to find out major factors resulting in variations in travel demand. In trip generation stage a multiple regression method was used (see equation 3.1 and 3.2. in chapter 3) and alternative sets of equations meeting the constraints have been examined. Then a correlation analysis was also carried out between independent variables to avoid propagation of statistical errors (EGO, 1987a). In the following table regression equations and correlation coefficients are presented:

**Table 5.11: Calibrated Results of Trip Generation Equations (1985)**

| **Trip Purpose** | **Production** | | **Attraction** | |
|---|---|---|---|---|
| | **Equation** | **$R^2$** | **Equation** | $R^2$ |
| **Home-based Work** | 0,6975*LF | 0,91 | 0,6666*EMP | 0,88 |
| **Home-based School** | 0,4952*RS | 0,88 | 0,4960*SCH | 0,54 |
| **Other trips** | 0,0259*POP+0,591*CAR +0,0358*EMP | 0,68 | 2,6918*HOS+0,1410*EMP | 0,35 |

Source: (EGO, 1987a)

These equations are employed to simulate trip making frequencies of analysis zones and total trip generation in the city for target year 2004 (Specified variables by the year 2015 can be found in EGO, 1987a: 36). Then the following trip generation table is obtained:

**Table 5.12: Productions and Attractions by Zones -2004**
(Predicted According to 1985 IBI Model Assumptions)

| **2004-predicted** | **production** | | | **attraction** | | |
|---|---|---|---|---|---|---|
| | **work** | **school** | **other** | **work** | **school** | **other** |
| **1** | 1438 | 83 | 4291 | 69432 | 5191 | 27681 |
| **2** | 51 | 29 | 716 | 13453 | 5601 | 14249 |
| **3** | 2126 | 1227 | 3981 | 54165 | 4474 | 21626 |
| **4** | 638 | 368 | 1922 | 30429 | 2236 | 11901 |
| **5** | 2227 | 1285 | 1734 | 9245 | 4237 | 4154 |
| **6** | 8099 | 4673 | 5427 | 16473 | 6304 | 6443 |
| **7** | 7785 | 4491 | 4693 | 5628 | 5999 | 2201 |
| **...** | ... | ... | ... | ... | ... | ... |
| **99** | 196 | 113 | 162 | 1210 | 96 | 473 |
| | **825701** | **475613** | **374858** | **826167** | **476193** | **374930** |

In trip distribution a doubly constrained spatial interaction model is employed (see equations 3.12 and 3.15 in chapter 3). In Ankara Transportation Study (1985) trip distribution model was calibrated by comparing the simulation outputs with those of questionnaire survey (EGO, 1987a). In this stage simulation checks are carried out by three different values: intra-zonal trips for each trip purpose, mean trip times and trip length frequency distributions, and trip interchanges for the five super-zones representing CBD and its periphery (EGO, 1987a). Finally, the super-zone trip interchanges (person trips all modes) from the home interview survey and the simulated O-D matrices were compared. The correlations between actual and simulated trip matrices were:

**Table 5.13: Friction Parameters by Purpose IBI Model 1985.**

| Trip Purpose | Beta (generalized friction factor) | $R^2$ (actual versus simulated) |
|---|---|---|
| Work | 0,16 | 0,983 |
| School | 0,33 | 0,973 |
| Other | 0,17 | 0,784 |

(EGO, 1987a:16).

In the second stage (validation of IBI Model) these parameters are compared with those of 2004 (Specified variables by the year 2015 can be found in EGO, 1987a: 37). After performing this stage trip distribution matrix was obtained.

In modal split stage, trip interchange method was employed (see equations 3.17 and 3.18). This method is also used in the validation stage in order to find out differences between predicted and actual mode choice characteristics. The calibration of the modal split component was conducted in two stages:

1-Finding walk trip percentages as a function of trip lengths,

2-Fitting diversion curves to estimate transit trip percentages as a function of auto/transit travel time ratios (EGO, 1987a). Trip lengths and travel times are extracted from transportation network. In order to test the goodness of fit of the "stylized curves" a regression analysis is conducted to compare simulation values with those of home interview survey (EGO, 1987a).

The $R^2$ values were found at significant levels whereas school trips by auto mode have the lowest value: 0.8232 (EGO, 1987a). Significance tests are essential in order to enhance reliability of model.

**Table 5.14: Results of Regression between Actual O-D Matrices and Matrices Derived from Divergence Curves, 1985**

| Trip Purpose | Mode | | |
|---|---|---|---|
| | Transit | Auto | Walk |
| Work | 0,9945 | 0,9622 | 0,9839 |
| School | 0,9813 | 0,8232 | 0,9936 |
| Other | 0,9373 | 0,8711 | 0,9757 |

Note: Values indicate correlation coefficients ($R^2$).
Source: EG0, 1987a:31

At the end of this stage trips are allocated among travel modes for each purpose. In model validation stage predicted trip matrices by purpose are compared with those of predicted in 2004.

In network assignment stage of the IBI Model employed in Ankara Urban Transportation Study a static assignment model is employed (see equation 3.22 and figure 3.5) that vehicle assignment is based on assigning all person trips to one route between each O-D pair taking into account capacities of the links (EGO, 1987a). In 1985 study simulated passenger volumes are agreed within 10% of the field counts for both transit and private modes (EGO, 1987a). In that study static assignment method gave accurate results; however predictions cannot respond to actual traffic volumes observed in 2004. The most important observations of the cordon and screen line counts and simulations in Ankara Urban Transportation study were:

> 1-Simulation results matches counted trips across the cordon.
> 2-Private car assignment patterns through the cordon are suitable for producing corridor demand estimates
> 3-Simulated versus counted traffic and transit trips at the east-west screen line did not agree. Some downtown routes achieved satisfactory assignments while others did not replicate the field counts very well. In this part, capacity-restrained assignment is necessitated to refine the assignment.

4-Simulated traffic in the off-peak is lower than the observed traffic. This is considered as a problem characteristic of traffic models, but it is not considered serious since the peak directional traffic is used for design purposes.

5-Overall comparisons of simulated trips and field counts provided good agreement in the areas critical for designing transportation systems and estimating travel behaviors (EGO, 1987a, 32).

In model application, significant results were obtained ($R^2$=0.86); however (calibration) the model could not guarantee its reliability for future estimations; that is, in order to achieve significant estimations for traffic volumes validation checks are necessary. When IBI (developed in 1985) model is performed to estimate traffic volumes 2004, significant results are not observed in the network assignment stage that due to input and inherent (internal) and therefore propagated uncertainties in previous stages.

**Table 5.15: Comparison of Simulated and Actual Trips at Cordon Stations, Inbound Vehicle Trips, IBI Model, 2004 (8.30-9.30 A.M.)**

| No | Cordon Station | Private Vehicle | | |
|---|---|---|---|---|
| | | Count | Simulated | Percent Error (%) |
| **1** | İstanbul Highway | 4984 | 3833 | 0,30 |
| **2** | İvedik Street | 5458 | 3977 | 0,37 |
| **3** | Etlik Street | 3429 | 2379 | 0,44 |
| **4** | Fatih Street | 2187 | 2783 | -0,21 |
| **5** | İ. Baştuğ Street | 3677 | 2739 | 0,34 |
| **6** | Samsun Highway | 5046 | 3926 | 0,29 |
| **7** | Plevne Street | NA | 3048 | NA |
| **8** | Mamak Street | 1413 | 1185 | 0,19 |
| **9** | Tıp Fakültesi Street | 1596 | 1348 | 0,18 |
| **10** | Kıbrıs Street | 1377 | 1532 | -0,10 |
| **11** | Libya Street | 2589 | 1879 | 0,38 |
| **12** | Akay Street | 1372 | 1521 | -0,10 |
| **13** | Atatürk Boulevard | 5011 | 4783 | 0,05 |
| **14** | Dikmen Street | 4268 | 3632 | 0,18 |
| **15** | İnönü Boulevard | 5089 | 4874 | 0,04 |
| **16** | Fen Fakültesi Street | 2206 | 2037 | 0,08 |
| **Total** | | **49702** | **44304** | |
| **Percent root mean square error** | | **26,30** | | |

Source: IBI Model Estimates in 1985; Count Volumes are Obtained from Greater Ankara Municipality, Department of Public Works, 2004

The final outputs (traffic volumes) are shown in Figure 5.25. This study suggests that an appropriate percent error should be less than 10%. Model application showed that traffic volumes are underestimated. This problem rises due to several factors.

**Figure 5.25: Simulated Inbound Traffic Volumes, IBI Model, 2004 (8.30-9.30 A.M.)**
Source: IBI Model Estimations, 1985

The cordon counts are conducted on main arterials; however total number of vehicles entering to central area is less than actual ones. In general the volumes assigned to links are less than those of traffic counts.

Since simulated volumes are not consistent with the observed counterparts, model parameters need revision to achieve consistency. The observations confirm that the model faces with uncertainty and the resulting estimated link volumes do not converge with those of traffic counts (Figure 5.26). The magnitude of errors in link volume estimation seems to be much higher than reasonable.

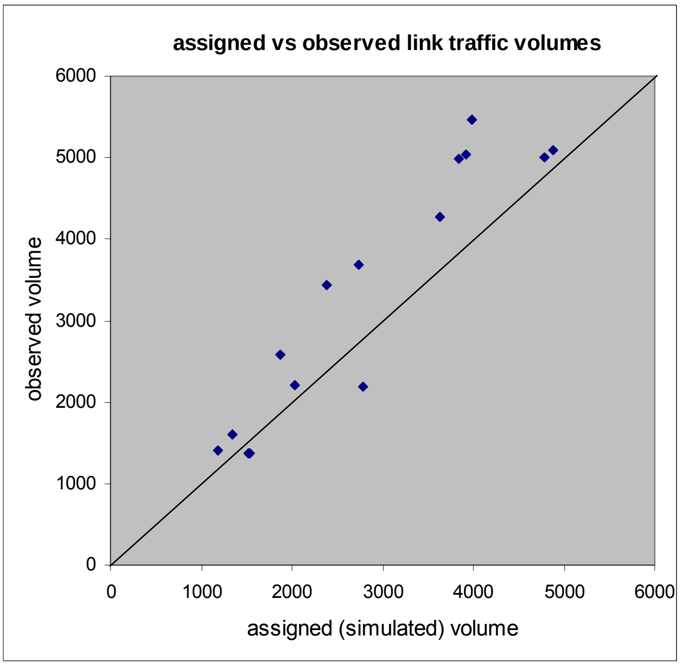



**Figure 5.26: Assigned versus observed traffic volumes on count stations (IBI Model, target year 2004)**

Due to underestimation in previous stages prediction errors are accumulated through model stages, particularly in network assignment stage. Hence, IBI Model (1985) fails to accurately estimate travel demand due to dynamic structure of the city. The population estimations for the southwestern and southern development areas of the city are less than the expected values. However; the population estimations for the northern and northwestern parts of the city are less than the corresponding values of the actual state.

For the city center; the employment is underestimated. This means that the tendency of the dispersal of the work places from the city center is low. The main problem in urban transportation planning is the deviation from planning goals by unsettled policy changes in the last two decades have been leading to uncertainties. Research outputs showed that the incompliance of policy changes with the stated planning goals resulted in estimation errors.

Uncertainty in transportation planning leads to deviations between estimated and actual travel demand. Case study analysis showed there are various types and sources of uncertainty in travel demand modeling. These are:

Population-labor force estimation (input uncertainty): Research findings showed that in 1985 Study total population was overestimated. In addition significant deviations are observed between predicted and existing population distributions.

Spatial expansion (input uncertainty): In 1985 Study decentralization was a major policy for urban development. However, city center and its periphery are still major concentration areas for working population. Estimation errors are shown in the following figures:

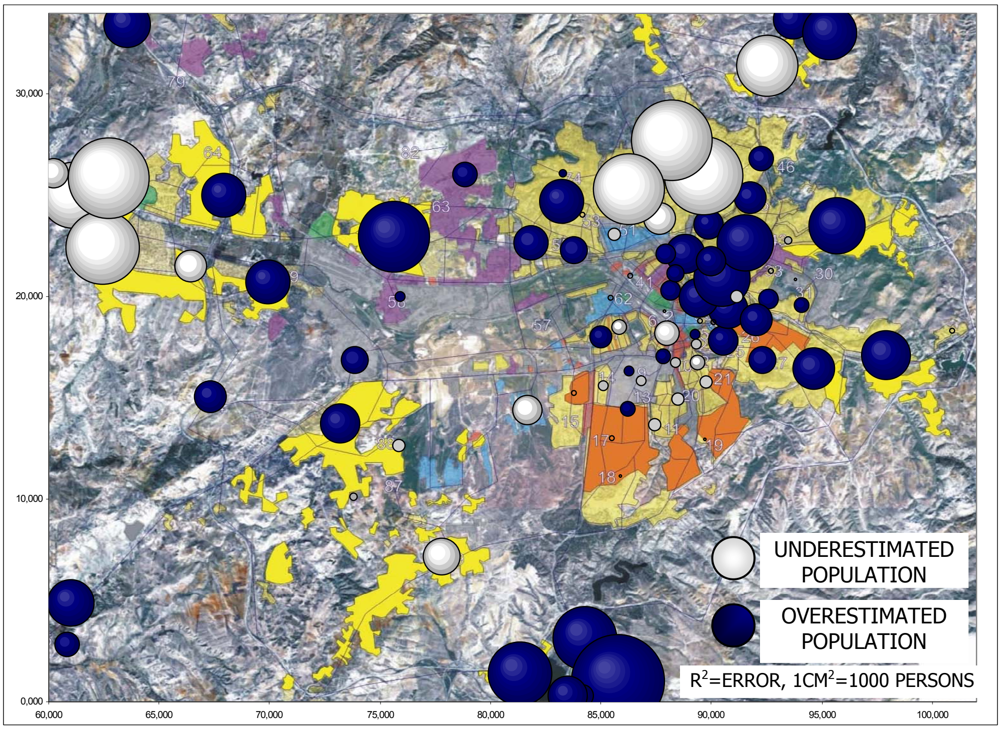



**Figure 5.27: Estimation errors in population distribution, 2004 (1985 Study)**

In this figure bubbles represent differences between the estimated and the actual populations in 2004. The ones which are more than estimated are shown with white points and the ones which are less than estimated are shown with dark blue points.

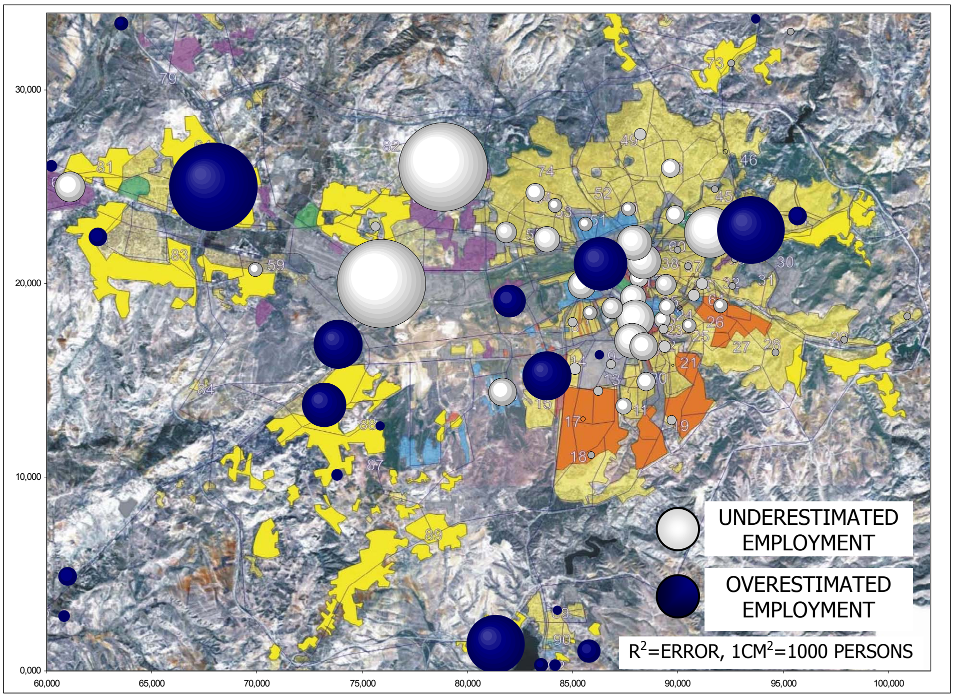



**Figure 5.28: Estimation errors in employment distribution, 2004 (1985 Study)**

The differences between the estimated and actual employment number for 2004. The sizes of the points indicate the differences between the estimated and actual employment. The ones which are more than estimated are shown with white points and the ones which are less than estimated are shown with dark blue points.

The figure shows that the employment numbers in the city center did not decrease as much as expected. In addition, the concentrations of population and work places on the major highways have not reached to expected levels. However; a level of employment more than expected emerged in industrial sites such as İvedik, Ostim and Sasmaz. This acquire of the different characters is one of the main reasons of the deviation in the travel estimations. The city center grows toward northern and southern parts. Hence; traffic congestion concentrated in the city center has reached to dramatic levels.

Estimation errors in trip per capita (epistemic uncertainty): This factor is an essential component in travel demand prediction. Trip per capita seems to be much higher than predicted values. In questionnaire survey and validated IBI Model application it is observed that individuals' trip making frequencies are much higher than those of predicted in 1985 Study.

Socio-economic deviations, such as the economic crisis (external uncertainty) are thought to have considerable impacts on travel demand. In addition travel rising travel costs might have significant influence on individuals' travel behavior.

Increase in car ownership (input and epistemic uncertainty): This factor, is an input variable in travel demand prediction, is underestimated in 1985 Study. On the other hand friction factors in trip distribution are dependent upon individuals' income and car ownership. Besides individuals' mode choices are also influenced by this factor. Hence model assumptions fail to predict traffic volumes accurately.

Increase in other trips (epistemic uncertainty): Predicting other trips is a difficult work in travel demand models. There may be several factors influencing recreation, shopping, business and other purposes which are specified in transportation studies. Compared to work and school trips sensitivity test results give lower rates of correlation coefficients. This problem is commonly emphasized in the literature. These kinds of uncertainty, which are called epistemic uncertainties, are associated with model assumptions and specifications.

Increase in service vehicles (stochastic uncertainty): Due to socio-economic factors and problems in public transportation, in Ankara service vehicle usage has increased in the last two decades. There may be several factors influencing this tendency. These factors, like technological advancement, economic fluctuation and individuals' preferences, are called stochastic and they their impacts on travel behavior are called stochastic uncertainty.

Difference between the planned roads and the constructed roads (political and programmatic uncertainty): This problem was mentioned in section 5.1. Ankara faced with considerable policy changes that resulted in uncertainty in travel demand estimations and investment policy. In such a dynamic environment prediction would always be problematic. At the end of 1990s Greater Ankara Municipality declared construction of more than forty grade separated junctions and thousands kilometers of road improvement in order to relieve congestion. Most of those projects were not envisioned in Ankara Transportation Plan.

It is accepted that dynamic network assignment aimed at short termed traffic prediction and outputs of these models are used in signal control and other traffic management systems. Grade separated junctions do not allow operational flexibility since transportation network is almost fixed. Due to this problem further efforts may not be affective to relieve congestion under increasing travel demand.

Transit trips by rail mode are overestimated (policy and programmatic uncertainty): According to 1985 plan third stage of rail system would be completed in 2000; however due to changing political preferences and financial problems those projects are not realized yet. 1985 plan was prepared in a manner that aims to reduce shares of car and para-transit modes in total trips. However, corresponding values have increased gradually and individuals are suffering from congestion problems especially in the central parts of the city. Research findings showed that political and programmatic uncertainties have vital impacts on the performance of travel demand model.

These kinds of uncertainties mentioned above are accumulated through all stages of travel demand model and transportation planning. Zhao and Kockelman (2001) focused on propagation of uncertainty and associated these problems with sequential structure of the model. In this study accumulation of uncertainty are regarded as structural and epistemic uncertainty in transportation planning, that is, most of those problems are beyond the scope of prediction models.

Variations in model parameters because of the lack of validation result in epistemic uncertainty which rises when sufficient numbers of scenarios are not developed. It is necessary to validate travel demand estimation and revise transportation plans in order to envision political, programmatic and stochastic uncertainties. Since individuals' preferences vary in time and space parametric uncertainty usually coexist in models.

There was a high consistency between estimated and observed travel demand in 1985. However, IBI Model's forecasts for the year 2004 have a high degree of errors and the co-linearity between predicted and observed traffic volumes decreases due to the problems mentioned above. Deviation from model estimations and actual case seem to be resulted from forecasting errors which are accumulated through sequential stages.

Problems that are found in stage 1 (application of IBI Model) are taken into account in the next stages in order to improve reliability of that model. In calibration stage traffic counts conducted by Greater Ankara Municipality, Department of Public works (2004) and questionnaire survey findings are used and a probabilistic manner is elaborated to achieve convergence between predicted and actual values.

### 5.4.2 Validation of the IBI Model (stage 2)

In the second stage IBI Model is validated in order to accurately estimate traffic volumes for 2004. In this stage model structure is conserved but parameters are revised. To do this both aggregate and disaggregate validation methods are used. The former one implies comparing actual and simulated values of population, total travel demand, total inbound trips and similar variables; while the latter one requires specific analysis.

Disaggregate analysis is carried out in order to match model outputs with specific values of the actual travel demand (i.e. traffic volumes, variables found in the questionnaire survey are associated to corresponding zone). Besides, disaggregate validation can be carried out by checking model outputs for specific zones. The parameters and constraints that were specified in IBI Model-1985 are validated in 2004 (started in 2002 and finalized in 2004) and model outputs compared observed traffic volumes.

Calibration is the process of measuring model parameters in an iterative process. In this process, model outputs are compared with values of current travel demand until significant convergence is achieved. During this process parameters are checked after specified increments. After every iteration, sensitivity checks are performed in order to assess whether the calibrated model respond to actual case. If significant convergence is not achieved this process is repeated.

Research findings in the first stage showed that total population is overestimated, whereas, car ownership and the vehicle trip per capita rate (by auto) are underestimated. It is observed that concentration of employment in central zones results in higher traffic volumes in central streets than predicted. In addition, friction parameters seem to be lower than expected. Such structural (and internal) parameters are recalculated in a manner that variation intervals are determined in order to find fitting values for specified parameters.

Model application in the first stage suggests that it is essential to update input data. In the second stage probabilistic method is used to estimate variability of parameters. This method is developed in a manner that travel demand estimation in corresponding stages could be eliminated. Errors of estimate are necessarily detected in every step separately, in disaggregate analysis. Thus, validation process is carried out in a way that prediction errors (of existing model) are measured and reduced at corresponding stages. Finally, traffic volumes assigned to the links of underlying network are compared with those of cordon counts.

Initially inputs data (population, employment, student enrollment, hospital bed capacity, car ownership, and transportation network properties) are updated, then model estimates are carried out until total travel assigned to links, which were specified in cordon counts, match observed traffic volumes. If assigned volumes do not match observed volumes a feedback process which involves trip generation, trip distribution, modal split and network assignment is repeated until significant convergence is achieved. Then network assignment models can be compared in terms of performance. The aim of this process is to reduce estimation errors propagated in previous stages of the model.

At the end of this stage new traffic volume table is obtained. By the way network assignment models can be compared with respect to performance that either static or dynamic models are performed by using validated model outputs (updated trip distribution table for vehicle trips).

In trip generation stage the structure of multiple regression method is conserved. In this process alternative sets of equations meeting the constraints have been examined and four stages of the model are performed until significant convergence between simulated and observed volumes is obtained. In this stage network assignment is carried out by static model. It is observed that variables and constraints of the equations used in the IBI Model do not accurately represent trip generation volumes for the target year 2004. Then the following equations are validated.

**Table 5.16: Calibrated Results of Trip Generation Equations (2004)**

| Trip Purpose | Production | | Attraction | |
|---|---|---|---|---|
| | Equations | | Equations | |
| | min | max | min | max |
| **Home-based Work** | 0,79*LF | 0,89*LF | 0,802*EMP | 0,95*EMP |
| **Home-based School** | 0,59*RS | 0,68*RS | 0,59*SCH | 0,68*SCH |
| **Other** | 0,037*POP+0,591*CAR+0,0358*EMP | 0,07*POP+0,78*CAR+0,0358*EMP | 2,6918*HOS+0,80*EMP | 2,6918*HOS+1,3*EMP |

In 1985 Study 1.73 trips per capita, including walk trips, was found and it was estimated that this rate would reach to 2.263 by the year 2015 (EGO, 1987a: 33). The corresponding value is estimated to be 2.04 by the year 2004. Surprisingly this value matches that of predicted in this study. In 1985 the vehicle trips per capita was found as 1.16 and was assumed to reach 1.36; whereas in this study the corresponding rate is estimated to be between 1.44 and 1.52.

In trip distribution stage, friction factors are most influential components of specified equations. In the IBI Model this function was expressed as an exponent of travel time (a generalized combination of travel times by transit and car). In this stage (validated IBI Model) this function is conserved in order to find out friction factor for 2004. According to 1985 Study the corresponding values were assumed to remain constant (EGO, 1987a: 37, see Table 5.17); however, case study showed that friction factors ($\beta$) show significant variations in time. In this stage certain intervals are specified for corresponding values of those parameters, and then friction new factors are obtained. Model outputs showed there is a decreasing trend in friction factors.

