



Escola de Camins

Escola Tècnica Superior d'Enginyeria de Camins, Canals i Ports
UPC BARCELONATECH

PROJECTE O TESINA D'ESPECIALITAT

Títol

**Travel-time impacts analysis of system-wide signal
timing optimization methodology**

Autor/a

Luis María Ainchil Cayuela

Tutor/a

Tutor extern: Dr. Zongzhi Li

Tutor UPC: Dr. Francesc Robusté

Departament

Infraestructura del transport i del territori

Intensificació

Data

Març 2014

TRAVEL TIME IMPACTS ANALYSIS OF SYSTEM-WIDE SIGNAL TIMING
OPTIMIZATION METHODOLOGY

BY:

LUIS MARIA AINCHIL

DEPARTMENT OF CIVIL, ARCHITECTURAL AND ENVIRONMENTAL
ENGINEERING

ILLINOIS INSTITUTE OF TECHNOLOGY

Submitted in partial fulfillment of the
requirements for the degree of
“Ingeniero de Caminos, Canales i Puertos”
in the Escola Tècnica Superior d’Enginyeria de Camins, Canals i Ports
Universitat Politècnica de Catalunya

Chicago, Illinois

March 2014

ACKNOWLEDGEMENT

I would like to take this opportunity to express my sincere appreciation to all those who have helped me through the elaboration of this research project. Special thanks should be given to Professor Zongzhi Li for allowing me to join the Transportation Engineering department at Illinois Institute of Technology.

I would like to express my profound gratitude to Dr. Arash M. Roshandeh, my co-advisor at Illinois Institute of Technology, for his continuous guidance, patience and insight throughout the period of this project.

I wish to acknowledge the help provided by Professor Francesc Robusté, my research supervisor at the Technical University of Catalonia-BarcelonaTech (UPC), for his valuable and constructive suggestions during the planning and development of this research work.

At this point I would like to thank my parents, Javier and Conxita, my brothers and sisters, Albert, Carlos, Montse and Maria del Mar, for their continued support and encouragement throughout my studies.

Finally, I would also like to extend my thanks to the Community of De La Salle Brothers (FSC) and Volunteers in Chicago, for being a second home during my time in the U.S., and wish them all the very best.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENT.....	iii
LIST OF TABLES.....	v
LIST OF FIGURES.....	vi
AUTHORS NOTE.....	vii
ABSTRACT.....	vii
CHAPTER	
1. INTRODUCTION AND OBJECTIVES.....	1
2. LITERATURE REVIEW.....	5
2.1 The Method of Simultaneous Optimization of Vehicle and Pedestrian Delays.....	5
2.2 Travel-time User Benefits Analysis.....	9
3. METHODOLOGY.....	17
3.1 Justification of the Chosen Methodology for User Benefit Analysis in terms of Travel Time.....	17
3.2 TDM Methodology for Calculating Travel Time User Benefits.....	18
4. METHODOLOGY APPLICATION.....	25
4.1 TDM Methodology Application.....	25
4.2 Analysis of Results.....	33
5. SUMMARY AND CONCLUSIONS.....	39
5.1 Summary.....	39
5.2 Conclusions.....	40
5.3 Recommendations and future works.....	40
REFERENCES.....	41

LIST OF TABLES

Table		Page
3.1	AASHTO Guidelines for assigning Values of Time in Highway Projects	21
4.1	Occupancy rates. U.S. Department of Transportation (1990-2013).....	27
4.2	Trip purposes weights over a working day.....	29
4.3	Occupational employment and wages by major occupational group, United States and the Chicago-Joliet-Naperville Metropolitan Division, May 2012.....	29
4.4	Value of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using the Basic and the HCM Model	33
4.5	Value of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using HSL Model.....	36

LIST OF FIGURES

Figure	Page
2.1 Consumer surplus in the demand curve.....	13
2.2 Social Consumer Surplus variation, European Commission (2008).....	14
3.1 Flowchart of the TDM methodology used.....	19
4.1 Division of the CBD in the four areas of study.....	25
4.2 Accumulated value of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using the HCM Model	34
4.3 Stack up Zone values of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using the HCM Model.....	35
4.4 Stack up Zone values of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using the HSL Model.....	37
4.5 Accumulated value of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using the Basic and the HCM Model.....	37

AUTHOR'S NOTE

The following study has been developed using International System Units. In some cases U.S. Customary Units will be used in the report for information purposes, along with their I.S. equivalents shown in brackets.

When talking about currency, US dollars in 2013 is the currency used for calculations. When converting from foreign currencies, values provided by U.S. Federal Reserve have been used as for February 14th, 2014. For instance, Euro has been converted as follows: 1.3690 \$ = 1€.

As for notation on written numbers, U.S. tradition is observed regarding decimal point use (.) and the concept of billion (10^9).