**Table 5.17: Calibrated Results of Trip Distribution Equations (2004)**

| Beta | Work trips | | School trips | | Other trips | |
|---|---|---|---|---|---|---|
| **IBI model 1985** | 0,16 | | 0,33 | | 0,17 | |
| **IBI model assumption for 2004** | 0,16 | | 0,33 | | 0,17 | |
| | min | max | min | max | min | max |
| **Validated IBI model 2004** | 0,11 | 0,16 | 0,18 | 0,33 | 0,12 | 0,17 |

Then modal split and network assignment procedures are carried out. In the modal split stage the structure of modal split model is conserved. In 1985 Study car ownership was assumed to increase by 6.8% per year (EGO, 1987a: 37). However, planning group set up a policy for transit usage and according to them transit share in total trips was found as 64% and this share was assumed to reach at 70% for the year 2015. The corresponding value was assumed to be 68% for 2004; however this value is estimated to be between 65% and 67%.

In network assignment stage capacity restraint method is used to predict traffic volumes. The outputs are compared with those of dynamic assignment in the next section (stage 3). The purpose of this stage is to calibrate model parameters in order find out best fitting equations that are based on assumptions. Then model parameters could be revised to obtain trip distribution matrices by modes. Both dynamic and static assignment models are performed by using same trip distribution matrix of vehicle trips.

**Table 5.18: Simulated and Actual Trips at Cordon Stations, Inbound Vehicle Trips, Validated IBI Model-Static Assignment, 2004 (8.30-9.30 A.M.)**

| No | Cordon Station | Private Vehicle | | |
|---|---|---|---|---|
| | | Count | Simulated | Percent Error (%) |
| **1** | İstanbul Highway | 4984 | 5167 | -0,04 |
| **2** | İvedik Street | 5458 | 4787 | 0,14 |
| **3** | Etlik Street | 3429 | 2719 | 0,26 |
| **4** | Fatih Street | 2187 | 2574 | -0,15 |
| **5** | İ. Baştuğ Street | 3677 | 3158 | 0,16 |
| **6** | Samsun Highway | 5046 | 5424 | -0,07 |
| **7** | Plevne Street | NA | | |
| **8** | Mamak Street | 1413 | 1707 | -0,17 |
| **9** | Tıp Fakültesi Street | 1596 | 1903 | -0,16 |
| **10** | Kıbrıs Street | 1377 | 1292 | 0,07 |
| **11** | Libya Street | 2589 | 2061 | 0,26 |
| **12** | Akay Street | 1372 | 932 | 0,47 |
| **13** | Atatürk Boulevard | 5011 | 5995 | -0,16 |
| **14** | Dikmen Street | 4268 | 3863 | 0,10 |
| **15** | İnönü Boulevard | 5089 | 5881 | -0,13 |
| **16** | Fen Fakültesi Street | 2206 | 2402 | -0,08 |
| **Total** | | **49702** | **49865** | |
| **Percent root mean square error** | | **15,55** | | |

Source: Count Volumes are Obtained from Greater Ankara Municipality.

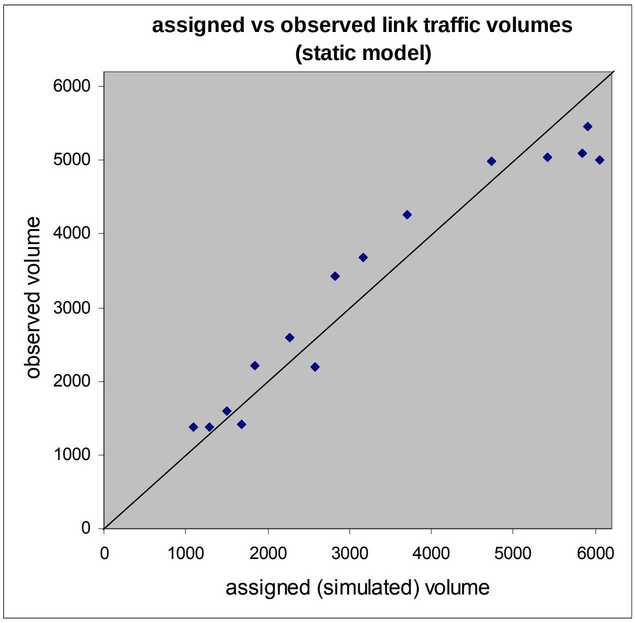



**Figure 5.29: Assigned versus observed traffic volumes on count stations (Validated IBI Model, static assignment)**

The findings of the model application in this step are as follows:

1-In general simulation results are converged to traffic volumes across the count stations (percent root mean square error is 15.55) (see Table 5.18 and Figure 5.29).

2- Simulated traffic volumes through cordon counts match the observed volumes. This result indicates that validation process is successfully accomplished with exception of assignment stage. Traffic volumes through the cordon are suitable for producing travel demand estimates; however estimation errors could be eliminated in assignment stage. Although total number of vehicles through cordon stations match observed volumes percent errors between simulated and observed volumes on specific links are still higher than tolerable (10%). Due to this fact in the next section static assignment model is replaced by dynamic assignment model in order to compare model performances.

3- Compared to observed traffic volumes major roads are assigned with higher volumes while surrounding links are assigned with much less volumes. In this part, capacity-restrained assignment is performed. This model takes into account the effects of congestion; however, trip allocation process is not time dependent. In the next step a dynamic model will be employed to take into account congestion effects and the role of time losses in individuals' route choice.

### 5.4.3 Stage 3: Traffic Volume Estimation (Validated Model)

In the validation stage, like second stage, a probabilistic method is used to calibrate simulation model (see Figure 4.2 and Figure 4.3 in Chapter 4). Validation process has been accomplished in the second stage and in this stage traffic assignment process is repeated that a dynamic network assignment method is involved.

Dynamic traffic assignment methods are developed in order to analyze and predict performance of transportation system in congestion. These methods are introduced to transportation planning literature in a manner that time-dependent travel demand is incorporated in traffic flow. In the solution algorithm temporal variations in individuals' travel behavior in response to congestion are encountered. It is assumed that roadway capacities change instantaneously with congestion as well as traffic management and control measures could be adjusted throughout the day.

Dynamic traffic assignment models can be employed to assess "induced traffic" and "diverted traffic" (Litman, 1999; Lee and Camus et al, 1999). These consequences in congested networks shall be encountered and measured in travel demand estimation methods. Induced traffic is beyond the scope of this study; however in trip generation stage measuring induced traffic would improve model performance. Diverted traffic can be measured by dynamic traffic assignment methods.

Case study analysis showed that Ankara road network does not provide as much alternative routes as expected in network assignment. It is commonly accepted that in congested networks alternative dynamic assignment models seek alternate routes and network flexibility has considerable impact on the performances of these models. Network flexibility is an essential issue in dynamic network assignment in order to perform of advanced traffic control systems effectively.

In this study a dynamic shortest path algorithm is employed to assess network flexibility. In this algorithm initially all possible routes are detected then "feasible" routes are selected. Here the term "feasibility" refers to least cost routes. Since both time and distance are significant factors in determining the travel routes, travelers' ability to pay for a trip is limited by their budget. In this regard for due to computation capacity, 6 least cost routes are preferred among various alternatives, and then volumes are assigned to selected routes.

Ankara road network consists of 99 zones 625 nodes and 1645 links. In the network assignment stage $8,86*10^{22}$ possible routes have been analyzed in the computation process. Among them 58.212 feasible routes are assigned by traffic volumes. The findings of the model application in this stage are as follows:

1-The simulation results match counted traffic volumes across the cordon. This process was accomplished in the second stage. In this stage allocation of vehicles on the underlying network is carried out in a manner that major roads are less congested than those of stage 2; whereas surrounding secondary arterials are loaded with higher volumes. This result suggests that in dynamic network assignment could provide reliable predictions in the future (percent root mean square error is 7,22) unless travel demand model is validated.

2-Simulated traffic volumes across central links are lower than observed volumes, but the differences are not noteworthy (see Figure 5.30 and Table 5.19). On the other hand peripheral links are assigned with higher volumes but the differences are also negligible. In this part, a dynamic model is employed to incorporate travelers' behavior in response to congestion.

In the static network assignment algorithm trips are allocated on predetermined shortest paths, whereas dynamic network assignment algorithm analyses travel speeds to allocate trips on un-congested links. Model outputs showed that dynamic network assignment provides more accurate estimation of traffic volumes in congested networks (See Table 5.19).

**Table 5.19: Simulated and Actual Trips at Cordon Stations, Inbound Vehicle Trips, Validated IBI Model-Static Assignment, 2004 (8.30-9.30 A.M.)**

| No | Cordon Station | Private Vehicle Count | Private Vehicle Simulated | Percent Error (%) |
|---|---|---|---|---|
| **1** | İstanbul Highway | 4984 | 4691 | 0,06 |
| **2** | İvedik Street | 5458 | 5103 | 0,07 |
| **3** | Etlik Street | 3429 | 3192 | 0,07 |
| **4** | Fatih Street | 2187 | 2309 | -0,05 |
| **5** | İ. Baştuğ Street | 3677 | 3394 | 0,08 |
| **6** | Samsun Highway | 5046 | 5417 | -0,07 |
| **7** | Plevne Street | NA | | |
| **8** | Mamak Street | 1413 | 1519 | -0,07 |
| **9** | Tıp Fakültesi Street | 1596 | 1643 | -0,03 |
| **10** | Kıbrıs Street | 1377 | 1541 | -0,11 |
| **11** | Libya Street | 2589 | 2719 | -0,05 |
| **12** | Akay Street | 1372 | 1612 | -0,15 |
| **13** | Atatürk Boulevard | 5011 | 4811 | 0,04 |
| **14** | Dikmen Street | 4268 | 4029 | 0,06 |
| **15** | İnönü Boulevard | 5089 | 4967 | 0,02 |
| **16** | Fen Fakültesi Street | 2206 | 2558 | -0,14 |
| **Total** | | **49702** | **49505** | |
| **Percent root mean square error** | | **7,22** | | |

Source: Count Volumes are obtained from Greater Ankara Municipality.

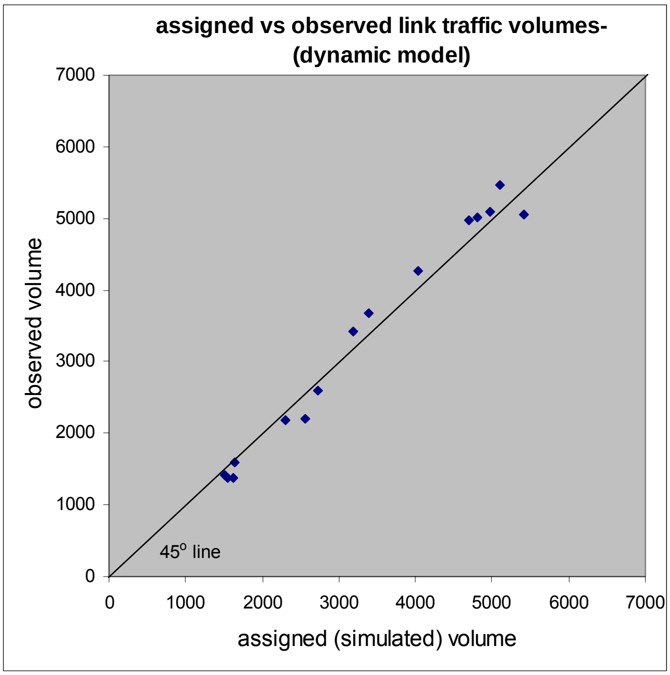



**Figure 5.30: Assigned versus observed traffic volumes on count stations (Validated IBI Model, dynamic assignment)**

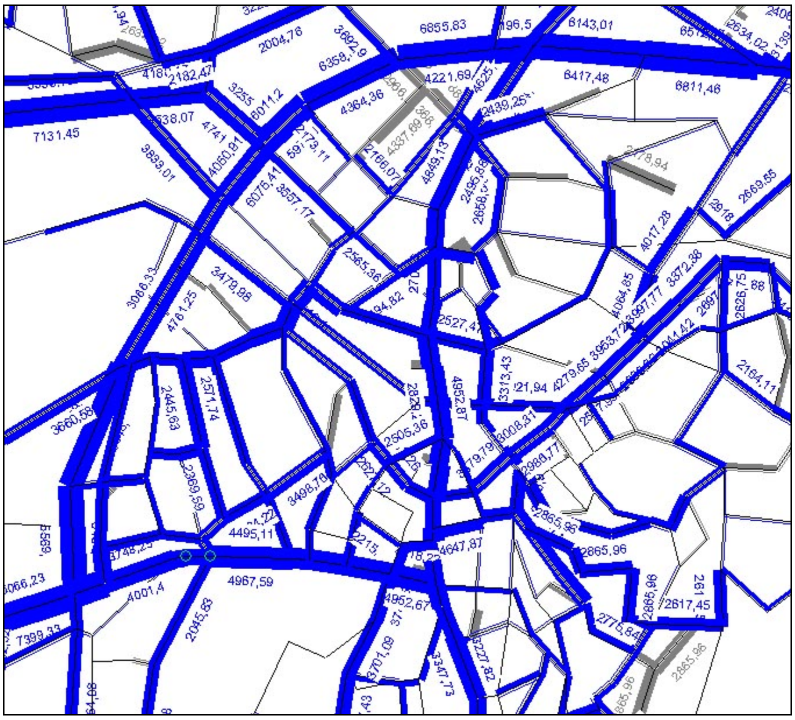



**Figure 5.31: Traffic volumes on the road network**
**(Stage 3: Dynamic assignment in validated IBI Model)**

Overall comparisons of simulated trips and field counts showed that dynamic assignment models can be installed to model structure so as to predict "short term" impacts of road improvement and traffic management projects.

Travel demand estimation (especially network assignment) is an essential component of strategy development and investment programming in urban transportation planning. This study attempts to analyze the relevancy of dynamic network assignment in dynamic travel demand conditions. Accurate estimation of traffic flow is necessary to improve reliability of models which provide background information for setting transportation investment policy.

## 5.5. Evaluation of Outputs:

After model validation, percent errors of link volumes from simulation were less than IBI Model predictions in 1985, and closer to the observed (count) volumes. This leads to systematically reduced percentage root mean square errors compared with those of 1985 IBI Model (reduced from 26% to 15%). That is model performance is considerably improved since input data and outputs of preliminary stages of the model are updated. Hence, validated model findings, traffic volumes, were found to be more consistent with the observed data; however, further improvement was necessary in order to achieve accuracy in estimated traffic flows. In the last stage dynamic traffic assignment method is integrated and a probabilistic method is involved in model structure. In the following figure traffic volumes that are obtained from three stages are compared with those of count stations.

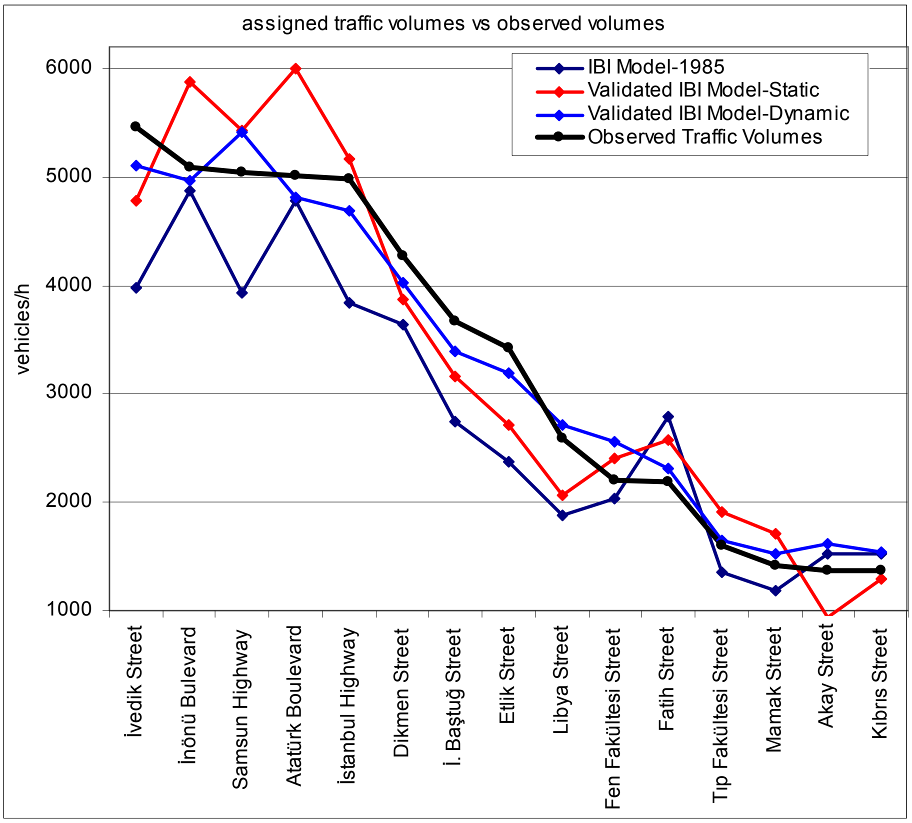



**Figure 5.32: Assigned traffic volumes (model outputs and observed volumes)**

After model validation, percent errors of link volumes from simulation were less than IBI Model predictions in 1985, and closer to the observed (count) volumes. This leads to systematically reduced percentage root mean square errors compared with those of 1985 IBI Model (reduced from 26% to 15%). That is model performance is considerably improved since input data and outputs of preliminary stages of the model are updated. Hence, validated model findings, traffic volumes, were found to be more consistent with the observed data; however, further improvement was necessary in order to achieve accuracy in estimated traffic flows. In the last stage dynamic traffic assignment method is integrated and a probabilistic method is involved in model structure.

The model reasonably fit the observed volumes; percent root mean square has been reduced to 7.22. Percent errors in link volumes vary between -15% and 8%. Estimation errors were sought in preliminary stages of the model but there is still some sort of uncertainty. In this stage a link based analysis is carried to understand specific properties of assignment models. To do this, 14 links are specified around city center and link volumes that are assigned by these two models are compared (See Figure 533, Figure 5.34 and Figure 5.35). It is observed that static model tends to assign volumes on congested links whereas dynamic model seeks less congested links.

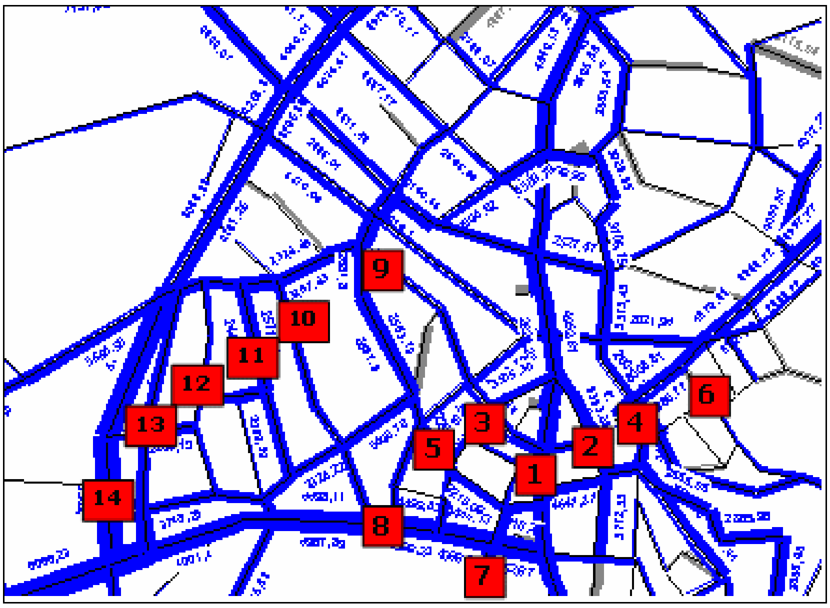



**Figure 5.33: Specified Links around the City Center.**

**Table 5.20: Comparison of Static and Dynamic Models: Simulated Volumes**

| | | | Validated IBI Model-Static Assignment | | Validated IBI Model-Dynamic Assignment | |
|---|---|---|---|---|---|---|
| | Section | Capacity | Volumes | V/C | Volumes | V/C |
| 1 | Atatürk Blvd-Kızılay | 2820 | 5995 | 2,13 | 4812 | 1,71 |
| 2 | Mithatpaşa Street | 3480 | 7429 | 2,13 | 5743 | 1,65 |
| 3 | Necatibey Street | 2960 | 4695 | 1,59 | 3941 | 1,33 |
| 4 | Libya Street | 2407 | 2061 | 0,86 | 2719 | 1,13 |
| 5 | Gençlik Street | 2250 | 2047 | 0,91 | 2544 | 1,13 |
| 6 | Kıbrıs Street | 1659 | 1292 | 0,78 | 1541 | 0,93 |
| 7 | Dikmen Street | 3345 | 3863 | 1,15 | 4029 | 1,20 |
| 8 | İnönü Boulevard | 3960 | 5881 | 1,49 | 4967 | 1,25 |
| 9 | Fen Fakültesi Street | 2440 | 2402 | 0,98 | 2758 | 1,13 |
| 10 | Fevzi çakmak Street | 3185 | 3048 | 0,96 | 4493 | 1,41 |
| 11 | Azerbaycan Street | 1645 | 927 | 0,56 | 1446 | 0,88 |
| 12 | Kazakistan Street | 1655 | 732 | 0,44 | 1154 | 0,70 |
| 13 | Biskek Street | 1920 | 654 | 0,34 | 1662 | 0,87 |
| 14 | Konya Highway | 4380 | 6558 | 1,50 | 5298 | 1,21 |
| | | | 47584 | | 47107 | |

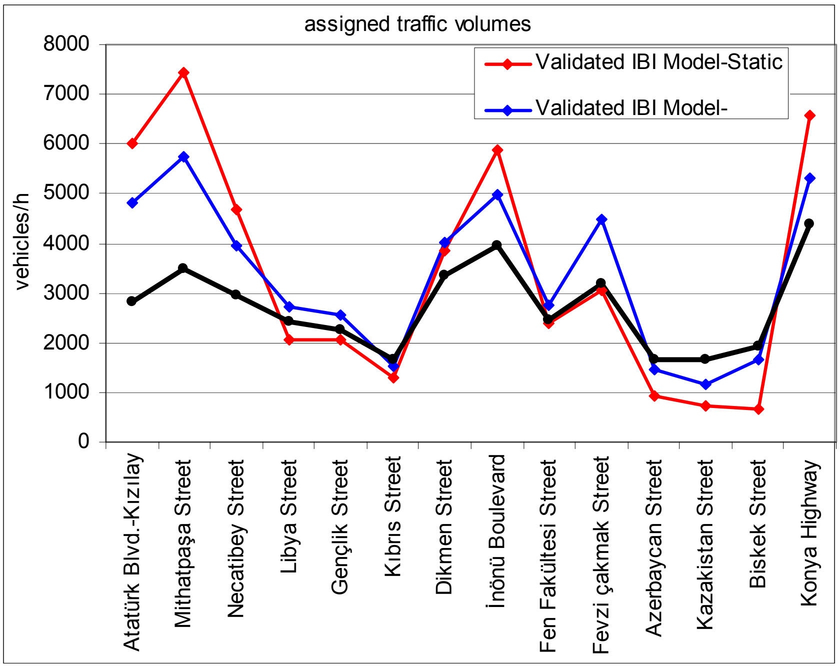



**Figure 5.34: Comparison of Static and Dynamic Models: Simulated Volumes**

It is observed that static model persistently assigns trips on initial shortest paths even though they are congested; whereas, dynamic model continuously seeks alternative shortest paths when an initial shortest path is occupied by vehicles. As stated before, In dynamic assignment method, trips are assigned as a function of travel time which is influenced by flow, density, and actual speed. Hence local distributor roads are assigned by higher traffic volumes; whereas in static assignment these roads are assigned by much less trips. Hence in road capacity utilization rates are different (Figure 5.35).

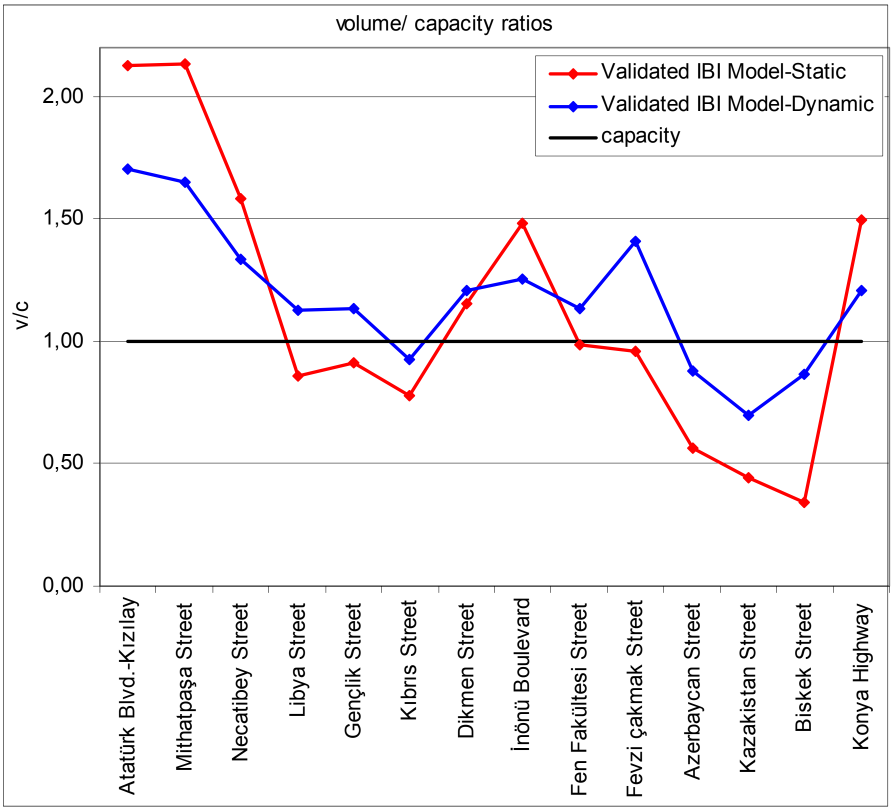



**Figure 5.35: Link Volume/Capacity Ratios around the City Center: Dynamic and Static Model Outputs.**

In the last two decades road capacities have been increased by 20% at average; while central links exhibit lower increases peripheral links have been improved to accommodate higher traffic volumes. Whereas, traffic volumes have increased by 90% at average and resulted in decreasing level of services since (See Table 5.21).This problem resulted in systematic expansion of congested region around the city center.

**Table 5.21: Increases in Traffic Volumes and Road Capacities: 1985-2004**

| | 1985 (morning peak: 7.30-8.30) | | | 2004 (morning peak: 8.00-9.00) | | |
|---|---|---|---|---|---|---|
| **Count station** | **Volume** | **Capacity** | **V/C** | **Volume** | **Capacity** | **V/C** |
| İvedik Street | 2286 | 2256 | 1,01 | 5458 | 3380 | 1,61 |
| İnönü Boulevard | 1168 | 2955 | 0,40 | 5089 | 3960 | 1,29 |
| Atatürk Boulevard | 2869 | 2116 | 1,36 | 5011 | 2820 | 1,78 |
| İstanbul Highway | 1293 | 2793 | 0,46 | 4984 | 4160 | 1,20 |
| Dikmen Street | 2289 | 2403 | 0,95 | 4268 | 3345 | 1,28 |
| İ. Baştuğ Street | 1972 | 2488 | 0,79 | 3677 | 3630 | 1,01 |
| Etlik Street | 2488 | 2430 | 1,02 | 3429 | 3645 | 0,94 |
| Libya Street | 1882 | 2407 | 0,78 | 2589 | 2407 | 1,08 |
| Çiftlik Street | 663 | 2579 | 0,26 | 2206 | 2579 | 0,86 |
| Fatih Street | 2968 | 1689 | 1,76 | 2187 | 2490 | 0,88 |
| Tıp Fakültesi Street | 810 | 2291 | 0,35 | 1596 | 2291 | 0,70 |
| Mamak Street | 1201 | 3315 | 0,36 | 1413 | 3315 | 0,43 |
| Kıbrıs Street | 793 | 1659 | 0,48 | 1372 | 1659 | 0,83 |
| Plevne Street | 1201 | 3115 | 0,39 | NA | | |
| TOTAL | 23883 | 34496 | | 43279 | 39681 | |

Source: 1985 values are obtained from EGO, 1987a and 2004 values are obtained from Greater Ankara Municipality, The Department of Public Works.

At the final stage of the study some predictions are carried out for 2010 in order to simulate traffic volumes and predict congestion. Zero case scenarios assume a continuation of current land use and socio economic trends, the expansion of urban areas and no additional investment in ground transportation infrastructure. The new speed and travel times are obtained from network assignment depending on the preliminary stages of the model.

According to zero case assumption transportation network (especially around city center) is expected to face hyper-congestion. Congested roads are shown in the figure above. Predictions showed that severe congestion problems are expected around city center. Hence in hyper-congestion case the network does not provide alternative feasible paths (See Figure 5.36 and Figure 5.37). Network performance (in terms of providing alternative routes) in congested networks is determined by characteristics of the road network; such as, robustness and network flexibility.

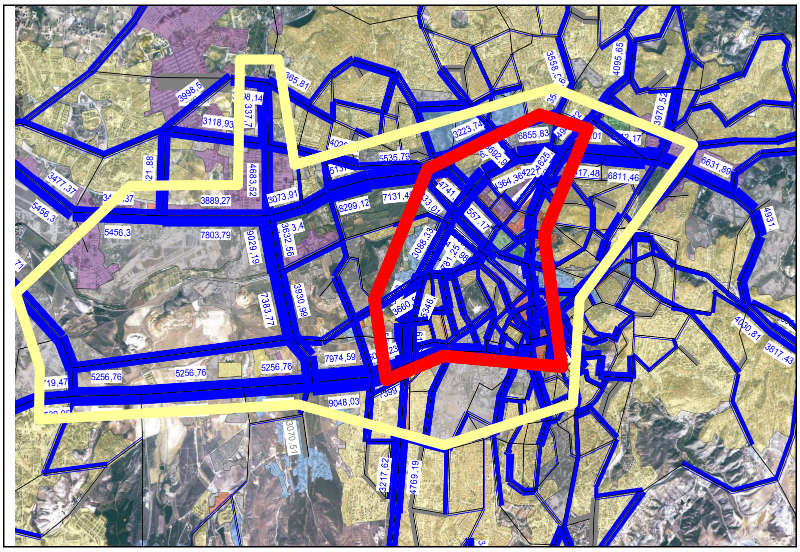


**Figure 5.36: Traffic volumes on the road network-2010 (zero case)**

The most substantive result specific to the city of Ankara is that even though priority was given to road transportation in the last decade congested region has expanded gradually and traffic problems are expected to rise unless land use and public transportation solutions are not employed. In Figure 5.37 the expansion of congested region between 1985 and 2010 (predicted) is presented.

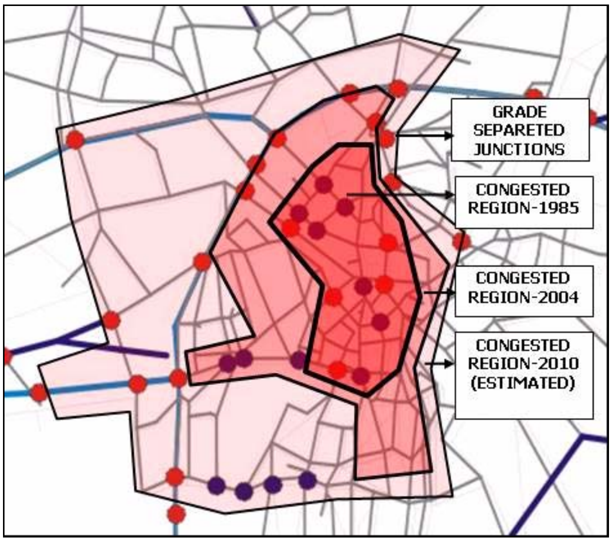



**Figure 5.37: Expansion of the Congested Region**

These are important issues in the city of Ankara and in other cities with similar characteristics both for policy planning and project design. Hence in order to overcome these problems a systematic approach, comprising multimodal and strategic planning methods, to transportation problems is necessary.

### 5.6. Research Outcomes

In Ankara; compared to other studies significant changes have emerged parallel to the rapid transformation of urban space. These factors have considerable influences on travel demand:

1. Urban development is in a lower degree than expected and it has not been decentralized as expected. The envisioned decentralization strategy includes workplace-residential proximity and low values in private vehicle trips with respect to the improvements in public transport infrastructure. In addition to this, the friction parameter in trip distribution was assumed to be fixed. This model has been updated for the year 2004 and gave respectively more realistic results. This model has been validated for year 2004 and it is estimated that friction factors have declined.

2. Despite the assumption vehicle trips would not increase rapidly, the share of vehicle trips has increased parallel to the increase in car ownerships. In addition, traffic volumes are more than expected. Proposed rail transit projects are not realized yet and this problem have significant role in the increasing share of vehicle trips.

3. It is assumed that the share of employment in the city center within total employment would decrease. In addition, low traffic volumes were expected around city center. However, the city center was developed through the northern and southern parts and it has not been decentralized yet.

Meyer and Miller (1984) and Salter and Hounsel (1996) stated likely problems of transportation planning and simulation models, which may result in successive errors. Following problems which were stated by the researchers are observed in the case study:

1. Due to errors in the determination of dependent variables for current state. Since ideal fit is usually not possible, using linear regressions may result in inaccurate or biased estimations. In this study this problem is stated as variability.

2. The assumption that the independent variables have incremental impacts on equations may result in biased estimations. In other words, future values may be outside of the range of existing values. Case study showed that such problems lea to accumulated parametric uncertainty.

3. The model's coefficients may not be stable over time that these values of the independent factors and coefficients are scattered in time. This problem is recognized as radical parametric variation.

4. The central problem emerges due to aggregate analysis that by using zonal averages, considerable socioeconomic variations within the zone may yield "spurious" results. This problem is widely referred in the literature and also observed in the Ankara case. For further information about stated problems see Meyer and Miller (1984), Salter and Hounsel (1996) and Zhao and Kockelman (2001).

Due to external and stochastic uncertainties, as in Ankara case, reliability of the IBI Model has weakened. According to Zhao and Kockelman (2001) stochastic errors in travel demand estimation arise from three sources; "inherent uncertainty", "input uncertainty", and "propagated uncertainty". They argued that "point" estimates of these modeling methods may be highly biased since uncertainty compounds due to sequential structure of four-staged travel demand model.

In this study, like in Zhao and Kockelman (2001) a multi-staged analysis is conducted in order to identify sources and types of uncertainty in travel demand. They investigated the stability of the contemporary transport demand model outputs by simulating a four-step travel demand model over a 25-zone network. They investigated different forms of uncertainty in a small town, with minimal a size of network and called for further studies on other possible forms of uncertainty. In the case study various types of uncertainty are identified and measured and it is understood that in the literature little attention is paid for uncertainty or limited studies have been conducted concerning this concept. This study provided a methodology of understanding, measuring and reducing uncertainty through traffic assignment models depending on preliminary stages of the conventional four stage model.

## 5.7. Recommendations

In this study travel demand analysis is regarded as a dynamic process which comprises of dynamic travel demand analysis (uninterrupted monitoring) that can be an integrated part of flexible traffic management. Here monitoring refers to uninterrupted analysis of travel demand in order to respond individual' behaviors. In the literature monitoring methods includes advanced traffic count methods and vehicle detection systems. This study suggests a broader context in which questionnaire surveys, traffic counts and predictions and model validation processes are essential components. In urban transportation planning process, monitoring has substantial role in the performances of modeling and planning proposals. Travel demand monitoring system consists of:

-Continuous flow of input data,

-Periodical assessment of impacts from external factors on travel behavior,

-Uninterrupted validation

-Periodical assessment of the impacts of network operations on planning goals.

Briefly, although, several models and solution algorithms have been developed and implemented in transportation planning traffic congestion is still a growing problem in most cities in the world due to its uncontrolled growth. Recently developing an appropriate policy and method to cope with congestion has become the primary goal of transportation planners. In addition in order to implement these methods effectively, transportation network should provide opportunities and flexibility in terms of physical capacity and traffic management measures. Therefore, great emphasis is necessary for the appropriate design and development of transportation network. Further studies motivated around this problem will have sound contribution to the field of transportation planning.

Hence travel demand models need to have dynamic properties in terms of flexibility, adaptability and responsiveness (Peeta and Ziliaskopoulos, 2001). Flexibility refers to providing possible travel demand variations. This principle implies probabilistic approaches. Responsiveness (Peeta and Ziliaskopoulos, 2001) implies including various factors in the representation of travelers' behaviors like actual travel speeds and on-street parking. Furthermore, as in Ankara case taxis and service vehicles are not represented in traffic assignment models. In addition, temporal changes in traffic flow in response to urban development, network improvement and facility location need to be accounted through modeling.

According to Litman (1999) "induced traffic" and "diverted traffic" shall be encountered and measured in travel demand estimation methods. Induced traffic is beyond the scope of this study, however in trip generation stage and in the following stages it is necessary to estimate induced traffic. Such feedbacks are necessary to obtain accurate simulation results.

In this study a family of approaches is provided to cope with uncertainty in transportation planning. In this manner dynamic simulation as an essential component of network planning is recommended to cope with uncertainty in various stages of transportation planning. This procedure comprises four methods:

1-Measure uncertainty: Dynamic travel demand monitoring
2-Reduce uncertainty: Dynamic travel demand simulation
3-Predict uncertainty: Probabilistic demand simulation methods
4-Manage uncertainty: Scenario analysis, flexible network operations and design (Adapted from van Greenhuizen and Nijkamp, 2003)

Measurement and reduction strategies involve statistical analysis methods (i.e. sensitivity analysis) and validation checks. In Figure 5.38 recommended procedure is presented. One of the main concerns is the improvement of prediction methods under uncertain traveler demand conditions. This process differs from than static modeling procedures and requires integrated analysis of travel demand:

1-Uninterrupted information flow (input data)
2-Uninterrupted monitoring
3-Instantaneous simulation
4-Continuous validation and feedback in simulation process and
5-Instantaneous impact assessment and feedback in planning process.

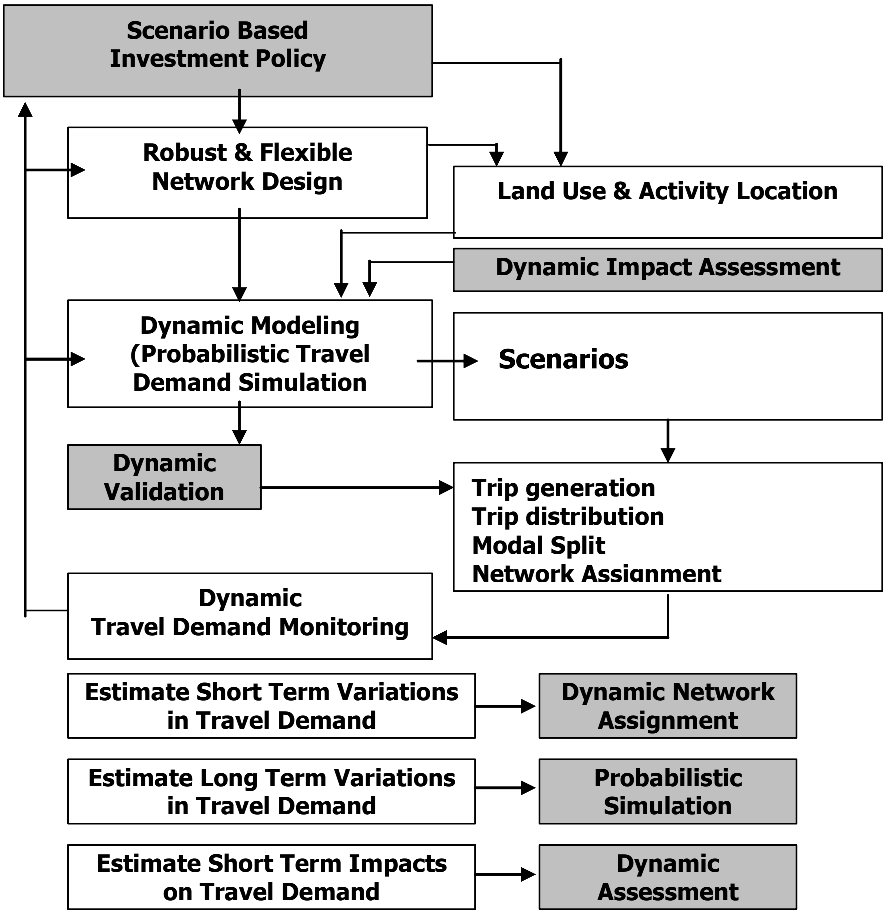



**Figure 5.38: Components of Dynamic Travel Demand Estimation and Transportation Planning Process**

This process is essential in order to improve the performance of the traffic estimation models and transportation network can be efficiently utilized by means of traffic management. Hence an integrated approach to travel demand simulation and efficient use of road network is necessary. In Ankara the road network within the vicinity of the city center is hard to intervene because of the concentrated built up area.

Parking problems and the increasing traffic flow causes city center to decline. However; there is no efficient progress about the alternative development areas for the city center. Hence; the speed of dispersion at the shopping malls and office centers which were not estimated is increasing. Besides, locations of urban activities lead to the short term changes in the physical infrastructure are resulting in problems which are difficult to estimate.

Thus a dynamic estimation procedure, as a part of short term planning strategies, is suggested to ensure the effectiveness of the transportation planning.

In this study, network flexibility is recognized as another essential component of traffic management. Since transportation networks have reflective effects on travel patterns network flexibility is perceived as a significant factor in determining the relative importance of a network in traffic flow. Case study analysis showed that network structure does not provide adequately alternative routes in the case of congestion.

This study put emphasis on the fact that dynamic network assignment models can be relevant as far as the road network provides alternative routes. Therefore the relevance of these models is also dependent on network structure. Network performance in congested networks is determined by characteristics of road network; i.e, robustness and network flexibility. Network flexibility is measured by some parameters; such as openness; while robustness is measured by network density, connectivity and other similar indexes. This study emphasizes the role of flexibility in urban transportation planning in the following dimensions:

1-Flexibility in proposals (a range of possible outputs may be provided),
2-Flexible definition of planning horizon (case specific),
3-Flexible model structure (feedback analysis and probabilistic estimations), and
4-Flexibility in network design and traffic management.

When the concept of flexibility is underemphasized in urban transportation planning it is hard to reduce uncertainty. Travel demand monitoring and dynamic simulation procedures are recommended in order to evaluate transportation and land use projects. The objectives of the component are as follows:

1. Measuring and estimating possible impacts of land use, activity location and transportation projects on individuals' travel behavior,
2. Measuring benefits and adverse effects of transportation network improvement projects,
3. Measuring possible impacts of major commercial and residential projects,

4. Estimating possible benefits of traffic management and advanced traffic control systems which aim improving the performance of the existing road system.

In addition transportation network characteristics have significant affects on travel patterns. Litman (1999) and Lee et al (1999) stated that due to increased capacity traffic may be shifted from congested links to less capacitated ones. This argument suggests that if total capacity of the network is not sufficient, advanced controlling and operational methods are necessary. These methods include setting priority on peripheral parts of the city center, installing intelligent route guidance systems, ramp metering, and setting temporal management measures.

The recommended procedure provides necessary information in order to assess possible impacts of traffic management schemes. In the case of less flexible transportation networks, traffic management may provide significant solutions. Case study showed that there are some limitations in the current road transportation structure of Ankara:

1. Commercial activities are mainly concentrated in two portions of the city center; however there are limited access roads to city center that trips attracted by city center are dramatically increasing.

2. There are so many one way streets around city center that alternative access routes to city center are limited.

Due to these limitations network flexibility and traffic management strategies need to be integrated in a complementary system. Taking into account these factor and problems in transportation planning process dynamic simulation process can help professionals in order to cope with uncertainty.

Literature survey and case study analysis showed that most of the methods and algorithms developed by researchers are based on shortest path algorithms and these dynamic assignment methods are mostly tested on hypothetic networks. Some of them are applied in real networks but there is no direction for long term network planning in order to cope with uncertainty. Hence appropriate models are necessary to be applied in a range of stated problems in terms of spatiality and temporality (See table 5.22).

**Table 5.22: Spatial and Temporal Dimensions of Travel Demand Simulation Models and Strategies**

| Time horizon<br>Type of urban network | Long term | Medium term | Short term |
|---|---|---|---|
| **Small with/without congestion** | Static-sequential, | Dynamic (Behavioral), disaggregated, | Dynamic (Behavioral), disaggregated, |
| **Large without congestion** | Static-combined | Dynamic (combined) | Dynamic (combined) |
| **Large with congestion** | Flexible and probabilistic models, flexible investment strategies | Under construction (behavioral) | Under construction (behavioral) probabilistic, |
| **Large without congestion but transforming** | Flexible models, flexible investment strategies | Need and flexible models | Need multi-criteria analysis |
| **Large with congestion and transforming** | Need more complicated flexible and probabilistic models, flexible investment strategies | Need more complicated and flexible models | Need multi-criteria analysis in dynamic models |

Adopted from Bell and Shield (1997) and revised by the author.

In the case study model application showed that dynamic assignment models are more reliable than static models to represent short term travel behavior. However, further research motivated around improving whole structure of four staged model is necessary in order to predict long term travel demand.

## 5.7. Concluding Remarks

Case study analysis showed that due to urban growth and socio economic development travel demand has increased gradually. Besides, urban growth pattern and transportation investments differ from those that envisioned in Ankara Transportation Study in 1985. Hence, under dynamic urban development patterns predicting benefits and impacts of major transportation projects may be problematic. Hence, dynamic travel demand simulation is necessary to assess impacts of service provision, land use planning and major transportation projects on urban traffic.

The research showed that, as stated in the literature, with typical (static) current modeling practice traffic volumes are underestimated. The clearest conclusion is that IBI Model, developed in Ankara Transportation Study in 1985, is incapable of providing accurate predictions for 2004 and differences of a few percent in one stage are meaningful since they are accumulated at the final stage. Even though the results of the separate stages seem reasonable planners cannot feel comfortable with those models that do not take into account dynamic patterns of individuals' travel behavior. In this study with respect to model comparisons, specific results are as follows:

1. IBI Model, which was developed in 1985 in order to predict travel demand for 1995, 2005 and 2015, is less reliable in forecasting the actual traffic volumes for 2004.

2. Validated IBI Model, in which input data are updated and model parameters are estimated by probabilistic method, gives relatively more reliable results.

3. Compared to first two stages the validated IBI Model with dynamic traffic assignment component gives more reliable results. This model, which is also based on probabilistic assumption, provides a set of scenario based outputs.

4. When static and dynamic models are compared in terms of traffic volume estimation, the dynamic model provides more accurate results.

The research showed that central links are loaded up to capacity levels. Taking into account this fact dynamic model tends to allocate vehicle trips on less congested streets whereas in static model central links are assigned with higher traffic volumes. Even though dynamic traffic assignment model provided reliable outputs in these models a fixed origin destination matrix is assumed to represent actual travel pattern. However, an increase in total travel demand leads to biased predictions.

Briefly, there is uncertainty associated with the estimated or predicted travel demand and a measure of the uncertainty can be obtained from the validated model. These problems showed that monitoring travel pattern (understanding and predicting individuals' behavior) is an essential task in order to improve reliability of dynamic simulation models. In this study travel demand forecasting is recognized as an uninterrupted process. This ensures that a dynamic transportation planning method comprising of a dynamic simulation model can respond to the travel demand that is always changing.

# CHAPTER 7

# CONCLUSIONS

The purpose of the study was to investigate the relevance of dynamic traffic assignment models under uncertainty in the Ankara case. In Ankara, parallel to rapid transformation of urban space, substantial modifications have been made in the transportation network. Car ownership rate and travel demand are continuously rising, and proposed public transport facilities are not been fully implemented yet. These factors have considerable influences on the properties of travel demand, and in spite of major road improvement projects, they have not been effective to reduce traffic congestion.

Literature survey showed that in the major cities of the world, economic growth and urban sprawl led to increasing rates of car usage; hence traffic congestion and similar problems reached dramatic levels. Such problems lead to the degradation of the urban environment and have considerable impacts on individuals' life quality. Recently, advanced traffic control systems and intelligent transportation systems, in which dynamic assignment models are applied, are considered as promising ways to relieve traffic problems. In this study a dynamic traffic assignment model is performed in order to prove its relative advantages compared to static assignment.

Research outcomes showed that traffic assignment is substantially dependent on trip distribution. Accumulation of uncertainty reduces model performance and causes significant deviations in traffic flow predictions. After examining previous planning experiences in Ankara, it is argued that existing transportation master plan (1985 – revised in 1992) and its simulation model need revisions due to considerable deviations between estimated and actual travel demand.

The research mainly focused on network assignment and it is observed that mere dynamic traffic assignment model would not be capable of obtaining significant results as the city has a dynamic structure. In addition, it is argued that biased estimations have considerable impacts on model performance. In this framework, preliminary stages of the model - trip generation, trip distribution and modal split were also operated. Research outcomes suggested that in order to obtain accurate predictions of traffic flows it is necessary to identify and reduce uncertainty through sequential stages.

Statistical measurement tools are used to quantify effects of uncertainty through sequential stages of travel demand estimation model. The examination of travel demand simulation model developed in Ankara Transportation Study in 1985, showed that four different sources of uncertainty weaken reliability of the model:

1. Uncertainty in Travel Demand Model: The analysis showed very high percentage of deviation between actual travel demand and base year estimates (due to the static nature of the model).

- Uncertainty in parameters referring to the differences between the estimated values and those of the current state are at significant levels. Insufficient number of parameters and deviations in parameters are likely factors of uncertainty. Especially regression parameters, friction factors and travel cost parameters showed substantial variations which were not predicted in Ankara Transportation Study in 1985.