ABSTRACT

Over the last few decades congestion has increased in a very significant way. Recent research show that the costs related to congestion in the United States increased from \$94 billion to \$121 billion from 2000 to 2011, as found by Texas A&M Transportation institute (2012). As this cost affect the social and economical welfare of citizens and companies, suitable solutions must be found by transportation agencies in order to eliminate or at least reduce this negative effect.

Land availability, limited budgets and time or the need of long term solutions, may imply giving priority to low impact solutions adapted to the specific needs of a certain area. The study conducted by Roshandeh *et al.* (2014) is an example of a congestion reduction program that uses existing infrastructure in a smart way. By means of signal timing optimization models that consider both vehicle and pedestrian delays in the Chicago Central Business District (CBD), vehicle delays and travel times are expected to be reduced up to 13 percent when only considering vehicle delays, and by 5 percent when simultaneously considering vehicle and pedestrian delays.

This study analyzes the economic impact that users would experience with the travel time variation due to system-wide signal timing optimization. To do this, a comprehensive analysis of travel time user benefits is conducted using traffic volume, speed and other attributes of road network, before and after signal timing optimization. Obtained results show that average daily benefits from 50,000\$ up to 125,000\$ could be achieved in the Chicago CBD area due to optimizing the timing plans of traffic signals. It needs to be specified that, applying different weighting factors for pedestrian and vehicle delays, would results into various set of achievements.

CHAPTER 1

INTRODUCTION AND OBJECTIVES

In the last 30 years traffic congestion has increased substantially as to become one of the major issues of every city. Recently, after passing a period of economic recession, many regions are experiencing traffic congestion due to more economical activities and development within urban areas. It is alarming the fact that in 2011 the extra time suffered by the average urban auto commuter was 38 hours, which it was around 52 hours in areas with over three million people, as stated by *Texas A&M Transportation Institute* (2012).

The amount of time spent due to traffic congestion implies an economical cost to the society. As for 2011, the cost to the average commuter was \$818 compared to an inflation-adjusted \$342 in 1982. If we talk about fuel, about 19 gallons (72 liters) were spent due to increase of travel time in the same year. Externalities, like air and noise pollution can be considered another cost related to this traffic condition. Over 56 U.S. billion pounds (25.4 billion kg) of additional carbon dioxide (CO₂) greenhouse gas was released into the atmosphere during urban congested conditions

Taking all these facts into consideration, transportation agencies try to find solutions to minimize vehicle congestion and increase the capacity of the system. Even after a remarkable economic recession, with low prices for construction, traditional high impact improvements like new roads, adding lanes or ring roads may not be a smart solution. Limited land availability, time and budget are serious determinants in these days. Most of the time, this kind of major projects take 5 to 15 years to develop, requiring high programming and huge funding efforts that most cities cannot afford.

Moreover, these plans run the risk of being inefficient right after inauguration due to the complexity of traffic forecast. This situation opens the door to methodologies based in the performance improvement of an existent infrastructure.

In 2013, Roshandeh *et al.* (published in 2014) developed a ground breaking methodology to minimize delays in both vehicles and pedestrians, in Chicago, one of the U.S. Cities with highest congestion (The Washington Post, 2011). This new approach is crucial in zones with a large pedestrian density, like business districts and tourism areas in major cities. The procedure to reach this goal consists in an adjustment of green splits in all intersections, without changing cycle lengths.

This methodology upgrades prior existing methods mainly in two ways: first, by taking into consideration a city's whole network of intersections; and second, by considering simultaneously pedestrian and vehicle delays.

Using a shockwave model, wave speeds of vehicles were calculated, for both undersaturated and oversaturated traffic conditions. Two different models were implemented in Roshandeh *et al.* (2014): the first one is a basic model that handles only vehicle delays; and the second one, is an enhanced model that works simultaneously with vehicles and pedestrians, using two pedestrian delay estimation methods. The models are run separately using an extensive regional travel demand simulation tool (TRANSIMS).

The method was applied using Chicago streets' geometric designs, signal timing plans, vehicle and pedestrian counts and regional travel demand. The results after signal timing optimization were analyzed, concluding that vehicle delays in the Chicago Business District area could be reduced by 13% when only considering vehicle delays for signal timing optimization and 5% when simultaneously considering vehicle and

pedestrian delays. Moreover it was observed that the effectiveness of vehicle delay reduction varied greatly between different subareas, showing in this way those areas that could improve their traffic performance.

The travel time variation of this methodology provides the agencies with data regarding travel time and delays. However, in order to ensure the viability of this methodology, a comprehensive cost-benefit analysis needs to be performed.

The Benefit related to changes in travel times is one of the primary components of user costs and benefits that need to be evaluated. In this context, the goal of the current thesis is to calculate the Travel-time User Benefits due to the implementation of Roshandeh *et al.*'s (2014) work in the Chicago Central Business District (CBD). Moreover, this study wants to determine which model and pedestrian weight consideration provides better results for each zone and for the whole area.