- Uncertainty in input data referring to variations in model inputs; such as, demographic variables, network data and land use variables has significant impacts on model performance. In the Ankara case the differences between the base year estimation and the target year were considerable.

- Uncertainty in Model Structure, as frequently stated in the literature, results in accumulation of uncertainty through model sequences. Literature survey and case study analysis showed that although sequential model is widely used in practice, the structure of the model needs improvement in order to represent complexity of the issue of travel. In this study specific problems of model structure are sought; such as reduction of errors at the final stage of the model. Unlike propagation of errors, this problem emerges due to the reciprocal decrease of the errors through sequential stages of the model.

Specifically, overestimation in one stage reduces underestimation errors in previous stages. n addition to uncertainty through model stages following external factors have considerable impacts on model performance and planning objectives:

2. Permanent (epistemic) Uncertainty: Due to the complexity of urban travel, the source of uncertainty may not sometimes be identified. Although dynamic assignment model provided significant outcomes it was not able to eliminate all estimation errors. These errors can be generated by either external or internal factors. It is argued that behavioral models have substantial contributions to the field of transportation planning.

3. Uncertainty in Transportation Policy**:** The periodical amendments in transportation policy have considerable effects on planning objectives. The effectiveness of planning is being reduced through this process.

4. Uncertainty in Programming: Project implementation process that was not foreseen in the planning period has changed. Instead of public transportation facilities, at present more attention is paid for road transportation. This factor has restricted achieving previously defined goals.

Research outcomes showed that an aggregate sum of uncertainties is found in the previously defined four categories. Thus; a static approach of planning is inevitably ineffective under uncertainty. In this study problems of the model are mainly addressed to external factors. Hence planning methodology and scope need consecutive revisions. In this study major sources of uncertainty are identified. It has not been possible however, to measure all types of uncertainty through model structure and transportation planning. The research suggests that further investigation is necessary to reduce uncertainty; such as, developing complex model algorithms, model validation methods and monitoring strategies.

After uncertainty analysis, IBI Model 1985 is validated in order to reduce uncertainty and obtain reliable estimations for traffic volumes. Validation process is carried out in three stages: input data are updated, model parameters are updated and estimation procedure is repeated. Then both static and dynamic traffic assignment methods are employed in order to determine relative advantages and breakdowns of these models in a transforming and congested network. Case study analysis showed that dynamic network assignment methods give significantly better results in estimating traffic volumes provided that travel demand model (four staged model) is validated.

In the first stage of model application considerable estimation errors were observed in predicting traffic volumes; percentile root square error was more than 26%. These errors originated from different types of uncertainties which are accumulated in the previous stages of the model.

In the second stage, demographic and land use variables were obtained from census data and municipal records and these variables were updated for the years 2002 and 2004. Then traffic flow estimation is carried out for the year 2004 (short term). In this stage, structure of the IBI Model was kept validated in order to obtain traffic estimates of the static assignment method. Application of validated IBI Model provided more consistent outcomes when compared to those of the previous works (1985 and 1992). It is recognized that, although the internal structure of the model used in 1985 did not result in enormous errors; the existing errors were due to input data; such as, population and employment distribution and transportation network properties.

When the outputs of the validated IBI Model with static assignment component were compared with actual traffic volumes; the outcomes were observed to be more compatible with the state than the first stage. However; the percentile root mean square error (15%) could not be eliminated.

In the third stage of model application, a dynamic traffic assignment algorithm was integrated into the model structure replacing the static assignment model. In dynamic traffic assignment methods, allocation of trips on the underlying network is more sensitive to congestion and a time-dependent calculation process is incorporated. It is assumed that road capacities change in congestion and these instant changes are encountered in the shortest path analysis. The model employed in this study is developed under the assumption that both travel time and distance as disutility factors have significant impacts on individuals' route choice.

Outcomes of the dynamic traffic assignment model reasonably fit the observed traffic volumes; percentile root mean square has been reduced to 7.22%. Percent errors vary between -15% and 8% for specified link groups.

When short run variations of travel demand in the transforming network of Ankara are examined, significant differences are observed between dynamic and static network assignment models in predicting traffic flow. It is obvious that efficient use of capital resources requires sensitive analysis of travel demand.

Research findings showed that dynamic traffic assignment model, which is developed in a manner that time dependent estimation is necessary to respond actual traffic flow, gives more accurate results than the static model. In those cases the configuration of the network has significant role in allocation of traffic volumes. It is observed that grade separated junctions, which are not able to relieve congestion, have weakened network flexibility. Adopting advanced traffic control systems, route guidance and dynamic traffic management systems can be effective strategies to cope with increasing congestion in Ankara which have a transforming network.

When long term variations of travel demand are concerned significant differences are not observed between dynamic and static network assignment models to predict traffic flow. Unsurprisingly both models fail to predict long run travel patterns due to external factors. Network assignment stage is highly dependent on trip distribution and reliability of assignment model is weakened due to accumulated uncertainty through sequential stages. As far as validated model is concerned, more accurate estimates are obtained by employing dynamic assignment model. Hence difficulties in long run predictions also weaken reliability of short term solutions. Instantaneous validation of the demand model is regarded as an essential strategy to cope with uncertainty which rises in transforming networks dramatically.

This research suggests that travel demand analysis, model validation, and prediction of traffic flow shall be an uninterrupted process which is necessary to enhance reliability of models. In this process scenario analysis and probability analysis have crucial roles. Travel demand monitoring process in transportation planning is essential since any model that is "reliable" in the current state does not guarantee accurate forecasting in the future. Conventionally in transportation planning either short term or long term proposals depends on predetermined assumptions; however, in dynamic urban environments it is necessary to take into account possible effects of external factors.

The objective of this study was to investigate possible strategies to cope with uncertainty in travel demand. In addition, this study provided a framework for traffic assignment methods. In this respect; a dynamic modeling method is compared with a static model according to predictive capabilities. In addition, the advantages and disadvantages of both approaches are examined in the city of Ankara where the transportation demand shows fundamental variations.

This study suggests that dynamic assignment algorithm can be applied in a broader context, that a dynamic travel demand estimation procedure can be developed in a manner that flexible prediction methods can be involved in long term planning studies. The concept of flexibility can be applied in various stages of planning, but such attempts were beyond the scope of this study. In addition, inspired by dynamic assignment models a holistic simulation procedure can be developed. That procedure can be based on the probabilistic approach and takes into account possible variations in travel demand rather than precise estimates. This study suggests that further research is necessary to improve travel demand models and investigate planning strategies. Further studies on dynamic prediction methods and traffic control systems to be applied in the cities of developing countries will have sound contributions to urban transportation planning.

It is observed that, transportation planning studies conducted in the last two decades have substantial contributions to transportation policy in the city of Ankara. However, the planned rail systems were not to be constructed till the 1990s. On the other hand several road improvement projects that were not envisioned in the transportation plan were realized. Among them grade separated junctions were regarded as single solutions to congestion. Similar unforeseen decisions and increasing travel demand have significant effects on the performance of the transportation system.

The dynamic structure of urban development in Ankara as a result of dramatic increases in vehicle trips; requires efficient use of road space rather than extensive road provision. One of the recommendations for planning practice is to stress the importance of the integration of the traffic management methods with transportation studies which are usually motivated around public transportation projects.

Urban transportation planning methods and planning techniques have changed in the last four decades in response to changing spatial and socio-economic structure of cities.

Static understanding of urban transportation experience has evolved into a problem based, specialized, and more dynamic process. Compared to the earlier stages of this field, researchers deal with specific and complex models. Besides professionals seek more effective techniques which are motivated around contemporary issues.

In the last decades, new issues and concerns, methodological developments, advances in technology are integrated to this field and more attention is given to short-term traffic management systems and site specific solutions. Disaggregate models, dynamic assignment models, neural network based models have been developed. This study showed that, static models have limited capability to predict long term variations. However, a substantial appropriate method has not been developed yet, in order to accurately predict long term travel demand variations in dynamic and transforming cities.

In the conventional long range transportation plans, transportation service and infrastructure improvement proposals are developed. Such kinds of proposals are expected to be implemented in an orderly and efficient manner. However, static planning methods, which incorporate modeling methods, may not respond to continuously varying external factors which have significant impacts on the performance of transportation system. It is argued that uncertainty reduce efficiency in the provision of the transportation infrastructure. Hence, long term planning methods depending on static travel demand models are not proper tools of planning in transforming cities.

There are various studies and models held on the use of advanced estimation techniques and the intelligent transportation systems for the reduction in transport costs. However; the use of the dynamic transportation assignment and the application of the intelligent transportation systems do not provide long term solutions in the cities which are having rapid and important changes in the issues of land use, the transportation infrastructure, the model inputs and the parameters.

Dynamic travel demand prediction procedures can be developed in order to analyze and predict traffic flow and develop strategies to respond dynamic and uncertain nature of individuals' travel demand. In the case study it is found that Ankara as a dynamic city has experienced spatial, social and economic transformations. These changes may result in increasing rates of travel demand and variations in travel behavior that cannot be predicted in static procedures. The recommended procedure aims at providing necessary information which is essential in transportation planning process. Dynamic models aim at responding instantaneous variations in travel demand. Hence the scope and purpose of traffic estimation in this study is not reduced to dynamic traffic assignment models that are developed in order to predict short term variations in individuals' route choice in response to congestion.

Further studies on dynamic estimation models inspired by dynamic traffic assignment will have sound contributions to the field of transportation planning. This study does not suggest a specific model, but investigates deficiencies of model structures and provides an alternative modeling approach to be applied in transforming networks.

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## APPENDIX A

## LITERATURE SUMARY

### Table 7.1: Research on Urban Travel Demand

| **Urban Travel Demand Analysis** | | | |
|---|---|---|---|
| Authors | Description | Model | Result / peculiarity |
| Bagley M. N. and P.L. Mokhtarian, 2001. | This paper examines the relationship between residential neighborhood type and travel behavior incorporating attitudinal, demographic and life-style variable. | System of structural equations | When attitudinal, socio-demographic and life-style variable are accounted for, neighborhood type has little influence on travel behavior. |
| Crane R. 2000 | The basis for using land use and urban form is to selectively change travel behavior | Categorizing research. | Current understanding of this complex group of relationships remains tentative. |
| Ewing R. Richard A., Schieber, MD, and C.V. Zegeer 2003 | It is sought to determine the association between urban sprawl and traffic fatalities. | Creating a sprawl index | Regression analysis is used to determine associations between the index and traffic fatalities. |
| Handy S. 1996 | The paper explores how the automobile has directly led to dramatic changes in patterns of accessibility to retail and service activity within metropolitan region. | | Access to retail activity is dependent on the automobile but vulnerable to increasing levels of congestion that are driven by dependence on the automobile. |
| Williams, H.C.W.L. 1977 | The aim of this work is to extend the method of user benefit analysis considering the direct integration of consumer surplus in a non marginal calculation when demand is projected in a singly constrained gravity model. | Micro-economic models of travel demand: user benefit analysis. | A set of measures which can be used to assess the relative benefit of different combinations of land use configuration and transport networks, is considered. Throughout, the emphasis is on the development of an operational methodology. |
| Boarnet M. G. and S. Sarmiento 1998 | This paper reproduce the research on non-work automobile trip generation and land-use | Impact analysis | The results suggest that any links between land use and non-work trip behavior act primarily on influencing trip costs, in terms of distances traveled and speeds achieved, rather than directly influencing the number of trips made. |
| | | | |

**Table 7.1 continued**

| | | | |
|---|---|---|---|
| Authors | Description | Model | Result / peculiarity |
| | | | |
| Cervero R. 2001 | This research challenges past results by employing a path model to casually sort out links between freeway investments and traffic increases. | Path model | It reveals significant 'induced growth' and 'induced investment' effects while real estate development has gravitated to improved freeways corridor and road investments have been shaped by traffic investment in California. |
| Purvis C. L. 2005 | This analysis discusses the importance of "disaggregate validation" of models to test for statistical difference in travel models that include or exclude these variables. | Travel Demand Model | Neighborhood land use density variables and accessibility variables are shown to improve the performance of trip-based travel demand models. |

**Table 7.2: Research on Network Assignment**

| **Network Assignment** | | | |
|---|---|---|---|
| Authors | Description | Model | Result / peculiarity |
| Ben-Akiva M. E. Koutsopoulos H. N. Mishalani Qi R. Yang G. 1997 | This paper presents a simulation laboratory for performance evaluation and design refinement of dynamic traffic management systems. | Object-oriented programming | The modeling system used provides a unique tool for evaluating integrated ATIS and ATMS applications in computer-based laboratory environment. |
| Ben-Akiva M. De Palma, A. Kanaroglou P. 1986 | The paper develops a dynamic model of peak period traffic congestion that considers a limited number of bottlenecks. The model is predicting temporal distribution of traffic volumes with an elastic demand model. | An elastic demand model. | The results demonstrate the response of the traffic conditions at the bottlenecks by a change in system. |
| Boyce D. E. Lee D-H., Janson B. N. and S. Berka 1997 | The dynamic route choice model employed in this paper is solved efficiently by a modified version of Janson's DYMOD algorithm. | Dynamic Network Equilibrium Model | Convergence and computational results are presented and analyzed. |
| Levinson D. 2003 | This paper analyzes systems that provide the driver the fastest path between his or her current location and final destination, updated in real-time to consider recurring and nonrecurring congestion. | in-vehicle navigation systems | Simulation results indicate that typical information benefits are at a maximum on the high levels of congestion. |
| | | | |

| **Table 7.2 continued** | | | |
|---|---|---|---|
| Lozano A. Storchi G. 2002 | In this work both the multimodal hyper-graph and the viable hyper-path conceptualizations are presented. The shortest viable hyper-path problem (SVHP) in a multimodal transportation network is defined. | multimodal transportation network | An application example on a multimodal network is presented. |
| Hasan, M. K. Safwat K. N. 2000 | The objective of this paper is to compare the simultaneous approach using a Simultaneous Transportation Equilibrium Model (STEM) and the conventional sequential approach using the Texas Demand Model. | Simultaneous Transportation Equilibrium Model (STEM) | The application results showed that predictions of STEM were consistently better than those of the TxDOT by an average improvement of 25%. |
| Yang, H. Huang H-J. 2004 | This paper examines system optimality problem in a network with a discrete set of VOTs for several user classes. | the multi-criteria or the cost versus-time network equilibrium | There is a possibility of uniform link tolls across all individuals that can support a multi-class user equilibrium flow pattern as a system optimum when the system objective function is measured by either money or time units. |
| Peeta S. Zialaskopoulos A. 2001 | This paper will summarize the current understanding of DTA, review the existing literature. | Dynamic Traffic Assessment (DTA) | Connection to the approaches presented and attempt to hypothesize about the future. |
| Vlahogianni E. I. Golias J.C. And Karlaftis M. G. 2004 | This field of research was examined by disaggregating the process of developing short-term traffic forecasting algorithms into three essential clusters. | Short-term traffic forecasting models | A critical discussion clarifies several interactions between the results in a logical flow that can be used as a framework for developing short-term traffic forecasting models. |
| Bard J. F. Kontoravdis G. Yu G. 2002 | This paper addresses the problem of finding the minimum number of vehicles required to visit a set of nodes subject to time window and capacity constraints. | Linear programming (LP) relaxation | A new approach for obtaining feasible solutions from the LP relaxation is also discussed. Numerical results for standard 50- and 100-node benchmark problems are reported. |

### Table 7.3: Research on Network Structure, Assignment and Design

| **Network Structure, Assignment and Design** | | | |
|---|---|---|---|
| Authors | Description | Model | Result / peculiarity |
| Huang D.<br>Zhao K. 2004 | This paper constructs a fuzzy network planning method that have three different sets of critical paths instead of only one critical path obtained by traditional methods. | Transportation network planning technique, | The illustrating examples given in this paper indicate that the new method can provide more useful information for the finish time forecasting and controlling of a project. |
| Xiong Y.<br>Schnider J. B. 1995 | This paper presents a method for doing constraint processing within a cumulative genetic algorithm. | Constraint processing method and optimization process. | This study shows that the cumulative genetic algorithm, which employs a neural network, works very well in processing the constraints. |
| Ge Y. E.<br>Zhang H. M.<br>Lam W. H. K. 2003 | This paper provides a hierarchical framework for studying the impact of traveler information on network reserve capacity. | A genetic algorithm-based solution method. | Numerical results indicate that the reserve capacity of a road network does not increase monotonically with the increase of information level. |
| Chien, S.<br>Schonfeld, P. 1997 | The model presented here shows how an optimization approach can be successful without oversimplification of the spatial characteristics and demand pattern of urban areas. | Sequential optimization process | Network characteristics and operating headways that minimize the total cost, including supplier and user costs are found. |
| Hsu R. 2002 | By assuming fictitious observations made on the constraints, the pseudo observation-equation is formed and then solved according to the least-squares principle. | Theil model | The proposed method results in a smaller matrix dimension for the corresponding pseudo-normal equation. |
| Lo, H. K.<br>W.Y. Szeto. 2003 | This study develops a single-level optimization program to design the network improvements over time and to study the tradeoff among these parties for a range of budget values | A single-level optimization program | Three numerical studies of a small network are provided to illustrate the equity issues among users and among private toll road operators, and the cost-effectiveness of the design from the government perspective. |
| Lo H.K. and Y-K.Tung 2003 | This study developed an approach to model network performance when its link capacities are subject to stochastic degradations. | Probabilistic user equilibrium (encounter travel time variability) | The results showed that the formulation can be used to analyze existing networks or to improve them by link capacity modifications. |
| | | | |

| **Table 7.3 continued** | | | |
|---|---|---|---|
| De Lotto, R. D. Ferrara A. 2002 | The aim of this paper is to formulate a transportation network model conceived as a basis of possible tools to approach location problems in an urban context. | A static representation of transportation network. | Different related results, such as the minimum path matrix and the induced traffic in each link of the network can be retrieved. |
| Lin F. Sayed T. Deleur P. 2003 | The evolution of the information system for estimating crash reductions a description of current and future enhancements, and the applications for a road safety-engineering tool | Safety analysis software | The system determines the expected CRFs and the range and reliability associated with a safety improvement at a specific location. |
| Easa S. M. Strauss T. R. Hassan Y. Souleyrette R. R 2002 | This paper presents a state-of-the-art review of recent developments in three-dimensional analysis for transportation planning and highway design. | 3D analysis in transportation planning design operation and management | Summarizing current and emerging developments of 3D analysis in transportation. |
| Trietsch D. 1987 | In this paper, the consequence to "A Family of Method for Preliminary Highway Alignment" the results from the latter, in addition to some network design models which include locating road junctions are applied. | A Family of Methods for Preliminary Highway Alignment | Satisfying given bilateral transportation demands at minimal total cost. |
| Feitelson E., Salomon I. 2000 | This paper suggests that in a multi-network setting, network flexibility is a significant factor in determining the relative importance of a network for the organization of space. | network flexibility | Emerging map is more differentiated than the current one, changing the trend of that prevailed during the last fifty years toward greater equalization of space. |

**Table 7.4: Research on Uncertainty in Transportation Planning**

| Authors | Description | Model | Result / peculiarity |
|---|---|---|---|
| Silva E. A. 2002 | This paper presents the fact that uncertainty, associated with indecision, in locating major infrastructure hubs constrains individual actions according to governments' perceived powers. | Decision making process: uncertainty of preferences | The data is contrasted with urban and regional plans to verify if indeed indecision associated with the location of a major airport was an important factor in speeding up land consumption. |
| Van Geenhuizen M. Nıjkamp P. 2003 | This article maps uncertainty surrounding new transport technology and identifies two specific strategies to deal with uncertainty in policy making. | interactive technology watching and experimentation in the market | The findings are ustrated with electric vehicles. The paper concludes with a discussion of success factors that influence the outcomes of such strategies. |
| Batabyal A. A. 2000 | In this study, the Arrow-Fisher-Henry (AFH) analysis of land development under uncertainty has been conducted. An optimal land use development approach is investigated. | optimal decision rule in urban economics | They investigated a probabilistic comparison of the revenue obtainable from accepting a specific offer, i.e., developing now, with the revenue to be obtained by preserving now and developing later. |
| Zhao Y. and K.M.Kockelman 2001 | This work investigates the stability of contemporary transport demand model outputs by quantifying the variability in model inputs. | Sensitivity analysis and Monte Carlo Simulation. | The results of this work suggest that uncertainty is somewhat compounded over the four stages of the travel demand model. Mispredictions at early stages of the multi-stage model appear to be amplified across later stages. |
| Pradhan A. Kockelman K. M. 2002 | This study examines the impact of uncertainty in the land use component of a partially integrated and use-transportation modeling and propagation of uncertainty across model stages as well as at each model stage. | Variation analysis, Monte Carlo Simulation | The results suggest that while several model inputs may affect model outputs in the short run, only those inputs that have a cumulative effect are likely to have a significant impact on outputs in the long run: error propagation. |
| Amekudzi A.and S. McNeil 2000 | This paper develops a computer simulation approach to explore the effects of data and model uncertainties on highway performance estimation. | Highway Economic Requirements System | The results of this case study indicate that highway performance estimates may be as much influenced by changes in the input data as by the modeling approach, between instances of information development and provision. |
| Eustache, D., Russell, E., R., Landman, E., D. 2003 | In this paper it is argued that robustness analysis can be successfully used in urban transportation planning in conjunction with urban travel demand software | robustness analysis | The results indicate that the method is simple to understand, and provides the flexibility required in typical urban planning problems where decision making is needed to be taken under conditions of uncertainty. |

## **Table 7.5: Research on Traffic Flow**

| **Traffic Flow** | | | |
|---|---|---|---|
| Authors | Description | Model | Result / peculiarity |
| Akçelik R. 1991 | This paper presents a time-dependent form of the original Davidson function, derived using the coordinate transformation technique. | time-dependent form of the original Davidson function | The new travel time function given in this paper could overcome various problems with Davidson's function. |
| Akçelik R. 2003 | The purpose of this exercise was to adopt the HCM 2000 Level of Service method in aaSIDRA. | Speed-Flow Models | These allow for comparison with the speed-flow models for multilane highways. Speed-flow models for the running time component of the HCM urban street classes derived using Akçelik's speed-flow function have been provided. |
| Parthasarathi, P. Levinson, D.M. Karamalaputi, R. 2003 | This paper investigates induced demand hypothesis using a disaggregate approach at the link level. A model that predicts the traffic flow on the link based on the flow and capacity conditions is used. | A disaggregate approach of traffic flow prediction. | The results indicate that capacity enhancements in the previous years, given by lane additions, have a positive and significant effect on the vehicle kilometers traveled of the link, confirming the induced demand hypothesis |
| Tang; Y. F. William H. K. Lam, M.A.; Pan L. P. N, 2003 | In this study, time series, neural network, nonparametric regression, and Gaussian maximum likelihood GML methods are tested in AADT Forecasting in Hong Kong. | neural network, | These methods were adapted to develop four models for short-term prediction of the daily traffic flows by day of week and by month, as well as the AADT for the whole current year. |
| Nagel K. 2002 | This study presents computational of a stochastic car following model. | Probabilistic traffic flow model | By changing one of its parameters, model can be moved from having two phases (laminar and jammed) to having only one phase. |
| Nesterov,Y. 1998 | In this paper a new theory of static equilibrium in congested transportation networks is developed. | Equilibrium | Authors introduce a concept of the stable equilibrium and prove the existence theorems. |
| Jost D. and K.Nagel 2002 | This paper presents computational evidence that a stochastic car following model, by changing one of its parameters, can be moved from having two phases (laminar and jammed) to having only one phase. | Stochastic car following model | Having a stochastic model is important to understand the potentially probabilistic nature of the transition. |

| | | | |
|---|---|---|---|
| **Table 7.5 continued** | | | |
| | | | |
| Nagel, K. Rasmussen, S. and C.L.Barrett 1996 | This paper presents an overview of an approach to address complexity issues and real-life engineering problems in large, urban transportation systems. | Introduction of a traffic management system for unpredictable traffic dynamics. | Traffic management can indeed make traffic more efficient, but may in addition lead to higher fluctuations and, as a consequence, lower predictability, since the system is driven closer to capacity and thus to criticality. |
| Nesterov Y. 1998 | This paper develops a new theory of static equilibrium in congested transportation networks. | Stable flows | Considerations are based on a physical meaning of the flows rather than on an artificially chosen model of travel time functions. |
| Johnston, R. A. Lund, J. R. and P. P. Craig 1995 | In this paper, recommendations are made regarding capacity-allocation measures with potential to reduce congestion and to increase economic efficiency. | Methods for mitigating equity impacts. | The equity impacts of capacity allocation measures are identified. |
| Kockelman. K. M. 2000 | This research investigates freeway-flow impacts of different traveler types by specifying and applying a mixture model of congested and uncongested driving behaviors. | Driver behavior | Results indicate that mixture models are promising tools for traffic data analysis and that information on travelers, their vehicles, and weather conditions explains significant variation in flow data. |
| Hellinga, B.R. and L. Fu 2002 | This paper proposes a methodology for reducing the effect of this bias. The method, requires that vehicle count data be obtained from an in-road loop detector or other traffic surveillance method. | Stratified sampling technique | The results for the single intersection approach indicate a low correlation between the biased estimate and the population mean and an improved correlation between the proposed estimation method and the population mean. |
| Parthasarathi, P. Levinson, D. M. Karamalaputi, R. 2003 | This paper analyses the induced demand hypothesis using a disaggregate approach at the link level. | Induced traffic | The results indicate that capacity enhancements in the previous years, given by lane additions, have a positive and significant effect on the VKT of the link, confirming the induced demand hypothesis. |
| Daganzo, C. F. 1998 | This paper explores some of the traffic phenomena that arise when drivers have to navigate a network in which queues back up past diverge intersections. | time-dependent traffic assignment | Findings suggest that in certain situations the time-dependent traffic assignment problem with physical queues is chaotic in nature and that it may be impossible to obtain input data with the required accuracy to make reliable predictions of cumulative output flows. |

| Table 7.5 continued | | | |
|---|---|---|---|
| Tang,Y. F., William H. K. Lam, M. and L. P Pan 2003 | In this paper, time series, neural network, nonparametric regression, and Gaussian maximum likelihood (GML) methods were adapted to develop four models for short-term prediction of the daily traffic flows by day of week and by month, as well as the AADT. | Nonparametric regression, Gaussian maximum likelihood and neural networks | The results of the four models were compared with the real data for validation. The GML model appears to be the most promising and robust of these four models for extensive applications to provide the short-term traffic forecasting database for the whole territory of Hong Kong. |

**Table 7.6: Research on Travel Demand Simulation**

| Authors | Description/purpose | Model /method | Result / peculiarity |
|---|---|---|---|
| | | | |
| Jörnsten, K., Wallace, S., W., 1993 | Paper argues that, modeling wise, changing the traffic count data so as to achieve consistency, is not a sound approach because inconsistent data is a natural part of any origin-destination matrix estimation problem | Stochastic programming approach. | By using stochastic programming approach the inconsistent input data becomes a natural part of the estimation process. |
| Bhat C. R. and J. Guo 2004 | In this paper, authors bring recent developments together to propose a mixed spatially correlated logit (MSCL) model for location-related choices. | mixed spatially correlated logit (MSCL) model | Empirical results underscore the need to capture unobserved taste variations and spatial correlation, both for improved data fit and the realistic assessment of the effect of socio-demographic, transportation system, and land-use changes on residential location choice. |
| Sherali, H., D., Narayanan, A., Sivanandan, R. 2003 | In this paper, authors develop an approach for synthesizing OD flows based on only a partial set of link volume information. | Estimation of OD flows from Partial link volumes | Computational results on three sample networks from the literature are presented to evaluate the method and to provide insights into its performance relative to some maximum entropy and bilevel programming approaches. |
| Levinson D., M., Kumar A. 1994 | This paper presents a multimodal trip distribution function estimated and validated for the metropolitan Washington region. | multimodal distribution travel time feedback and a methodology for measuring accessibility | The benefits are defined as the accessibility between homes and jobs provided by the network given a fixed land use pattern. The use of multimodal distribution with travel time feedback is necessary to estimate accessibility by auto, a major component in total accessibility. |
| | | | |
| | | | |

| **Table 7.6 continued** | | | |
|---|---|---|---|
| Authors | Description/purpose | Model /method | Result / peculiarity |
| | | | |
| Ashok K. Ben-Akıva M. E. 2002a | This paper examines two different approaches for real-time estimation/prediction of time dependent Origin–Destination (O–D) flows. | Differential variation of departure rates and shares over time | Preliminary results indicate that the filtering procedure is robust and that, compared to the original model, a formulation based on departure rates and shares yields better predictions with some loss of accuracy in filtered estimates. |
| K. Ashok M. E. Ben-Akiva 2002b | This paper presents a new suite of models for the estimation and prediction of time-dependent Origin-Destination (O-D) matrices. The key contribution of the proposed approach is the explicit modeling and estimation of the dynamic mapping (the assignment matrix) between time-dependent O-D flows and link volumes. | Dynamic Traffic Assignment models | The proposed approach provides a systematic way of modeling the uncertainty to address both the offline and real-time versions of the O-D estimation/prediction problem. Preliminary empirical results indicate that generalized models with a stochastic assignment matrix could provide better results compared to conventional models with a fixed matrix. |
| Ben-Akiva M. Bowman J. L. 1998 | This study presents an integrated discrete choice model system of a household' s residential location choice and its members' activity and travel schedules. | Activity-based Model System, Residential Location Model, Nested logit model | A nested logic model system is estimated and applied for Boston. It does not fit the data quite as well as a work-trip -based comparison model, but its predictions capture additional effects attributable to the more comprehensive accessibility measure. |
| Cascetta, E., Inaudi, D., Marquis, G., 1993 | This paper proposes different "dynamic" estimators using time-varying traffic counts to obtain (discrete) time-varying OD flows or average OD flows. | GLS estimator | Satisfactory results have been obtained, showing also that in the "no a priori information" case significant estimates could be obtained. |
| Mozolin M. Thill J.-C. Lynn Usery E. 2000 | This study compares the performance of multilayer perceptron neural networks and maximum-likelihood doubly-constrained models for commuter trip distribution. | maximum-likelihood doubly-constrained models | It is concluded that current perception neural networks do not provide an appropriate modeling approach to forecasting trip distribution over a planning horizon for which distribution predictors (number of workers, number of residents, commuting distance) are beyond their base-year domain of definition. |

# APPENDIX B

## SHORTEST PATH ALGORITHM

**Construction of worksheets**

**Input data**

Find zone data, link data, O/D matrix,

**Output**

construct table for alternative routes, construct shortest path table for each O/D pair.

```
Sub DetermineLines()

"Dim i, j, k As Integer
Dim SZone, FZone As String

Set shZone = Sheets("Zone")
Set shLink = Sheets("Link")
Set shPass = Sheets("Pass")
Set shLine = Sheets("Line")
Set shRoute = Sheets("Route")

ZoneCount = shZone.Cells(2, 7).Value
NodeCount = shZone.Cells(3, 7).Value
LinkCount = shZone.Cells(4, 7).Value
ShortestPath = shZone.Cells(5, 7).Value
maxAlternatives = shZone.Cells(6, 7).Value

iAlternatives = 0

LineCount = 0

For i = 1 To ZoneCount
   For j = 1 To ZoneCount

         SZone = shZone.Cells((i + 1), 2).Value
         FZone = shZone.Cells((j + 1), 2).Value

         If SZone <> FZone Then
         LineCount = LineCount + 1
         shLine.Cells(LineCount + 1, 1).FormulaR1C1 = "P" & LineCount
         shLine.Cells(LineCount + 1, 2).FormulaR1C1 = SZone
         shLine.Cells(LineCount + 1, 3).FormulaR1C1 = FZone
         End If

   Next j
Next i
```

**Alternative paths**

For each O/D pair nine alternative shortest paths are determined. In this step route cost function is employed, then a sequence list of shortest paths is determined.

```
Sub DetermineRoutes()

Dim i, j, k As Integer
Dim SZone, FZone As String
Dim bTruePath As Boolean

RouteCount = 0

For i = 1 To LineCount
   SZone = shLine.Cells((i + 1), 2).Value
   FZone = shLine.Cells((i + 1), 3).Value

   arrCurrentRoute(0) = 0
   arrCurrentRoute(1) = ""
   iStep = 0

   For k = 0 To ShortestPath - 1
      arrShortestPaths(k, 0) = 0
      arrShortestPaths(k, 1) = ""
   Next k

   bTruePath = ComputeRoute(SZone, FZone)

   For j = 1 To ShortestPath

         RouteCount = RouteCount + 1
         shRoute.Cells(RouteCount + 1, 1).FormulaR1C1 = "R" & RouteCount
         shRoute.Cells(RouteCount + 1, 2).FormulaR1C1 = SZone
         shRoute.Cells(RouteCount + 1, 3).FormulaR1C1 = FZone

         shRoute.Cells(RouteCount + 1, 4).FormulaR1C1 = arrShortestPaths(j - 1, 0)
         If (arrShortestPaths(j - 1, 1) <> "") Then
            shRoute.Cells(RouteCount + 1, 5).FormulaR1C1 = SZone & "-" & arrShortestPaths(j - 1,
1)
         Else
            shRoute.Cells(RouteCount + 1, 5).FormulaR1C1 = ""
         End If

   Next j

Next i

'for computation limit (optional)
shRoute.Cells(2, 7).FormulaR1C1 = ProcCount

End Sub
```

**Costs of Alternative Paths**

“For each O/D pair 6 possible shortest paths and their costs are listed”. 'The function works recursive”

“The probabilistic route choice function may be replaced by alternative forms”

```
Function ComputeRoute(ByVal StartZone As String, ByVal FinalZone As String) As Boolean

Dim i As Integer
Dim isPath As Boolean

iAlternatives = iAlternatives + 1

For i = 2 To LinkCount + 1

“for count number”
ProcCount = ProcCount + 1

If shLink.Cells(i, 2) = StartZone Then
   If (Not isLoop(shLink.Cells(i, 3)) And (iStep <= ShortestPath - 1)) Then

      If shLink.Cells(i, 3) = FinalZone Then

         arrCurrentRoute(1) = arrCurrentRoute(1) & FinalZone & "-"
         arrCurrentRoute(0) = arrCurrentRoute(0) + shLink.Cells(i, 5) 'Time

         arrShortestPaths(iStep, 0) = arrCurrentRoute(0)
         arrShortestPaths(iStep, 1) = arrCurrentRoute(1)

         iStep = iStep + 1
         If iStep > ShortestPath - 1 Then
            isBetterRoute
            iStep = iStep - 1
         End If

         arrCurrentRoute(0) = arrCurrentRoute(0) - shLink.Cells(i, 5) 'Time
         arrCurrentRoute(1) = Left(arrCurrentRoute(1), Len(arrCurrentRoute(1)) - Len(FinalZone &
"-"))

      Else
         arrCurrentRoute(1) = arrCurrentRoute(1) & shLink.Cells(i, 3).Value & "-"
         arrCurrentRoute(0) = arrCurrentRoute(0) + shLink.Cells(i, 5) 'Time

         If iAlternatives > maxAlternatives Then
            iAlternatives = 0
            isPath = False
         Else
            isPath = ComputeRoute(shLink.Cells(i, 3), FinalZone)
            arrCurrentRoute(0) = arrCurrentRoute(0) - shLink.Cells(i, 5) 'Time
            arrCurrentRoute(1) = Left(arrCurrentRoute(1), Len(arrCurrentRoute(1)) -
Len(shLink.Cells(i, 3).Value & "-"))
         End If

      End If
   End If
Else
   isPath = False
End If
```

```
Next i

ComputeRoute = isPath

End Function
```

**Route Check**

"At this stage, duplications are checked; to prevent the traveler not to follow a link more than once on a certain route."

```
Function isLoop(pNode As String) As Boolean
    If InStr(1, arrCurrentRoute(1), pNode & "-", vbTextCompare) > 0 Then
        isLoop = True
    Else
        isLoop = False
    End If
End Function
```

**Sequence of paths in terns of travel cost**

"At this stage the shortest path found in previous stage is replaced by the less costly one compared in terms of time, which parameter is also optional, such as distance or total cost may be used.

```
Sub isBetterRoute()
    Dim i As Integer
    Dim maxTime As Integer
    Dim maxItem As Integer

    maxTime = arrShortestPaths(0, 0)
    maxItem = 0
    For i = 1 To ShortestPath - 1
        If (Int(arrShortestPaths(i, 0)) > maxTime) Then
            maxTime = arrShortestPaths(i, 0)
            maxItem = i
        End If
    Next i

    If (arrCurrentRoute(0) < maxTime) Then
        arrShortestPaths(maxItem, 0) = arrCurrentRoute(0)
        arrShortestPaths(maxItem, 1) = arrCurrentRoute(1)
    End If

End Sub
```

## APPENDIX C

## DATA

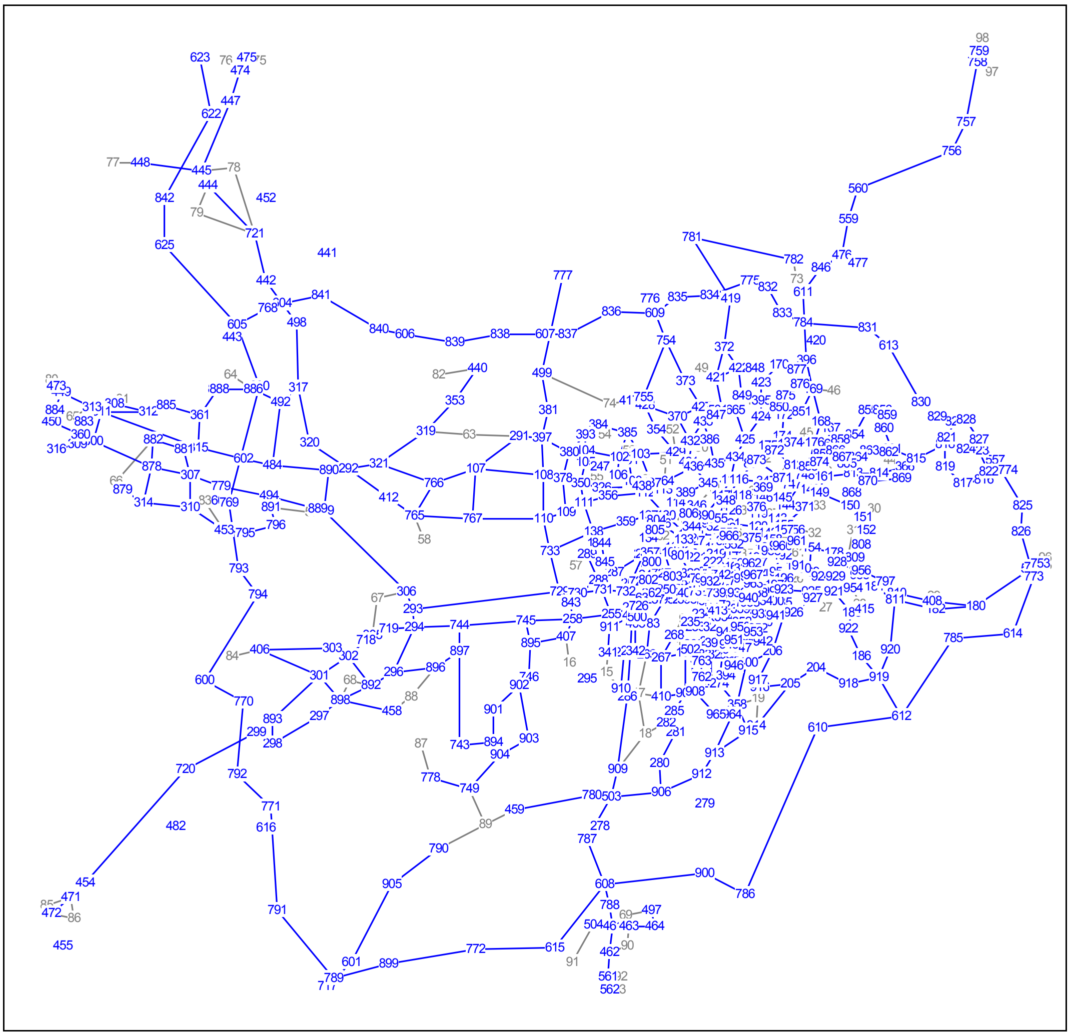

**Figure 7.1: Road Network**

# Table 7.7: Land Use Data- 1985

| zone | LocX | LocY | pop | employment | labor force | school enrolment | resident students | hospital beds | cars | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 87,800 | 21,300 | 9484 | 92855 | 2805 | 10417 | 2155 | 195 | 417 | altındağ | 516837 |
| 2 | 87,850 | 20,350 | 245 | 14382 | 72 | 11240 | 56 | 3341 | 11 | cankaya | 565300 |
| 3 | 87,400 | 19,450 | 11259 | 78148 | 3330 | 8979 | 2559 | 164 | 1464 | mamak | 434806 |
| 4 | 87,400 | 18,650 | 3106 | 29094 | 919 | 4478 | 706 | 0 | 404 | sincan | 52155 |
| 5 | 88,700 | 19,600 | 11758 | 8333 | 3478 | 8503 | 2672 | 200 | 1529 | golbasi | 6579 |
| 6 | 86,650 | 20,100 | 41202 | 13358 | 12187 | 7852 | 9363 | 0 | 3173 | etimesgut | 42397 |
| 7 | 85,400 | 19,500 | 39949 | 5038 | 11816 | 12040 | 9078 | 0 | 3076 | ymah | 297171 |
| 8 | 84,450 | 19,250 | 29625 | 4095 | 8763 | 7077 | 6732 | 0 | 2281 | kecioren | 385994 |
| 9 | 86,250 | 17,450 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | dış | 2449 |
| 10 | 87,950 | 18,100 | 21972 | 17324 | 6499 | 1136 | 4993 | 41 | 2856 | | 2303688 |
| 11 | 87,400 | 15,750 | 44078 | 6722 | 13038 | 1500 | 10016 | 0 | 5730 | | 2301239 |
| 12 | 86,800 | 15,870 | 46731 | 4057 | 13822 | 13500 | 10619 | 0 | 2056 | | |
| 13 | 86,200 | 16,750 | 30950 | 2573 | 9155 | 7362 | 7033 | 0 | 1362 | | |
| 14 | 84,750 | 17,630 | 24321 | 3165 | 7194 | 7109 | 5527 | 0 | 754 | | |
| 15 | 83,750 | 17,500 | 26597 | 3945 | 7867 | 5353 | 6044 | 200 | 1170 | | |
| 16 | 80,038 | 16,000 | 0 | 16879 | 0 | 26177 | 0 | 0 | 0 | | |
| 17 | 85,500 | 14,250 | 34199 | 1540 | 10116 | 2080 | 7772 | 0 | 445 | | |
| 18 | 85,850 | 13,550 | 25029 | 1803 | 7403 | 9179 | 5688 | 0 | 325 | | |
| 19 | 88,800 | 14,600 | 37339 | 3360 | 11044 | 4789 | 8485 | 0 | 1158 | | |
| 20 | 88,500 | 16,850 | 37509 | 7911 | 11095 | 3957 | 8524 | 40 | 4876 | | |
| 21 | 89,750 | 17,600 | 57301 | 2382 | 16949 | 5829 | 13021 | 20 | 2521 | | |
| 22 | 88,650 | 18,350 | 42375 | 4468 | 12534 | 5521 | 9629 | 0 | 1865 | | |
| 23 | 88,700 | 19,300 | 24905 | 3273 | 7367 | 5126 | 5660 | 0 | 772 | | |
| 24 | 89,600 | 19,900 | 43868 | 5080 | 12975 | 12982 | 9969 | 0 | 1930 | | |
| 25 | 90,100 | 18,750 | 27167 | 1570 | 8036 | 3033 | 6174 | 0 | 353 | | |
| 26 | 90,750 | 19,400 | 46207 | 4406 | 13667 | 9139 | 10500 | 0 | 1432 | | |
| 27 | 92,300 | 16,850 | 26073 | 1195 | 7712 | 2183 | 5925 | 0 | 339 | | |
| 28 | 93,250 | 18,400 | 53332 | 3207 | 15775 | 18727 | 12119 | 0 | 693 | | |
| 29 | 96,250 | 18,700 | 64339 | 3545 | 19030 | 13741 | 14621 | 0 | 836 | | |
| 30 | 93,800 | 22,400 | 22656 | 821 | 6701 | 1291 | 5148 | 0 | 295 | | |
| 31 | 93,150 | 21,100 | 17711 | 534 | 5239 | 7407 | 4025 | 0 | 230 | | |
| 32 | 91,450 | 21,200 | 28143 | 2444 | 8324 | 4106 | 6395 | 0 | 366 | | |
| 33 | 91,700 | 22,300 | 20280 | 2115 | 5999 | 2600 | 4609 | 0 | 629 | | |
| 34 | 90,200 | 21,100 | 25229 | 3763 | 7462 | 3433 | 5733 | 0 | 782 | | |
| 35 | 88,800 | 20,370 | 7376 | 6528 | 2182 | 7588 | 1676 | 700 | 325 | | |
| 36 | 88,450 | 21,350 | 29529 | 7872 | 8734 | 8256 | 6710 | 600 | 384 | | |
| 37 | 89,800 | 22,000 | 44959 | 3494 | 13298 | 7725 | 10217 | 750 | 584 | | |
| 38 | 88,800 | 22,100 | 38227 | 2499 | 11307 | 4877 | 8687 | 0 | 497 | | |
| 39 | 87,650 | 22,450 | 15316 | 25100 | 4530 | 6949 | 3480 | 830 | 674 | | |
| 40 | 87,200 | 22,700 | 16363 | 27252 | 4840 | 2985 | 3718 | 0 | 213 | | |
| 41 | 86,300 | 21,800 | 297 | 8639 | 88 | 0 | 67 | 0 | 13 | | |
| 42 | 89,600 | 23,880 | 55104 | 7840 | 16299 | 14750 | 12522 | 0 | 2425 | | |
| 43 | 90,500 | 23,330 | 12024 | 63982 | 3557 | 3164 | 2732 | 0 | 373 | | |
| 44 | 94,060 | 24,150 | 101590 | 2598 | 30049 | 11013 | 23086 | 0 | 1321 | | |
| 45 | 90,700 | 25,250 | 58907 | 3864 | 17424 | 8141 | 13386 | 0 | 766 | | |
| 46 | 92,230 | 26,850 | 12312 | 793 | 3642 | 1578 | 2798 | 0 | 382 | | |
| 47 | 90,800 | 23,200 | 75166 | 5917 | 22233 | 16328 | 17081 | 0 | 2330 | | |
| 48 | 87,200 | 20,200 | 136089 | 10870 | 40253 | 24690 | 30925 | 0 | 5988 | | |
| 49 | 87,000 | 29,930 | 86458 | 5535 | 25573 | 15191 | 19647 | 1050 | 1124 | | |
| 50 | 87,000 | 24,750 | 18226 | 4841 | 5391 | 2535 | 4142 | 2000 | 565 | | |
| 51 | 85,600 | 24,100 | 3555 | 5579 | 1052 | 1127 | 808 | 0 | 156 | | |
| 52 | 85,800 | 25,300 | 140623 | 7451 | 41594 | 21462 | 31956 | 0 | 6187 | | |
| 53 | 84,100 | 24,500 | 42071 | 5439 | 12444 | 6846 | 9560 | 0 | 1851 | | |
| 54 | 83,150 | 27,930 | 122958 | 10052 | 36369 | 21869 | 27942 | 0 | 3812 | | |
| 55 | 82,800 | 23,600 | 96982 | 13412 | 28686 | 11773 | 22039 | 0 | 4267 | | |
| 56 | 83,750 | 22,300 | 12902 | 12438 | 3816 | 28695 | 2932 | 0 | 168 | | |
| 57 | 82,000 | 9,800 | 13502 | 13135 | 3994 | 682 | 3068 | 28 | 176 | | |
| 58 | 75,900 | 20,950 | 1285 | 431 | 380 | 3426 | 292 | 0 | 40 | | |
| 59 | 69,900 | 9,100 | 30635 | 7592 | 9061 | 3427 | 6962 | 0 | 398 | | |
| 60 | 89,100 | 22,900 | 39938 | 2264 | 11813 | 8287 | 9076 | 0 | 1238 | | |
| 61 | 90,850 | 20,450 | 34896 | 5872 | 10322 | 6679 | 7930 | 2157 | 1082 | | |
| 62 | 85,450 | 21,100 | 0 | 15746 | 0 | 18380 | 0 | 0 | 0 | | |
| 63 | 58,230 | 25,100 | 6627 | 9656 | 1960 | 2628 | 1506 | 0 | 292 | | |
| 64 | 68,850 | 12,800 | 4056 | 8903 | 1200 | 1305 | 922 | 0 | 178 | | |
| 65 | 60,300 | 25,550 | 331 | 3374 | 98 | 0 | 75 | 0 | 15 | | |
| 66 | 61,220 | 28,100 | 51824 | 1157 | 15329 | 0 | 11777 | 0 | 2280 | | |
| 67 | 72,850 | 27,800 | 6421 | 3480 | 1899 | 0 | 1459 | 0 | 283 | | |
| 68 | 72,018 | 14,200 | 1241 | 7520 | 367 | 127 | 282 | 0 | 55 | | |
| 69 | 85,800 | 9,000 | 6579 | 2322 | 1946 | 1426 | 1495 | 0 | 289 | | |
| 70 | 93,606 | 18,846 | 339 | 853 | 100 | 0 | 77 | 0 | 15 | | |
| 71 | 95,292 | 27,049 | 2110 | 162 | 624 | 278 | 479 | 0 | 93 | | |
| 72 | 90,986 | 33,280 | 0 | 2031 | 0 | 719 | 0 | 0 | 0 | | |
| 73 | 87,200 | 29,800 | 1043 | 1107 | 309 | 748 | 237 | 0 | 46 | | |
| 74 | 80,500 | 28,650 | 888 | 410 | 263 | 0 | 202 | 0 | 39 | | |
| 75 | 64,750 | 44,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 76 | 68,300 | 40,600 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 77 | 63,500 | 35,950 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 78 | 66,908 | 34,031 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 79 | 66,350 | 26,311 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 80 | 58,300 | 28,750 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 81 | 62,200 | 28,250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 82 | 76,500 | 11,200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 83 | 63,450 | 18,900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 84 | 67,300 | 15,100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 85 | 55,200 | 5,500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 86 | 53,323 | 3,674 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 87 | 67,608 | 10,771 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 88 | 76,278 | 2,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 89 | 81,493 | 10,297 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 90 | 84,820 | 4,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 91 | 78,000 | 3,511 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 92 | 86,000 | 2,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 93 | 83,500 | 2,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 94 | 120,665 | 21,863 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 95 | 112,883 | 27,589 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 96 | 108,725 | 25,974 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 97 | 98,002 | 46,720 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 98 | 99,292 | 56,421 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 99 | 78,579 | -7,421 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | | | **2303688** | **681395** | **681399** | **523500** | **523500** | **12316** | **87054** | | |

# Table 7.8: Land Use Data- 2000

| zone | | | pop | employment | labor force | school enrolment | resident students | hospital beds | cars | pop | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 87,800 | 21,300 | 1784 | 95847 | 549 | 10480 | 472 | 195 | 278 | altındağ | 400435 |
| 2 | 87,850 | 20,350 | 166 | 18220 | 51 | 11308 | 44 | 3900 | 26 | cankaya | 758057 |
| 3 | 87,400 | 19,450 | 17208 | 72007 | 5300 | 19560 | 4552 | 420 | 2684 | mamak | 412647 |
| 4 | 87,400 | 18,650 | 215 | 40881 | 66 | 4513 | 57 | 0 | 34 | sincan | 278382 |
| 5 | 88,700 | 19,600 | 9169 | 12371 | 2824 | 8554 | 2425 | 800 | 1430 | golbasi | 35308 |
| 6 | 86,650 | 20,100 | 37395 | 21899 | 11518 | 12248 | 9891 | 0 | 5834 | etimesgut | 169842 |
| 7 | 85,400 | 19,500 | 38945 | 7528 | 11995 | 12112 | 10301 | 0 | 6075 | ymah | 534223 |
| 8 | 84,450 | 19,250 | 25262 | 8032 | 7781 | 7785 | 6682 | 0 | 3941 | kecioren | 666450 |
| 9 | 86,250 | 17,450 | 0 | 3848 | 0 | 301 | 0 | 0 | 0 | dış | 71384 |
| 10 | 87,950 | 18,100 | 22205 | 22985 | 6839 | 1205 | 5873 | 240 | 3464 | | 3326727 |
| 11 | 87,400 | 15,750 | 46952 | 9238 | 14461 | 2284 | 12419 | 0 | 7325 | | 3255344 |
| 12 | 86,800 | 15,870 | 50583 | 7301 | 15580 | 14784 | 13379 | 0 | 7891 | | |
| 13 | 86,200 | 16,750 | 36024 | 3640 | 11095 | 9274 | 9528 | 0 | 5620 | | |
| 14 | 84,750 | 17,630 | 25741 | 4431 | 7928 | 7534 | 6808 | 0 | 4016 | | |
| 15 | 83,750 | 17,500 | 64096 | 8781 | 19742 | 14943 | 16953 | 941 | 9999 | | |
| 16 | 80,038 | 16,000 | 15213 | 18607 | 4686 | 53401 | 4024 | 0 | 2373 | | |
| 17 | 85,500 | 14,250 | 38331 | 3340 | 11806 | 3251 | 10139 | 0 | 5980 | | |
| 18 | 85,850 | 13,550 | 30164 | 3049 | 9291 | 10553 | 7978 | 0 | 4706 | | |
| 19 | 88,800 | 14,600 | 59216 | 5031 | 18239 | 9609 | 15663 | 0 | 9238 | | |
| 20 | 88,500 | 16,850 | 38755 | 8452 | 11937 | 4317 | 10251 | 40 | 6046 | | |
| 21 | 89,750 | 17,600 | 61528 | 5713 | 18951 | 6986 | 16274 | 20 | 9598 | | |
| 22 | 88,650 | 18,350 | 42624 | 7210 | 13128 | 5621 | 11274 | 0 | 6649 | | |
| 23 | 88,700 | 19,300 | 25773 | 5507 | 7938 | 5391 | 6817 | 0 | 4021 | | |
| 24 | 89,600 | 19,900 | 34165 | 7669 | 10523 | 6602 | 9037 | 0 | 5330 | | |
| 25 | 90,100 | 18,750 | 30841 | 2897 | 9499 | 4100 | 8157 | 0 | 4811 | | |
| 26 | 90,750 | 19,400 | 31974 | 6345 | 9848 | 10719 | 8457 | 0 | 4988 | | |
| 27 | 92,300 | 16,850 | 29461 | 2984 | 9074 | 4773 | 7792 | 0 | 4596 | | |
| 28 | 93,250 | 18,400 | 51356 | 6381 | 15818 | 22911 | 13584 | 0 | 8012 | | |
| 29 | 96,250 | 18,700 | 51154 | 7371 | 15755 | 17150 | 13530 | 0 | 7980 | | |
| 30 | 93,800 | 22,400 | 37244 | 2686 | 11471 | 4391 | 9851 | 0 | 5810 | | |
| 31 | 93,150 | 21,100 | 19316 | 2242 | 5949 | 8550 | 5109 | 0 | 3013 | | |
| 32 | 91,450 | 21,200 | 26961 | 4491 | 8304 | 5215 | 7131 | 0 | 4206 | | |
| 33 | 91,700 | 22,300 | 28131 | 3709 | 8664 | 4278 | 7441 | 0 | 4388 | | |
| 34 | 90,200 | 21,100 | 26819 | 5328 | 8260 | 3769 | 7094 | 0 | 4184 | | |
| 35 | 88,800 | 20,370 | 3651 | 7739 | 1124 | 23837 | 966 | 2515 | 570 | | |
| 36 | 88,450 | 21,350 | 11456 | 7252 | 3528 | 8421 | 3030 | 600 | 1787 | | |
| 37 | 89,800 | 22,000 | 21115 | 6808 | 6503 | 10342 | 5585 | 750 | 3294 | | |
| 38 | 88,800 | 22,100 | 29314 | 6088 | 9029 | 5377 | 7754 | 0 | 4573 | | |
| 39 | 87,650 | 22,450 | 10238 | 26962 | 3153 | 6990 | 2708 | 830 | 1597 | | |
| 40 | 87,200 | 22,700 | 11227 | 35411 | 3458 | 3109 | 2969 | 0 | 1751 | | |
| 41 | 86,300 | 21,800 | 0 | 11702 | 0 | 5 | 0 | 0 | 0 | | |
| 42 | 89,600 | 23,880 | 52113 | 10024 | 16051 | 17213 | 13784 | 0 | 8130 | | |
| 43 | 90,500 | 23,330 | 12041 | 65452 | 3709 | 3187 | 3185 | 0 | 1878 | | |
| 44 | 94,060 | 24,150 | 63198 | 17246 | 19465 | 11572 | 16716 | 0 | 9859 | | |
| 45 | 90,700 | 25,250 | 51026 | 7796 | 15716 | 9556 | 13496 | 0 | 7960 | | |
| 46 | 92,230 | 26,850 | 11543 | 1436 | 3555 | 2901 | 3053 | 0 | 1801 | | |
| 47 | 90,800 | 23,200 | 95126 | 10785 | 29299 | 28128 | 25161 | 0 | 14840 | | |
| 48 | 87,200 | 20,200 | 206664 | 16589 | 63653 | 27358 | 54663 | 0 | 32240 | | |
| 49 | 87,730 | 29,930 | 164527 | 9591 | 50674 | 17446 | 43517 | 1050 | 25666 | | |
| 50 | 87,000 | 24,750 | 30776 | 7037 | 9479 | 2876 | 8140 | 2000 | 4801 | | |
| 51 | 85,600 | 24,100 | 8553 | 8066 | 2634 | 1734 | 2262 | 0 | 1334 | | |
| 52 | 85,800 | 25,300 | 214763 | 20477 | 66147 | 28550 | 56805 | 0 | 33503 | | |
| 53 | 84,100 | 24,500 | 51834 | 8283 | 15965 | 9369 | 13710 | 0 | 8086 | | |
| 54 | 82,600 | 27,740 | 108822 | 14995 | 33517 | 24994 | 28783 | 0 | 16976 | | |
| 55 | 82,800 | 23,600 | 96514 | 21126 | 29726 | 15481 | 25528 | 0 | 15056 | | |
| 56 | 83,750 | 22,300 | 6610 | 12580 | 2036 | 29579 | 1748 | 0 | 1031 | | |
| 57 | 82,000 | 19,900 | 15695 | 17515 | 4834 | 1276 | 4151 | 28 | 2448 | | |
| 58 | 75,900 | 20,950 | 0 | 5253 | 0 | 3463 | 0 | 0 | 0 | | |
| 59 | 69,900 | 22,700 | 47256 | 13359 | 14555 | 11035 | 12499 | 0 | 7372 | | |
| 60 | 89,100 | 22,900 | 26436 | 4461 | 8142 | 8337 | 6992 | 0 | 4124 | | |
| 61 | 90,850 | 20,450 | 19453 | 9761 | 5992 | 9256 | 5145 | 3746 | 3035 | | |
| 62 | 85,450 | 21,100 | 0 | 17619 | 0 | 26000 | 0 | 265 | 0 | | |
| 63 | 76,440 | 25,100 | 166313 | 21862 | 51224 | 43796 | 43990 | 0 | 25945 | | |
| 64 | 68,850 | 27,050 | 98101 | 14639 | 30215 | 23730 | 25948 | 0 | 15304 | | |
| 65 | 60,300 | 25,550 | 48732 | 13215 | 15009 | 255 | 12890 | 0 | 7602 | | |
| 66 | 60,560 | 27,290 | 104646 | 14533 | 32231 | 4938 | 27679 | 0 | 16325 | | |
| 67 | 72,850 | 27,800 | 6235 | 6471 | 1920 | 2255 | 1649 | 371 | 973 | | |
| 68 | 72,018 | 14,200 | 29257 | 7186 | 9011 | 8867 | 7738 | 0 | 4564 | | |
| 69 | 85,800 | 9,000 | 30050 | 9356 | 9255 | 14481 | 7948 | 0 | 4688 | | |
| 70 | 93,606 | 18,846 | 0 | 364 | 0 | 32 | 0 | 0 | 0 | | |
| 71 | 95,292 | 27,049 | 0 | 3146 | 0 | 3115 | 0 | 0 | 0 | | |
| 72 | 90,986 | 33,280 | 0 | 3332 | 0 | 6713 | 0 | 0 | 0 | | |
| 73 | 87,200 | 29,800 | 41167 | 682 | 12679 | 766 | 10889 | 0 | 6422 | | |
| 74 | 80,500 | 28,650 | 0 | 2260 | 0 | 15 | 0 | 0 | 0 | | |
| 75 | 64,750 | 44,000 | 0 | 6599 | 0 | 2859 | 0 | 37 | 0 | | |
| 76 | 68,300 | 40,600 | 7839 | 7050 | 2414 | 5191 | 2073 | 0 | 1223 | | |
| 77 | 63,500 | 35,950 | 2400 | 4020 | 739 | 0 | 635 | 0 | 374 | | |
| 78 | 66,908 | 34,031 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 79 | 66,350 | 26,311 | 0 | 0 | 0 | 0 | 0 | 318 | 0 | | |
| 80 | 58,300 | 28,750 | 40503 | 5356 | 12475 | 10720 | 10713 | 60 | 6318 | | |
| 81 | 62,200 | 28,250 | 84501 | 1170 | 26026 | 18363 | 22351 | 0 | 13182 | | |
| 82 | 76,500 | 27,500 | 59178 | 7451 | 18227 | 12548 | 15653 | 0 | 9232 | | |
| 83 | 63,450 | 18,900 | 18250 | 879 | 5621 | 2452 | 4827 | 0 | 2847 | | |
| 84 | 67,300 | 15,100 | 0 | 1179 | 0 | 0 | 0 | 0 | 0 | | |
| 85 | 59,540 | 5,500 | 5209 | 11239 | 1604 | 580 | 1378 | 106 | 813 | | |
| 86 | 53,323 | 3,674 | 0 | 5087 | 0 | 0 | 0 | 0 | 0 | | |
| 87 | 67,608 | 10,771 | 39731 | 5428 | 12237 | 7476 | 10509 | 80 | 6198 | | |
| 88 | 76,278 | 13,150 | 41061 | 2822 | 12647 | 7529 | 10861 | 380 | 6406 | | |
| 89 | 81,493 | 10,297 | 17640 | 200 | 5433 | 4490 | 4666 | 104 | 2752 | | |
| 90 | 84,820 | 4,000 | 7171 | 0 | 2209 | 2311 | 1897 | 0 | 1119 | | |
| 91 | 78,000 | 3,511 | 5258 | 441 | 1619 | 968 | 1391 | 0 | 820 | | |
| 92 | 86,000 | 2,000 | 1389 | 4197 | 428 | 325 | 367 | 0 | 217 | | |
| 93 | 83,500 | 2,000 | 3837 | 6968 | 1182 | 950 | 1015 | 0 | 599 | | |
| 94 | 120,665 | 21,863 | 0 | 0 | 0 | 6929 | 0 | 0 | 0 | | |
| 95 | 112,883 | 27,589 | 28362 | 5161 | 8735 | 7761 | 7502 | 241 | 4424 | | |
| 96 | 108,725 | 25,974 | 3757 | 520 | 1157 | 529 | 994 | 0 | 586 | | |
| 97 | 101,180 | 47,753 | 11419 | 3942 | 3517 | 2955 | 3020 | 52 | 1781 | | |
| 98 | 99,292 | 56,421 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 99 | 78,579 | -7,421 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| **total** | | | **3326727** | **1024188** | **1024632** | **879761** | **879919** | **20088** | **518969** | | |

# Table 7.9: Land Use Data predicted in 1985 for 2004

| zone | LocX | LocY | pop | employmer | labor force l | enrolment | nt students | spital beds | cars | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 87,800 | 21,300 | 7100 | 99473 | 2061 | 10487 | 167 | 195 | 923 | altındağ | 632272 |
| 2 | 87,850 | 20,350 | 250 | 19273 | 73 | 11316 | 59 | 3341 | 33 | cankaya | 773524 |
| 3 | 87,400 | 19,450 | 10500 | 77600 | 3048 | 9039 | 2477 | 164 | 1575 | mamak | 547600 |
| 4 | 87,400 | 18,650 | 3151 | 43595 | 915 | 4517 | 743 | 0 | 473 | sincan | 94994 |
| 5 | 88,700 | 19,600 | 11000 | 13245 | 3193 | 8560 | 2595 | 200 | 1650 | golbasi | 133285 |
| 6 | 86,650 | 20,100 | 40000 | 23601 | 11610 | 12736 | 9436 | 0 | 6000 | etimesgut | 238872 |
| 7 | 85,400 | 19,500 | 38450 | 8063 | 11160 | 12120 | 9070 | 0 | 5768 | ymah | 719552 |
| 8 | 84,450 | 19,250 | 33310 | 8745 | 9668 | 7864 | 7858 | 0 | 4997 | kecioren | 447196 |
| 9 | 86,250 | 17,450 | 1686 | 4408 | 489 | 334 | 398 | 0 | 219 | dış | 499784 |
| 10 | 87,950 | 18,100 | 22320 | 24404 | 6478 | 1213 | 5265 | 41 | 4910 | | 4087079 |
| 11 | 87,400 | 15,750 | 48368 | 9835 | 14038 | 2371 | 11410 | 0 | 10640 | | 3587295 |
| 12 | 86,800 | 15,870 | 52480 | 7912 | 15232 | 14927 | 12380 | 0 | 7872 | | |
| 13 | 86,200 | 16,750 | 41340 | 3884 | 11999 | 9486 | 9752 | 0 | 5374 | | |
| 14 | 84,750 | 17,630 | 26440 | 4724 | 7674 | 7581 | 6237 | 0 | 2380 | | |
| 15 | 83,750 | 17,500 | 69121 | 9620 | 20062 | 16009 | 16306 | 1023 | 6221 | | |
| 16 | 80,038 | 16,000 | 6425 | 19438 | 1865 | 56426 | 1516 | 0 | 964 | | |
| 17 | 85,500 | 14,250 | 40665 | 3655 | 11803 | 3381 | 9593 | 0 | 2440 | | |
| 18 | 85,850 | 13,550 | 32392 | 3292 | 9402 | 10706 | 7641 | 0 | 1944 | | |
| 19 | 88,800 | 14,600 | 63092 | 5390 | 18312 | 10144 | 14883 | 0 | 9464 | | |
| 20 | 88,500 | 16,850 | 39369 | 8803 | 11427 | 4357 | 9287 | 40 | 8661 | | |
| 21 | 89,750 | 17,600 | 63610 | 6279 | 18462 | 7114 | 15006 | 20 | 5725 | | |
| 22 | 88,650 | 18,350 | 42746 | 7762 | 12407 | 5632 | 10084 | 0 | 6412 | | |
| 23 | 88,700 | 19,300 | 26200 | 5945 | 7604 | 5420 | 6181 | 0 | 2358 | | |
| 24 | 89,600 | 19,900 | 47550 | 8220 | 13801 | 5893 | 11217 | 0 | 6182 | | |
| 25 | 90,100 | 18,750 | 32650 | 3144 | 9476 | 4219 | 7702 | 0 | 1959 | | |
| 26 | 90,750 | 19,400 | 53440 | 6779 | 15511 | 10894 | 12606 | 0 | 4810 | | |
| 27 | 92,300 | 16,850 | 40450 | 3285 | 11740 | 5061 | 9452 | 0 | 2427 | | |
| 28 | 93,250 | 18,400 | 76060 | 6953 | 22076 | 23376 | 17943 | 0 | 4564 | | |
| 29 | 96,250 | 18,700 | 82964 | 8049 | 24080 | 17529 | 19571 | 0 | 4978 | | |
| 30 | 93,800 | 22,400 | 40080 | 2985 | 11633 | 4735 | 9455 | 0 | 2405 | | |
| 31 | 93,150 | 21,100 | 23832 | 2509 | 6917 | 8677 | 5622 | 0 | 1430 | | |
| 32 | 91,450 | 21,200 | 34152 | 4873 | 9912 | 5338 | 8056 | 0 | 2049 | | |
| 33 | 91,700 | 22,300 | 29552 | 4013 | 8569 | 4464 | 6964 | 0 | 1771 | | |
| 34 | 90,200 | 21,100 | 26976 | 5685 | 7830 | 3806 | 6364 | 0 | 1619 | | |
| 35 | 88,800 | 20,370 | 4500 | 8139 | 1306 | 25642 | 1062 | 2717 | 585 | | |
| 36 | 88,450 | 21,350 | 30165 | 7432 | 8755 | 8439 | 7116 | 600 | 1810 | | |
| 37 | 89,800 | 22,000 | 59229 | 7410 | 17191 | 10633 | 13972 | 750 | 3554 | | |
| 38 | 88,800 | 22,100 | 49838 | 6696 | 11853 | 5433 | 9634 | 0 | 2450 | | |
| 39 | 87,650 | 22,450 | 15263 | 28095 | 4430 | 6995 | 3631 | 830 | 1374 | | |
| 40 | 87,200 | 22,700 | 16950 | 37534 | 4920 | 3123 | 3999 | 0 | 1017 | | |
| 41 | 86,300 | 21,800 | 325 | 12445 | 94 | 6 | 77 | 0 | 42 | | |
| 42 | 89,600 | 23,880 | 66281 | 10611 | 19238 | 17487 | 15636 | 0 | 8617 | | |
| 43 | 90,500 | 23,330 | 12050 | 67864 | 3497 | 3190 | 2843 | 0 | 1085 | | |
| 44 | 94,060 | 24,150 | 104320 | 19466 | 30278 | 11634 | 24609 | 0 | 6259 | | |
| 45 | 90,700 | 25,250 | 66163 | 8501 | 19203 | 9713 | 15608 | 0 | 3970 | | |
| 46 | 92,230 | 26,850 | 19650 | 1557 | 5703 | 3048 | 4635 | 0 | 1769 | | |
| 47 | 90,800 | 23,200 | 140968 | 11696 | 40915 | 29439 | 33254 | 0 | 2686 | | |
| 48 | 87,200 | 20,200 | 150042 | 17795 | 43549 | 27654 | 35395 | 0 | 3503 | | |
| 49 | 87,000 | 27,750 | 98487 | 10371 | 28585 | 17696 | 23233 | 1050 | 5909 | | |
| 50 | 87,000 | 24,750 | 20032 | 7523 | 5814 | 2914 | 4726 | 2000 | 1803 | | |
| 51 | 85,600 | 24,100 | 6900 | 8620 | 2003 | 1801 | 1628 | 0 | 897 | | |
| 52 | 85,800 | 25,300 | 170663 | 22628 | 49534 | 29338 | 40259 | 0 | 15358 | | |
| 53 | 84,100 | 24,500 | 55859 | 8884 | 16213 | 9649 | 13177 | 0 | 7262 | | |
| 54 | 83,150 | 25,150 | 139545 | 16059 | 40502 | 25341 | 32919 | 0 | 12558 | | |
| 55 | 82,800 | 23,600 | 117180 | 22709 | 34011 | 15893 | 27643 | 0 | 15231 | | |
| 56 | 83,750 | 22,300 | 16850 | 13028 | 4891 | 29677 | 3975 | 0 | 1011 | | |
| 57 | 82,000 | 19,900 | 16775 | 18604 | 4869 | 1342 | 3957 | 28 | 1007 | | |
| 58 | 75,900 | 20,950 | 1258 | 5969 | 365 | 3467 | 297 | 0 | 164 | | |
| 59 | 69,900 | 22,700 | 72979 | 14459 | 21182 | 11880 | 17216 | 0 | 4379 | | |
| 60 | 89,100 | 22,900 | 39220 | 4858 | 11383 | 8342 | 9252 | 0 | 3530 | | |
| 61 | 90,850 | 20,450 | 33694 | 10529 | 9779 | 9542 | 7948 | 3922 | 2022 | | |
| 62 | 85,450 | 21,100 | 450 | 18433 | 131 | 26847 | 106 | 294 | 68 | | |
| 63 | 77,750 | 25,100 | 236404 | 23970 | 68615 | 48370 | 55768 | 0 | 30730 | | |
| 64 | 68,850 | 27,050 | 129102 | 15779 | 37471 | 26222 | 30455 | 0 | 7746 | | |
| 65 | 60,300 | 25,550 | 1743 | 14762 | 506 | 283 | 411 | 0 | 105 | | |
| 66 | 60,950 | 23,350 | 48645 | 16519 | 14119 | 5487 | 11475 | 0 | 2919 | | |
| 67 | 72,850 | 27,800 | 14991 | 7026 | 4351 | 2506 | 3536 | 412 | 1349 | | |
| 68 | 72,018 | 14,200 | 49999 | 7396 | 14512 | 9838 | 11795 | 0 | 6500 | | |
| 69 | 85,800 | 9,000 | 79636 | 10459 | 23114 | 15932 | 18786 | 0 | 11944 | | |
| 70 | 93,606 | 18,846 | 517 | 322 | 150 | 35 | 122 | 0 | 31 | | |
| 71 | 95,292 | 27,049 | 18014 | 3586 | 5228 | 3430 | 4250 | 0 | 1081 | | |
| 72 | 90,986 | 33,280 | 33545 | 3591 | 9736 | 7379 | 7913 | 0 | 3019 | | |
| 73 | 87,200 | 29,800 | 1072 | 658 | 311 | 768 | 253 | 0 | 64 | | |
| 74 | 80,500 | 28,650 | 976 | 2543 | 283 | 17 | 230 | 0 | 59 | | |
| 75 | 64,750 | 44,000 | 15362 | 7559 | 4459 | 3177 | 3624 | 41 | 1383 | | |
| 76 | 68,300 | 40,600 | 29033 | 8076 | 8427 | 5768 | 6849 | 0 | 2613 | | |
| 77 | 63,500 | 35,950 | 6424 | 4605 | 1865 | 1578 | 1515 | 0 | 578 | | |
| 78 | 66,908 | 34,031 | 46623 | 14442 | 13532 | 9263 | 10998 | 0 | 4916 | | |
| 79 | 66,350 | 26,311 | 27288 | 6401 | 7920 | 7246 | 6437 | 353 | 1637 | | |
| 80 | 58,300 | 28,750 | 32107 | 6135 | 9319 | 6396 | 7574 | 0 | 2890 | | |
| 81 | 62,200 | 28,250 | 12499 | 1340 | 3628 | 2492 | 2949 | 0 | 1125 | | |
| 82 | 76,500 | 27,500 | 70152 | 8535 | 20361 | 13942 | 16549 | 0 | 6314 | | |
| 83 | 63,450 | 18,900 | 7876 | 1007 | 2286 | 1568 | 1858 | 0 | 473 | | |
| 84 | 67,300 | 15,100 | 12666 | 1350 | 3676 | 2525 | 2988 | 0 | 1140 | | |
| 85 | 55,200 | 5,500 | 30642 | 12874 | 8894 | 6508 | 7228 | 118 | 1839 | | |
| 86 | 53,323 | 3,674 | 7943 | 5827 | 2305 | 1582 | 1874 | 0 | 477 | | |
| 87 | 67,608 | 10,771 | 41770 | 6218 | 12123 | 8307 | 9854 | 0 | 6266 | | |
| 88 | 76,278 | 13,150 | 41995 | 3232 | 12189 | 8365 | 9907 | 0 | 9239 | | |
| 89 | 81,493 | 10,297 | 3294 | 229 | 956 | 655 | 777 | 0 | 725 | | |
| 90 | 84,820 | 4,000 | 108698 | 20019 | 31549 | 21694 | 25642 | 0 | 9783 | | |
| 91 | 78,000 | 3,511 | 53649 | 4647 | 15571 | 11579 | 12656 | 0 | 11803 | | |
| 92 | 86,000 | 2,000 | 8170 | 4807 | 2371 | 5250 | 1927 | 412 | 735 | | |
| 93 | 83,500 | 2,000 | 22573 | 7982 | 6552 | 4500 | 5325 | 0 | 2032 | | |
| 94 | 120,665 | 21,863 | 38771 | 14613 | 11253 | 7699 | 9146 | 0 | 2326 | | |
| 95 | 112,883 | 27,589 | 76654 | 17389 | 22248 | 15206 | 18083 | 0 | 4599 | | |
| 96 | 108,725 | 25,974 | 5608 | 4320 | 1628 | 6143 | 1323 | 588 | 336 | | |
| 97 | 98,002 | 47,753 | 17043 | 4516 | 4947 | 3377 | 4020 | 0 | 1534 | | |
| 98 | 99,292 | 56,421 | 21271 | 5797 | 6174 | 4829 | 5018 | 118 | 1914 | | |
| 99 | 78,579 | -7,421 | 967 | 1734 | 281 | 193 | 228 | 0 | 126 | | |
| **total** | | | **4087079** | **1183621** | **1183631** | **962006** | **960446** | **19257** | **383467** | | |

## Table 7.10: Land Use Data- 2004 residual

| zone | | | pop | employment | labor force | school enrolment | resident students | hospital beds | cars | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 88,150 | 20,330 | 1909 | 99984 | 649 | 16446 | 576 | 195 | 302 | altındağ | 428465 |
| 2 | 87,850 | 19,310 | 178 | 20099 | 60 | 19300 | 54 | 3900 | 28 | cankaya | 811122 |
| 3 | 87,970 | 18,230 | 18413 | 79430 | 6257 | 39456 | 5561 | 420 | 2909 | mamak | 441532 |
| 4 | 87,790 | 17,080 | 230 | 45095 | 78 | 4829 | 69 | 0 | 36 | sincan | 297869 |
| 5 | 89,280 | 18,140 | 9811 | 13647 | 3334 | 9153 | 2963 | 800 | 1550 | golbasi | 37780 |
| 6 | 86,860 | 18,720 | 40013 | 24157 | 13596 | 13105 | 12084 | 0 | 6322 | etimesgut | 181731 |
| 7 | 85,810 | 18,490 | 41671 | 8304 | 14160 | 12960 | 12585 | 0 | 6584 | ymah | 571619 |
| 8 | 85,000 | 18,000 | 27030 | 8860 | 9185 | 8330 | 8163 | 0 | 4271 | kecioren | 713102 |
| 9 | 86,250 | 16,310 | 0 | 4245 | 0 | 322 | 0 | 0 | 0 | dış | 67825 |
| 10 | 88,390 | 16,750 | 23760 | 25355 | 8073 | 1290 | 7175 | 240 | 3754 | | 3551043 |
| 11 | 87,400 | 13,680 | 50239 | 10190 | 17071 | 2444 | 15172 | 0 | 7938 | | 3483218 |
| 12 | 86,800 | 15,870 | 54124 | 8053 | 18391 | 15819 | 16345 | 0 | 8552 | | |
| 13 | 86,200 | 14,470 | 38546 | 4016 | 13098 | 9923 | 11641 | 0 | 6090 | | |
| 14 | 85,090 | 15,600 | 27543 | 4888 | 9359 | 8061 | 8318 | 0 | 4352 | | |
| 15 | 83,750 | 15,260 | 68583 | 6686 | 23304 | 15989 | 20712 | 941 | 10836 | | |
| 16 | 81,680 | 14,390 | 16278 | 20525 | 5531 | 57139 | 4916 | 0 | 2572 | | |
| 17 | 85,500 | 13,010 | 41014 | 3685 | 13937 | 3478 | 12386 | 0 | 6480 | | |
| 18 | 85,850 | 11,170 | 32275 | 3363 | 10967 | 11292 | 9747 | 0 | 5100 | | |
| 19 | 89,680 | 12,950 | 63361 | 5550 | 21530 | 10281 | 19135 | 0 | 10011 | | |
| 20 | 88,500 | 14,930 | 41468 | 9324 | 14091 | 4619 | 12523 | 40 | 6552 | | |
| 21 | 89,750 | 15,810 | 65835 | 6302 | 22371 | 7474 | 19882 | 20 | 10402 | | |
| 22 | 89,350 | 16,750 | 45607 | 7953 | 15497 | 6014 | 13773 | 0 | 7206 | | |
| 23 | 89,310 | 17,660 | 27577 | 6075 | 9371 | 5768 | 8328 | 0 | 4357 | | |
| 24 | 90,510 | 17,820 | 36557 | 8459 | 12422 | 7064 | 11040 | 0 | 5776 | | |
| 25 | 90,100 | 18,750 | 32999 | 3196 | 11213 | 4387 | 9966 | 0 | 5214 | | |
| 26 | 90,750 | 19,400 | 34212 | 7000 | 11625 | 11469 | 10332 | 0 | 5406 | | |
| 27 | 92,300 | 16,850 | 31523 | 3291 | 10712 | 5107 | 9520 | 0 | 4981 | | |
| 28 | 94,610 | 16,440 | 54951 | 7039 | 18672 | 24515 | 16595 | 0 | 8682 | | |
| 29 | 97,910 | 17,150 | 54735 | 8131 | 18599 | 18351 | 16530 | 0 | 8648 | | |
| 30 | 93,800 | 20,830 | 39851 | 2962 | 13541 | 4698 | 12035 | 0 | 6296 | | |
| 31 | 94,060 | 19,570 | 20668 | 2473 | 7023 | 9149 | 6242 | 0 | 3266 | | |
| 32 | 92,570 | 19,870 | 28848 | 4954 | 9803 | 5580 | 8712 | 0 | 4558 | | |
| 33 | 92,690 | 21,310 | 30100 | 4091 | 10228 | 4577 | 9090 | 0 | 4756 | | |
| 34 | 91,150 | 20,030 | 28696 | 5877 | 9751 | 4033 | 8666 | 0 | 4534 | | |
| 35 | 89,460 | 18,820 | 3906 | 8536 | 1327 | 25505 | 1180 | 2515 | 617 | | |
| 36 | 89,400 | 19,930 | 12258 | 7999 | 4165 | 9010 | 3702 | 600 | 1937 | | |
| 37 | 90,450 | 20,890 | 22593 | 7510 | 7677 | 11066 | 6823 | 750 | 3570 | | |
| 38 | 88,800 | 22,100 | 31366 | 6716 | 10658 | 5754 | 9473 | 0 | 4956 | | |
| 39 | 88,390 | 21,150 | 10955 | 29741 | 3722 | 7480 | 3308 | 830 | 1731 | | |
| 40 | 87,940 | 22,100 | 12013 | 39061 | 4082 | 7164 | 3628 | 0 | 1898 | | |
| 41 | 86,300 | 21,050 | 0 | 8909 | 0 | 0 | 0 | 0 | 0 | | |
| 42 | 89,840 | 23,550 | 55761 | 11057 | 18948 | 18418 | 16840 | 0 | 8810 | | |
| 43 | 93,480 | 22,780 | 12884 | 62199 | 4378 | 3411 | 3891 | 0 | 2036 | | |
| 44 | 95,660 | 23,540 | 67622 | 19024 | 22978 | 12382 | 20422 | 0 | 10684 | | |
| 45 | 91,730 | 24,890 | 54598 | 8600 | 18552 | 10225 | 16489 | 0 | 8626 | | |
| 46 | 92,230 | 26,850 | 12351 | 1584 | 4197 | 3104 | 3730 | 0 | 1951 | | |
| 47 | 91,550 | 22,660 | 101785 | 14896 | 34586 | 30097 | 30739 | 0 | 16082 | | |
| 48 | 89,650 | 26,000 | 221130 | 18300 | 75140 | 64231 | 66781 | 0 | 34939 | | |
| 49 | 88,210 | 27,750 | 176044 | 10580 | 59820 | 39640 | 53165 | 1050 | 27815 | | |
| 50 | 87,670 | 23,900 | 32930 | 7763 | 11190 | 27456 | 9945 | 2000 | 5203 | | |
| 51 | 85,600 | 23,080 | 9152 | 8898 | 3110 | 9845 | 2764 | 0 | 1446 | | |
| 52 | 86,290 | 25,300 | 229796 | 22588 | 78085 | 56421 | 69399 | 0 | 36308 | | |
| 53 | 84,150 | 24,030 | 55462 | 9137 | 18846 | 10025 | 16750 | 0 | 8763 | | |
| 54 | 83,220 | 24,690 | 116440 | 16540 | 39566 | 21400 | 35165 | 0 | 18397 | | |
| 55 | 81,810 | 22,690 | 103270 | 23304 | 35091 | 28302 | 31188 | 0 | 16317 | | |
| 56 | 83,750 | 22,300 | 7073 | 13877 | 2403 | 970 | 2136 | 0 | 1117 | | |
| 57 | 82,000 | 19,110 | 16794 | 17321 | 5706 | 1365 | 5072 | 28 | 2653 | | |
| 58 | 75,900 | 20,030 | 0 | 15500 | 0 | 0 | 0 | 0 | 0 | | |
| 59 | 69,900 | 20,740 | 50564 | 14736 | 17182 | 11807 | 15270 | 0 | 7989 | | |
| 60 | 90,000 | 21,790 | 28287 | 4921 | 9612 | 8920 | 8543 | 0 | 4469 | | |
| 61 | 92,000 | 18,840 | 20815 | 10768 | 7073 | 9904 | 6286 | 3746 | 3289 | | |
| 62 | 85,450 | 19,930 | 0 | 19436 | 0 | 0 | 0 | 265 | 0 | | |
| 63 | 75,620 | 22,970 | 177955 | 24116 | 60469 | 46862 | 53742 | 0 | 28117 | | |
| 64 | 67,920 | 25,020 | 104968 | 6148 | 35668 | 29877 | 31700 | 0 | 16585 | | |
| 65 | 61,100 | 25,010 | 52143 | 16000 | 17718 | 12460 | 15747 | 0 | 8239 | | |
| 66 | 62,440 | 22,420 | 111971 | 16032 | 38048 | 32114 | 33815 | 0 | 17691 | | |
| 67 | 73,840 | 16,900 | 6671 | 4138 | 2267 | 2413 | 2015 | 371 | 1054 | | |
| 68 | 73,170 | 13,760 | 31305 | 4927 | 10637 | 9488 | 9454 | 0 | 4946 | | |
| 69 | 84,260 | 3,140 | 32154 | 10320 | 10926 | 12881 | 9710 | 0 | 5080 | | |
| 70 | 100,900 | 18,320 | 0 | 401 | 0 | 0 | 0 | 0 | 0 | | |
| 71 | 93,690 | 33,700 | 0 | 3471 | 0 | 0 | 0 | 0 | 0 | | |
| 72 | 95,350 | 33,040 | 0 | 3675 | 0 | 0 | 0 | 0 | 0 | | |
| 73 | 92,530 | 31,410 | 44049 | 752 | 14968 | 12663 | 13303 | 0 | 6960 | | |
| 74 | 83,280 | 26,130 | 0 | 2493 | 0 | 0 | 0 | 0 | 0 | | |
| 75 | 64,750 | 44,000 | 0 | 7279 | 0 | 0 | 0 | 37 | 0 | | |
| 76 | 68,300 | 40,600 | 0 | 7777 | 0 | 0 | 0 | 0 | 0 | | |
| 77 | 64,810 | 35,300 | 2400 | 4435 | 816 | 565 | 725 | 0 | 379 | | |
| 78 | 66,908 | 34,031 | 0 | 13908 | 0 | 0 | 0 | 0 | 0 | | |
| 79 | 63,550 | 33,460 | 0 | 6164 | 0 | 0 | 0 | 318 | 0 | | |
| 80 | 60,240 | 26,100 | 43338 | 5908 | 14726 | 6159 | 13088 | 60 | 6847 | | |
| 81 | 62,710 | 25,850 | 90416 | 1290 | 30723 | 21516 | 27306 | 0 | 14286 | | |
| 82 | 78,840 | 26,030 | 63320 | 18219 | 21516 | 16934 | 19123 | 0 | 10005 | | |
| 83 | 66,410 | 21,540 | 19528 | 970 | 6635 | 4550 | 5897 | 0 | 3085 | | |
| 84 | 67,300 | 15,100 | 0 | 1300 | 0 | 0 | 0 | 0 | 0 | | |
| 85 | 61,000 | 4,880 | 5574 | 12398 | 1894 | 1390 | 1683 | 106 | 881 | | |
| 86 | 60,830 | 2,830 | 0 | 5611 | 0 | 0 | 0 | 0 | 0 | | |
| 87 | 73,800 | 10,120 | 42512 | 5988 | 14446 | 12331 | 12839 | 80 | 6717 | | |
| 88 | 75,850 | 12,630 | 43935 | 3112 | 14929 | 8055 | 13268 | 380 | 6942 | | |
| 89 | 77,810 | 7,150 | 18875 | 221 | 6414 | 6939 | 5700 | 104 | 2982 | | |
| 90 | 85,770 | 1,040 | 7673 | 19278 | 2607 | 2091 | 2317 | 0 | 1212 | | |
| 91 | 81,350 | 1,380 | 5626 | 487 | 1912 | 1036 | 1699 | 0 | 889 | | |
| 92 | 84,150 | 0,330 | 1486 | 4629 | 505 | 505 | 449 | 0 | 235 | | |
| 93 | 83,500 | 0,330 | 4106 | 7687 | 1395 | 1336 | 1240 | 0 | 649 | | |
| 94 | 120,665 | 21,863 | 0 | 14072 | 0 | 0 | 0 | 0 | 0 | | |
| 95 | 112,883 | 27,589 | 30347 | 16746 | 10312 | 7954 | 9165 | 241 | 4795 | | |
| 96 | 108,725 | 25,974 | 4020 | 4160 | 1366 | 1590 | 1214 | 0 | 635 | | |
| 97 | 98,002 | 47,753 | 12218 | 4349 | 4152 | 3252 | 3690 | 52 | 1930 | | |
| 98 | 99,292 | 56,421 | 0 | 5583 | 0 | 0 | 0 | 0 | 0 | | |
| 99 | 78,579 | -7,421 | 0 | 1670 | 0 | 0 | 0 | 0 | 0 | | |
| **total** | | | **3551043** | 1205088 | 1206644 | 1071284 | 1072415 | 20088 | 561065 | | |

# Table 7.11: Trip Generation- 2004: Predicted versus Residual

| | 2004- predicted production | | | attraction | | |
|---|---|---|---|---|---|---|
| | work | school | other | work | school | other |
| 1 | 1438 | 83 | 4291 | 69432 | 5191 | 27681 |
| 2 | 51 | 29 | 716 | 13453 | 5601 | 14249 |
| 3 | 2126 | 1227 | 3981 | 54165 | 4474 | 21626 |
| 4 | 638 | 368 | 1922 | 30429 | 2236 | 11901 |
| 5 | 2227 | 1285 | 1734 | 9245 | 4237 | 4154 |
| 6 | 8099 | 4673 | 5427 | 16473 | 6304 | 6443 |
| 7 | 7785 | 4491 | 4693 | 5628 | 5999 | 2201 |
| 8 | 6744 | 3891 | 4129 | 6104 | 3893 | 2387 |
| 9 | 341 | 197 | 331 | 3077 | 165 | 1203 |
| 10 | 4519 | 2607 | 4354 | 17034 | 600 | 6773 |
| 11 | 9793 | 5650 | 7893 | 6865 | 1174 | 2685 |
| 12 | 10626 | 6131 | 6295 | 5523 | 7389 | 2160 |
| 13 | 8371 | 4829 | 4386 | 2711 | 4696 | 1060 |
| 14 | 5353 | 3089 | 2260 | 3297 | 3753 | 1290 |
| 15 | 13995 | 8075 | 5811 | 6715 | 7924 | 5378 |
| 16 | 1301 | 751 | 1432 | 13568 | 27931 | 5307 |
| 17 | 8234 | 4750 | 2626 | 2551 | 1674 | 998 |
| 18 | 6559 | 3784 | 2106 | 2298 | 5299 | 899 |
| 19 | 12774 | 7370 | 7420 | 3762 | 5021 | 1471 |
| 20 | 7971 | 4599 | 6453 | 6144 | 2157 | 2511 |
| 21 | 12879 | 7431 | 5256 | 4383 | 3521 | 1768 |
| 22 | 8655 | 4994 | 5174 | 5418 | 2788 | 2119 |
| 23 | 5305 | 3061 | 2285 | 4150 | 2683 | 1623 |
| 24 | 9628 | 5555 | 5179 | 5738 | 2917 | 2244 |
| 25 | 6610 | 3814 | 2116 | 2195 | 2088 | 858 |
| 26 | 10820 | 6242 | 4469 | 4732 | 5393 | 1851 |
| 27 | 8190 | 4681 | 2600 | 2293 | 2505 | 897 |
| 28 | 15400 | 8885 | 4916 | 4853 | 11571 | 1898 |
| 29 | 16798 | 9692 | 5379 | 5618 | 8677 | 2197 |
| 30 | 8115 | 4682 | 2566 | 2084 | 2344 | 815 |
| 31 | 4825 | 2784 | 1552 | 1751 | 4295 | 685 |
| 32 | 6915 | 3989 | 2270 | 3401 | 2642 | 1330 |
| 33 | 5978 | 3449 | 1956 | 2801 | 2210 | 1096 |
| 34 | 5462 | 3151 | 1859 | 3968 | 1884 | 1552 |
| 35 | 911 | 526 | 754 | 5681 | 12693 | 9531 |
| 36 | 6107 | 3524 | 2117 | 5188 | 4177 | 3643 |
| 37 | 11992 | 6919 | 3900 | 5172 | 5263 | 4040 |
| 38 | 8269 | 4771 | 2978 | 4674 | 2689 | 1828 |
| 39 | 3090 | 1798 | 2213 | 19610 | 3463 | 9903 |
| 40 | 3432 | 1980 | 2384 | 26199 | 1546 | 10247 |
| 41 | 66 | 38 | 479 | 8687 | 3 | 3397 |
| 42 | 13420 | 7743 | 7189 | 7406 | 8656 | 2897 |
| 43 | 2440 | 1408 | 3383 | 47369 | 1579 | 18527 |
| 44 | 21122 | 12186 | 7098 | 13587 | 5759 | 5314 |
| 45 | 13396 | 7729 | 4364 | 5934 | 4808 | 2321 |
| 46 | 3978 | 2295 | 1610 | 1087 | 1509 | 425 |
| 47 | 28542 | 16467 | 5657 | 8164 | 14572 | 3193 |
| 48 | 30380 | 17528 | 6593 | 12421 | 13689 | 4858 |
| 49 | 19941 | 11505 | 6414 | 7239 | 8760 | 5656 |
| 50 | 4056 | 2340 | 1854 | 5251 | 1442 | 7434 |
| 51 | 1397 | 806 | 1017 | 6017 | 891 | 2353 |
| 52 | 34555 | 19936 | 14307 | 15794 | 14522 | 6177 |
| 53 | 11310 | 6525 | 6057 | 6201 | 4776 | 2425 |
| 54 | 28254 | 16301 | 11611 | 11209 | 12544 | 4384 |
| 55 | 23726 | 13689 | 12849 | 15851 | 7867 | 6200 |
| 56 | 3412 | 1968 | 1500 | 9094 | 14690 | 3557 |
| 57 | 3397 | 1960 | 1696 | 12986 | 664 | 5154 |
| 58 | 255 | 147 | 343 | 4166 | 1716 | 1630 |
| 59 | 14777 | 8525 | 4996 | 10092 | 5881 | 3947 |
| 60 | 7941 | 4582 | 3276 | 3391 | 4129 | 1326 |
| 61 | 6822 | 3936 | 2445 | 7349 | 4723 | 13425 |
| 62 | 91 | 52 | 712 | 12866 | 13289 | 5823 |
| 63 | 47866 | 27616 | 25142 | 16731 | 23943 | 6544 |
| 64 | 26140 | 15081 | 8487 | 11014 | 12980 | 4308 |
| 65 | 353 | 204 | 636 | 10304 | 140 | 4030 |
| 66 | 9849 | 5682 | 3576 | 11530 | 2716 | 4510 |
| 67 | 3035 | 1751 | 1437 | 4904 | 1240 | 3026 |
| 68 | 10124 | 5841 | 5401 | 5162 | 4870 | 2019 |
| 69 | 16124 | 9303 | 9496 | 7300 | 7886 | 2855 |
| 70 | 105 | 60 | 43 | 225 | 17 | 88 |
| 71 | 3647 | 2105 | 1234 | 2503 | 1698 | 979 |
| 72 | 6792 | 3919 | 2782 | 2507 | 3653 | 980 |
| 73 | 217 | 125 | 89 | 459 | 380 | 180 |
| 74 | 197 | 114 | 151 | 1775 | 8 | 694 |
| 75 | 3111 | 1795 | 1486 | 5276 | 1573 | 2174 |
| 76 | 5879 | 3392 | 2585 | 5637 | 2855 | 2205 |
| 77 | 1301 | 750 | 673 | 3214 | 781 | 1257 |
| 78 | 9440 | 5446 | 4630 | 10081 | 4585 | 3943 |
| 79 | 5525 | 3188 | 1903 | 4468 | 3587 | 2697 |
| 80 | 6501 | 3751 | 2759 | 4282 | 3166 | 1675 |
| 81 | 2531 | 1460 | 1037 | 935 | 1234 | 366 |
| 82 | 14204 | 8195 | 5854 | 5957 | 6901 | 2330 |
| 83 | 1595 | 920 | 520 | 703 | 776 | 275 |
| 84 | 2564 | 1480 | 1050 | 942 | 1250 | 369 |
| 85 | 6204 | 3579 | 2341 | 8986 | 3221 | 3832 |
| 86 | 1608 | 928 | 696 | 4067 | 783 | 1591 |
| 87 | 8457 | 4880 | 5008 | 4340 | 4112 | 1698 |
| 88 | 8503 | 4906 | 6664 | 2256 | 4141 | 882 |
| 89 | 667 | 385 | 522 | 160 | 324 | 63 |
| 90 | 22009 | 12698 | 9314 | 13973 | 10739 | 5465 |
| 91 | 10862 | 6267 | 8531 | 3244 | 5732 | 1269 |
| 92 | 1654 | 954 | 818 | 3355 | 2599 | 2421 |
| 93 | 4571 | 2637 | 2071 | 5571 | 2228 | 2179 |
| 94 | 7850 | 4529 | 2902 | 10200 | 3811 | 3989 |
| 95 | 15520 | 8955 | 5326 | 12138 | 7527 | 4747 |
| 96 | 1136 | 655 | 498 | 3015 | 3041 | 2761 |
| 97 | 3451 | 1991 | 1510 | 3152 | 1672 | 1233 |
| 98 | 4307 | 2485 | 1890 | 4046 | 2390 | 1900 |
| 99 | 196 | 113 | 162 | 1210 | 96 | 473 |
| | **825701** | **475613** | **374858** | **826167** | **476193** | **374930** |

| | 2004- residual production | | | attraction | | |
|---|---|---|---|---|---|---|
| | work | school | other | work | school | other |
| 1 | 512 | 343 | 3828 | 80187 | 9797 | 38518 |
| 2 | 48 | 32 | 743 | 16119 | 11497 | 18129 |
| 3 | 4943 | 3310 | 5242 | 63703 | 23504 | 31313 |
| 4 | 62 | 41 | 1644 | 36166 | 2877 | 17136 |
| 5 | 2634 | 1764 | 1767 | 10945 | 5453 | 7338 |
| 6 | 10741 | 7192 | 6078 | 19374 | 7807 | 9180 |
| 7 | 11186 | 7490 | 5726 | 6660 | 7720 | 3155 |
| 8 | 7256 | 4859 | 3839 | 7105 | 4962 | 3367 |
| 9 | 0 | 0 | 152 | 3404 | 192 | 1613 |
| 10 | 6378 | 4271 | 4003 | 20334 | 768 | 10280 |
| 11 | 13486 | 9030 | 6910 | 8173 | 1456 | 3872 |
| 12 | 14529 | 9729 | 7339 | 6459 | 9423 | 3060 |
| 13 | 10347 | 6929 | 5165 | 3221 | 5911 | 1526 |
| 14 | 7394 | 4951 | 3763 | 3920 | 4802 | 1857 |
| 15 | 18410 | 12328 | 9174 | 5362 | 9525 | 5071 |
| 16 | 4370 | 2926 | 2855 | 16461 | 34038 | 7799 |
| 17 | 11010 | 7372 | 5475 | 2955 | 2072 | 1400 |
| 18 | 8664 | 5802 | 4325 | 2697 | 6727 | 1278 |
| 19 | 17009 | 11389 | 8453 | 4451 | 6124 | 2109 |
| 20 | 11132 | 7454 | 5736 | 7478 | 2752 | 3651 |
| 21 | 17673 | 11834 | 8802 | 5054 | 4453 | 2448 |
| 22 | 12243 | 8198 | 6226 | 6378 | 3583 | 3022 |
| 23 | 7403 | 4957 | 3810 | 4872 | 3436 | 2309 |
| 24 | 9813 | 6571 | 5065 | 6784 | 4208 | 3215 |
| 25 | 8858 | 5932 | 4414 | 2563 | 2614 | 1214 |
| 26 | 9184 | 6150 | 4708 | 5614 | 6832 | 2660 |
| 27 | 8462 | 5666 | 4225 | 2640 | 3042 | 1251 |
| 28 | 14751 | 9877 | 7411 | 5645 | 14604 | 2675 |
| 29 | 14693 | 9839 | 7422 | 6521 | 10932 | 3090 |
| 30 | 10698 | 7163 | 5298 | 2376 | 2799 | 1126 |
| 31 | 5548 | 3715 | 2781 | 1984 | 5450 | 940 |
| 32 | 7744 | 5185 | 3936 | 3973 | 3324 | 1883 |
| 33 | 8080 | 5411 | 4068 | 3281 | 2727 | 1555 |
| 34 | 7703 | 5158 | 3949 | 4714 | 2402 | 2233 |
| 35 | 1049 | 702 | 815 | 6846 | 15193 | 10010 |
| 36 | 3291 | 2203 | 1883 | 6415 | 5367 | 4654 |
| 37 | 6065 | 4061 | 3212 | 6023 | 6592 | 4871 |
| 38 | 8420 | 5638 | 4327 | 5386 | 3428 | 2552 |
| 39 | 2941 | 1969 | 2492 | 23852 | 4456 | 13534 |
| 40 | 3225 | 2159 | 2963 | 31327 | 4268 | 14843 |
| 41 | 0 | 0 | 319 | 7145 | 0 | 3385 |
| 42 | 14969 | 10023 | 7660 | 8868 | 10972 | 4202 |
| 43 | 3459 | 2316 | 3905 | 49884 | 2032 | 23636 |
| 44 | 18153 | 12155 | 9491 | 15257 | 7376 | 7229 |
| 45 | 14656 | 9814 | 7421 | 6897 | 6091 | 3268 |
| 46 | 3316 | 2220 | 1666 | 1271 | 1849 | 602 |
| 47 | 27323 | 18296 | 13794 | 11947 | 17929 | 5661 |
| 48 | 59361 | 39748 | 29464 | 14676 | 38262 | 6954 |
| 49 | 47258 | 31644 | 23313 | 8485 | 23614 | 6845 |
| 50 | 8840 | 5919 | 4568 | 6226 | 16356 | 8330 |
| 51 | 2457 | 1645 | 1511 | 7136 | 5865 | 3381 |
| 52 | 61687 | 41306 | 30746 | 18116 | 33610 | 8583 |
| 53 | 14888 | 9969 | 7553 | 7328 | 5972 | 3472 |
| 54 | 31257 | 20930 | 15762 | 13265 | 12748 | 6285 |
| 55 | 27722 | 18563 | 14288 | 18690 | 16860 | 8855 |
| 56 | 1899 | 1271 | 1418 | 11129 | 578 | 5273 |
| 57 | 4508 | 3019 | 2808 | 13892 | 813 | 6657 |
| 58 | 0 | 0 | 555 | 12431 | 0 | 5890 |
| 59 | 13573 | 9089 | 7115 | 11819 | 7034 | 5600 |
| 60 | 7593 | 5085 | 3861 | 3946 | 5314 | 1870 |
| 61 | 5588 | 3741 | 3097 | 8636 | 5900 | 14167 |
| 62 | 0 | 0 | 696 | 15588 | 0 | 8097 |
| 63 | 47771 | 31987 | 24047 | 19341 | 27915 | 9164 |
| 64 | 28178 | 18868 | 13895 | 4931 | 17798 | 2336 |
| 65 | 13997 | 9373 | 7366 | 12832 | 7422 | 6080 |
| 66 | 30058 | 20127 | 15161 | 12857 | 19130 | 6092 |
| 67 | 1791 | 1199 | 1017 | 3319 | 1438 | 2570 |
| 68 | 8404 | 5627 | 4255 | 3951 | 5652 | 1872 |
| 69 | 8631 | 5780 | 4558 | 8277 | 7673 | 3922 |
| 70 | 0 | 0 | 14 | 322 | 0 | 153 |
| 71 | 0 | 0 | 124 | 2783 | 0 | 1319 |
| 72 | 0 | 0 | 132 | 2948 | 0 | 1397 |
| 73 | 11825 | 7918 | 5766 | 603 | 7543 | 286 |
| 74 | 0 | 0 | 89 | 1999 | 0 | 947 |
| 75 | 0 | 0 | 261 | 5838 | 0 | 2865 |
| 76 | 0 | 0 | 278 | 6237 | 0 | 2955 |
| 77 | 644 | 431 | 471 | 3557 | 337 | 1685 |
| 78 | 0 | 0 | 498 | 11154 | 0 | 5285 |
| 79 | 0 | 0 | 221 | 4944 | 0 | 3197 |
| 80 | 11634 | 7790 | 5858 | 4738 | 3669 | 2406 |
| 81 | 24271 | 16252 | 11825 | 1035 | 12817 | 490 |
| 82 | 16998 | 11382 | 8902 | 14612 | 10088 | 6923 |
| 83 | 5242 | 3510 | 2579 | 778 | 2710 | 369 |
| 84 | 0 | 0 | 47 | 1043 | 0 | 494 |
| 85 | 1496 | 1002 | 1170 | 9943 | 828 | 4997 |
| 86 | 0 | 0 | 201 | 4500 | 0 | 2132 |
| 87 | 11412 | 7642 | 5753 | 4802 | 7346 | 2491 |
| 88 | 11794 | 7897 | 5835 | 2496 | 4799 | 2205 |
| 89 | 5067 | 3393 | 2467 | 177 | 4134 | 364 |
| 90 | 2060 | 1379 | 1690 | 15461 | 1246 | 7326 |
| 91 | 1510 | 1011 | 750 | 390 | 617 | 185 |
| 92 | 399 | 267 | 359 | 3713 | 301 | 1759 |
| 93 | 1102 | 738 | 810 | 6165 | 796 | 2921 |
| 94 | 0 | 0 | 504 | 11286 | 0 | 5347 |
| 95 | 8146 | 5455 | 4553 | 13430 | 4738 | 7012 |
| 96 | 1079 | 723 | 673 | 3336 | 947 | 1581 |
| 97 | 3280 | 2196 | 1747 | 3488 | 1937 | 1792 |
| 98 | 0 | 0 | 200 | 4477 | 0 | 2121 |
| 99 | 0 | 0 | 60 | 1339 | 0 | 635 |
| | **953249** | **638301** | **505170** | **953155** | **638164** | **505655** |

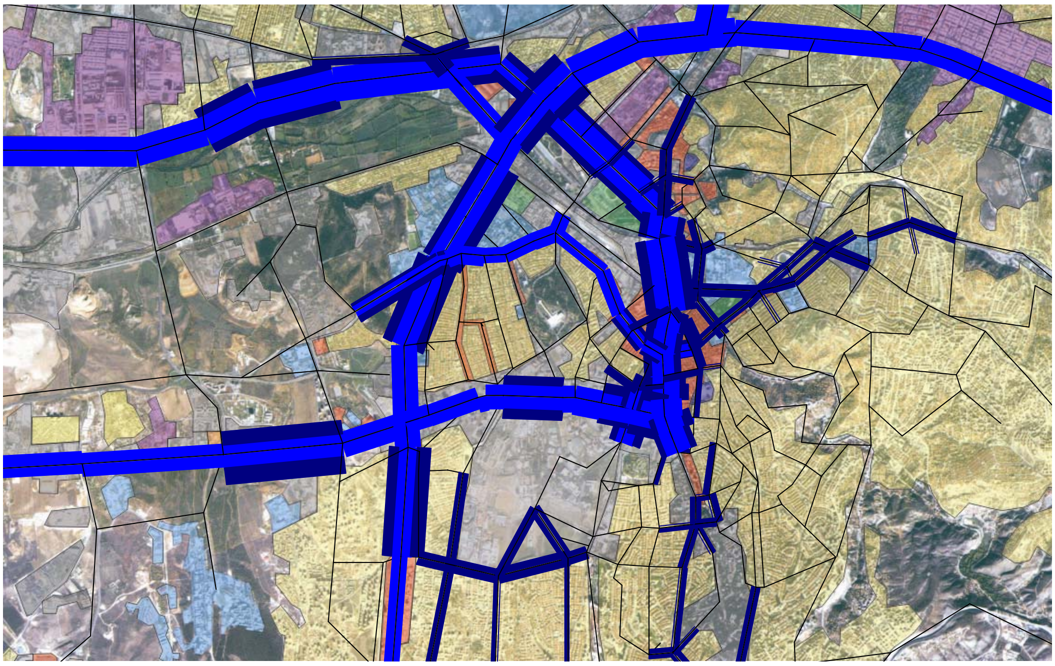

**Figure 7.2: Predicted versus observed volumes-2004 (IBI Model)**

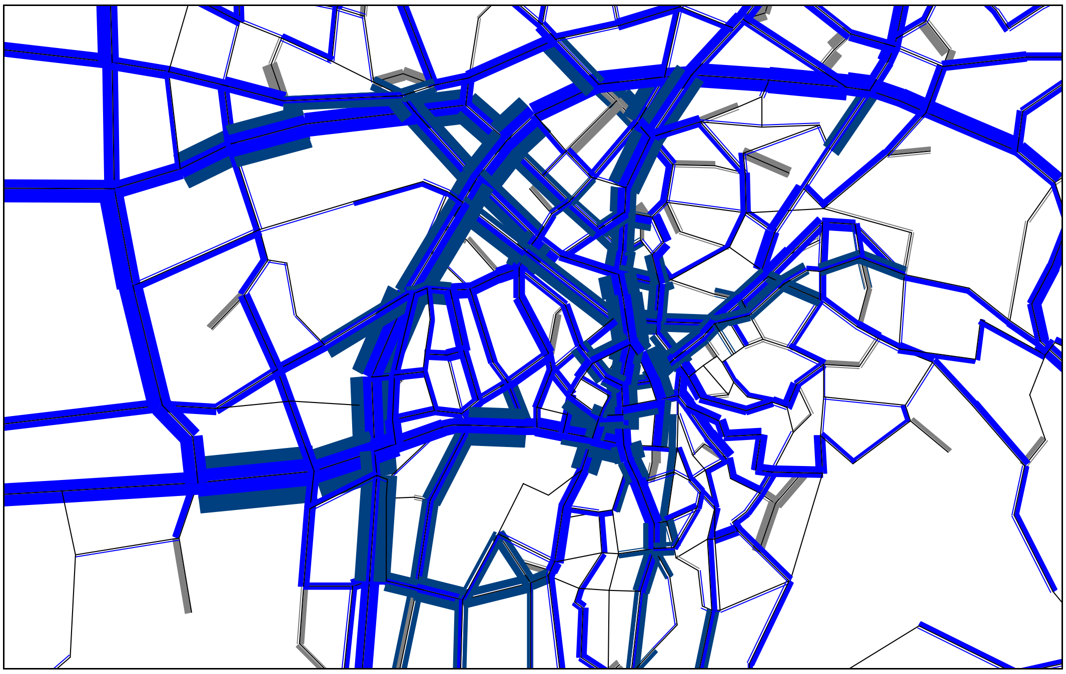

**Figure 7.3: Predicted versus observed volumes-2004 (Validated IBI Model)**

**APPENDIX D**

**PREDICTIONS**

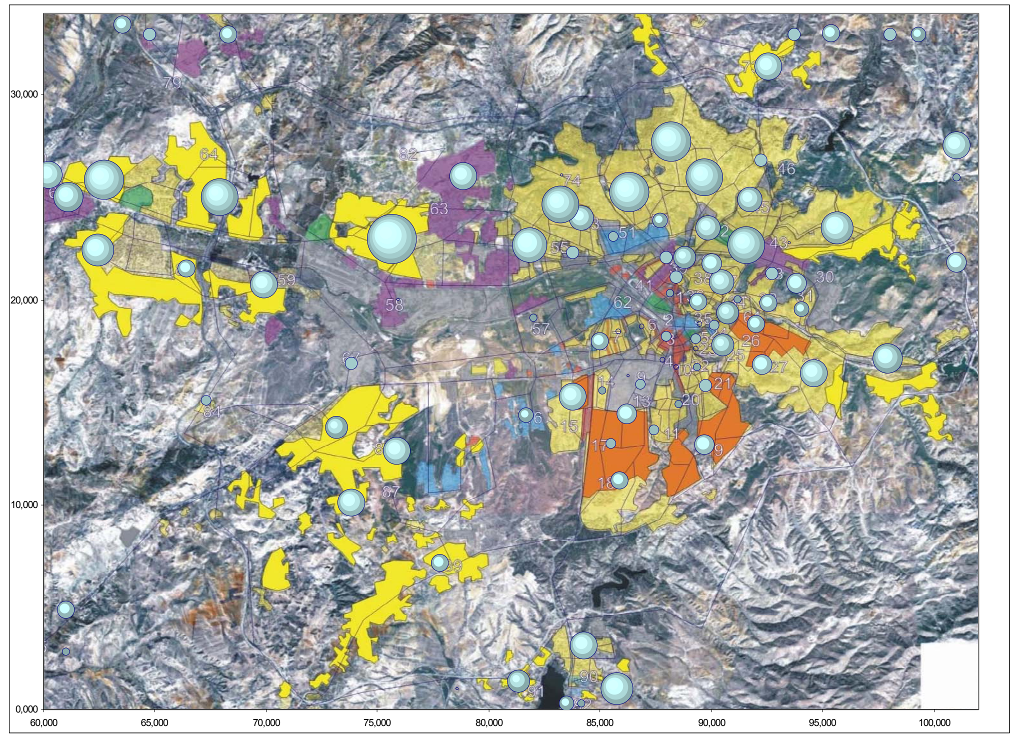


**Figure 7.4: Projected additional population increases 2004-2010**

# Table 7.12: Land use data- predicted for 2010

| zone | pop | employment | labor force | school enrolment | resident students | hospital beds | cars | | |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 2479 | 99984 | 842 | 16446 | 749 | 195 | 392 | altındağ | 478359 |
| **2** | 198 | 20099 | 67 | 19300 | 60 | 3900 | 31 | cankaya | 852376 |
| **3** | 19354 | 79430 | 6576 | 39456 | 5845 | 420 | 3058 | mamak | 479091 |
| **4** | 483 | 45095 | 164 | 4829 | 146 | 0 | 76 | sincan | 330199 |
| **5** | 10694 | 13647 | 3634 | 9153 | 3230 | 800 | 1690 | golbasi | 48477 |
| **6** | 39856 | 24157 | 13543 | 13105 | 12037 | 0 | 6297 | etimesgut | 202841 |
| **7** | 41897 | 8304 | 14237 | 12960 | 12653 | 0 | 6620 | ymah | 628459 |
| **8** | 29704 | 8860 | 10093 | 8330 | 8971 | 0 | 4693 | kecioren | 756142 |
| **9** | 135 | 4245 | 46 | 322 | 41 | 0 | 21 | dış | 107939 |
| **10** | 23995 | 25355 | 8153 | 1290 | 7246 | 240 | 3791 | | 3883883 |
| **11** | 51050 | 10190 | 17347 | 2444 | 15417 | 0 | 8066 | | 3775944 |
| **12** | 55096 | 8053 | 18722 | 15819 | 16639 | 0 | 8705 | | |
| **13** | 41864 | 4016 | 14225 | 9923 | 12643 | 0 | 6614 | | |
| **14** | 27966 | 4888 | 9503 | 8061 | 8446 | 0 | 4419 | | |
| **15** | 74131 | 6686 | 25190 | 15989 | 22387 | 941 | 11713 | | |
| **16** | 18420 | 20525 | 6259 | 57139 | 5563 | 0 | 2910 | | |
| **17** | 41911 | 3685 | 14241 | 3478 | 12657 | 0 | 6622 | | |
| **18** | 34875 | 3363 | 11851 | 11292 | 10532 | 0 | 5510 | | |
| **19** | 66785 | 5550 | 22694 | 10281 | 20169 | 0 | 10552 | | |
| **20** | 41989 | 9324 | 14268 | 4619 | 12681 | 40 | 6634 | | |
| **21** | 66958 | 6302 | 22752 | 7474 | 20221 | 20 | 10579 | | |
| **22** | 46033 | 7953 | 15642 | 6014 | 13902 | 0 | 7273 | | |
| **23** | 27928 | 6075 | 9490 | 5768 | 8434 | 0 | 4413 | | |
| **24** | 40373 | 8459 | 13719 | 7064 | 12193 | 0 | 6379 | | |
| **25** | 33767 | 3196 | 11474 | 4387 | 10198 | 0 | 5335 | | |
| **26** | 38501 | 7000 | 13083 | 11469 | 11627 | 0 | 6083 | | |
| **27** | 34770 | 3291 | 11815 | 5107 | 10501 | 0 | 5494 | | |
| **28** | 61056 | 7039 | 20747 | 24515 | 18439 | 0 | 9647 | | |
| **29** | 61394 | 8131 | 20862 | 18351 | 18541 | 0 | 9700 | | |
| **30** | 43068 | 2962 | 14635 | 4698 | 13007 | 0 | 6805 | | |
| **31** | 22581 | 2473 | 7673 | 9149 | 6819 | 0 | 3568 | | |
| **32** | 31589 | 4954 | 10734 | 5580 | 9540 | 0 | 4991 | | |
| **33** | 31392 | 4091 | 10667 | 4577 | 9480 | 0 | 4960 | | |
| **34** | 29152 | 5877 | 9906 | 4033 | 8804 | 0 | 4606 | | |
| **35** | 4268 | 8536 | 1450 | 25505 | 1289 | 2515 | 674 | | |
| **36** | 14679 | 7999 | 4988 | 9010 | 4433 | 600 | 2319 | | |
| **37** | 27347 | 7510 | 9292 | 11066 | 8259 | 750 | 4321 | | |
| **38** | 35366 | 6716 | 12017 | 5754 | 10681 | 0 | 5588 | | |
| **39** | 12180 | 29741 | 4139 | 7480 | 3678 | 830 | 1924 | | |
| **40** | 13373 | 39061 | 4544 | 7164 | 4039 | 0 | 2113 | | |
| **41** | 26 | 8909 | 9 | 0 | 8 | 0 | 4 | | |
| **42** | 61081 | 11057 | 20755 | 18418 | 18446 | 0 | 9651 | | |
| **43** | 12998 | 62199 | 4417 | 3411 | 3925 | 0 | 2054 | | |
| **44** | 75995 | 19024 | 25823 | 12382 | 22950 | 0 | 12007 | | |
| **45** | 59908 | 8600 | 20357 | 10225 | 18092 | 0 | 9466 | | |
| **46** | 13928 | 1584 | 4733 | 3104 | 4206 | 0 | 2201 | | |
| **47** | 113099 | 14896 | 38431 | 30097 | 34156 | 0 | 17870 | | |
| **48** | 232320 | 18300 | 78942 | 64231 | 70161 | 0 | 36707 | | |
| **49** | 187832 | 10580 | 63825 | 39640 | 56725 | 1050 | 29677 | | |
| **50** | 34865 | 7763 | 11847 | 27456 | 10529 | 2000 | 5509 | | |
| **51** | 9888 | 8898 | 3360 | 9845 | 2986 | 0 | 1562 | | |
| **52** | 241530 | 22588 | 82072 | 56421 | 72942 | 0 | 38162 | | |
| **53** | 59946 | 9137 | 20370 | 10025 | 18104 | 0 | 9471 | | |
| **54** | 127640 | 16540 | 43372 | 21400 | 38547 | 0 | 20167 | | |
| **55** | 112675 | 23304 | 38287 | 28302 | 34028 | 0 | 17803 | | |
| **56** | 8425 | 13877 | 2863 | 970 | 2544 | 0 | 1331 | | |
| **57** | 17227 | 17321 | 5854 | 1365 | 5202 | 28 | 2722 | | |
| **58** | 101 | 15500 | 34 | 0 | 30 | 0 | 16 | | |
| **59** | 56421 | 14736 | 19172 | 11807 | 17039 | 0 | 8915 | | |
| **60** | 31435 | 4921 | 10681 | 8920 | 9493 | 0 | 4967 | | |
| **61** | 23519 | 10768 | 7992 | 9904 | 7103 | 3746 | 3716 | | |
| **62** | 36 | 19436 | 12 | 0 | 11 | 265 | 6 | | |
| **63** | 196929 | 24116 | 66917 | 46862 | 59473 | 0 | 31115 | | |
| **64** | 115330 | 6148 | 39189 | 29877 | 34830 | 0 | 18222 | | |
| **65** | 58961 | 16000 | 20035 | 12460 | 17806 | 0 | 9316 | | |
| **66** | 119885 | 16032 | 40737 | 32114 | 36205 | 0 | 18942 | | |
| **67** | 7875 | 4138 | 2676 | 2413 | 2378 | 371 | 1244 | | |
| **68** | 35318 | 4927 | 12001 | 9488 | 10666 | 0 | 5580 | | |
| **69** | 38545 | 10320 | 13098 | 12881 | 11641 | 0 | 6090 | | |
| **70** | 41 | 401 | 14 | 0 | 13 | 0 | 7 | | |
| **71** | 1446 | 3471 | 491 | 0 | 437 | 0 | 228 | | |
| **72** | 2692 | 3675 | 915 | 0 | 813 | 0 | 425 | | |
| **73** | 49707 | 752 | 16891 | 12663 | 15012 | 0 | 7854 | | |
| **74** | 78 | 2493 | 27 | 0 | 24 | 0 | 12 | | |
| **75** | 1233 | 7279 | 419 | 0 | 372 | 37 | 195 | | |
| **76** | 2330 | 7777 | 792 | 0 | 704 | 0 | 368 | | |
| **77** | 2916 | 4435 | 991 | 565 | 881 | 0 | 461 | | |
| **78** | 3742 | 13908 | 1272 | 0 | 1130 | 0 | 591 | | |
| **79** | 2190 | 6164 | 744 | 0 | 661 | 318 | 346 | | |
| **80** | 49041 | 5908 | 16664 | 6159 | 14810 | 60 | 7748 | | |
| **81** | 102313 | 1290 | 34766 | 21516 | 30899 | 0 | 16165 | | |
| **82** | 68951 | 18219 | 23430 | 16934 | 20823 | 0 | 10894 | | |
| **83** | 22097 | 970 | 7509 | 4550 | 6673 | 0 | 3491 | | |
| **84** | 1017 | 1300 | 345 | 0 | 307 | 0 | 161 | | |
| **85** | 8033 | 12398 | 2730 | 1390 | 2426 | 106 | 1269 | | |
| **86** | 638 | 5611 | 217 | 0 | 193 | 0 | 101 | | |
| **87** | 48106 | 5988 | 16346 | 12331 | 14528 | 80 | 7601 | | |
| **88** | 49716 | 3112 | 16894 | 8055 | 15014 | 380 | 7855 | | |
| **89** | 21358 | 221 | 7258 | 6939 | 6450 | 104 | 3375 | | |
| **90** | 16397 | 19278 | 5572 | 2091 | 4952 | 0 | 2591 | | |
| **91** | 9932 | 487 | 3375 | 1036 | 2999 | 0 | 1569 | | |
| **92** | 2142 | 4629 | 728 | 505 | 647 | 0 | 338 | | |
| **93** | 5918 | 7687 | 2011 | 1336 | 1787 | 0 | 935 | | |
| **94** | 3112 | 14072 | 1057 | 0 | 940 | 0 | 492 | | |
| **95** | 36500 | 16746 | 12403 | 7954 | 11023 | 241 | 5767 | | |
| **96** | 4470 | 4160 | 1519 | 1590 | 1350 | 0 | 706 | | |
| **97** | 13586 | 4349 | 4617 | 3252 | 4103 | 52 | 2147 | | |
| **98** | 1707 | 5583 | 580 | 0 | 516 | 0 | 270 | | |
| **99** | 78 | 1670 | 26 | 0 | 23 | 0 | 12 | | |
| **total** | **3883883** | 1205088 | 1319744 | 1071284 | 1172933 | 20088 | 613654 | | |

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