The contribution of the current study is the identification of the travel-time reduction influence in the profitability of the new methodology. The analysis is carried out based in two concepts: the consumer surplus and the Value of time.

Chapter 1: In this stage the methodology on which the study is based on, is introduced. The context and main objectives are stated.

Chapter 2: Presents a literature review of the main methods used worldwide for evaluation of transportation improvements, as well as different approaches to the concept of value of time.

Chapter 3: Describes the general methodology proposed and why it has been chosen. Several concepts are introduced and explained.

Chapter 4: The methodology is here applied using real data from Roshandeh *et al.* (2014)'s model, as well as information from governmental agencies. A detailed example is provided and the data treatment explained. Final results are shown and discussed.

Chapter 5: This last section summarizes the main results and the conclusions. Recommendations and future work are also proposed.

CHAPTER 2

LITERATURE REVIEW

In order to provide insight on the state of the art regarding this study, Roshandeh *et al.*'s Methodology (2014) is reviewed briefly in the first section, naming some of the documentation that laid the foundations of its development. The second section, focuses on the main goal of this work, which is the Travel Time User Benefit Analysis. To this end, the concepts of user benefits and different existing methodologies for calculation purposes are examined. A comprehensive investigation is run over the concepts and approaches of consumer surplus, vehicle occupancy and value of time.

2.1 The Method of Simultaneous Optimization of Vehicle and Pedestrian Delays

2.1.1. Introduction

As previously mentioned, Roshandeh *et al.* (2014) developed an innovative methodology to minimize delays in both vehicles and pedestrians, in Chicago, by adjusting green splits of traffic signals at all intersections, without changing cycle lengths. This methodology upgrades prior existing methods mainly in two ways:

- The first one is that it takes into consideration major portion of Chicago city's network of intersections, including 875 signalized intersections. This is a new approach, since previous traffic models based on kinematic wave theory try to solve congestion and vehicle delays for isolated intersections (Michalopoulos and Stephanopoulos, 1981; Dion *et al.*, 2004; Liu *et al.*, 2009) or urban corridors (Hisai and Sasaki, 1993; Ban *et al.*, 2011). These models were unable to handle accurately parallel corridors or an urban street network. Strong limitations are

observed when studying benefits from reductions in delays and congestion that could affect drivers using related intersections or corridors.

- The second innovation is related to simultaneous consideration of vehicle and pedestrian behavior. Existing models do not simultaneously treat vehicle and pedestrian delays for intersections along corridors or within a network. This may lead to excessive delays and congestion to motorists on perpendicular corridors and to pedestrians as well.

2.1.2. Methods to Increase Network Efficiency

Roshandeh *et al.* (2014) introduced a new methodology that arises from kinematic wave theory for system wide signal timing optimization to achieve the lowest level of delays using a dense urban street network. In the research to offer useful measures to improve efficiency of intersection capacity utilization, several traffic flow models have been developed (Robert, 1998; and Garber and Hoel, 2001).

Many models use kinematic wave theory, also known as the Lighthill-Whitham-Richards (LWR) theory, to explain traffic dynamics on a roadway segment or intersection approach with kinematic waves, including decelerating (shock) waves and accelerating waves. Previous work that use this theory with signal coordination could be found in Michalopoulos and Stephanopoulos (1981) and Hisai and Sasaki (1993). Some authors used loop detectors (Liu *et al.*, 2009) or mobile traffic sensors (Ban *et al.*, 2011) to estimate intersection queue length.

Additionally, several researchers investigated pedestrian walking behaviors like Dijkstra and Timmermans (2002), Osaragi, (2004), Hoogendoorn and Bovy, (2004) and Antonini *et al.*, (2006), to mention the most recent. In another study performed by Teknomo (2006), a simple multi-agent simulation was performed using kinematic

theory. Robin *et al.* (2009) proposed a model for pedestrian walking behavior based on discrete choice modeling under unconstrained and constrained conditions, respectively. Very few research conducted analysis of the interaction between vehicle and pedestrian movements. As an example, Airault *et al.* (2004) developed a microscopic simulation tool, ARCHISIM, that could model pedestrian movements on virtual lanes and in case of obstacles that pedestrians could maneuver around them.

2.1.3. Different Models

Signal timing optimization is carried out using three models as defined in Roshandeh *et al.* (2014): a basic model that handles vehicle delays only and two enhanced models that simultaneously deal with vehicle and pedestrian delays, using two different pedestrian delay estimation methods.

The first enhanced model is defined by considering pedestrian delay using Highway Capacity Manual formulation (HCM, 2010), while the second enhanced model uses Herbert S. Levinson theory (Li *et al.*, 2012). In these two enhanced models, a weighed total of average vehicle and pedestrian delays per cycle replaces the objective function of the basic model, assigning relative weights from 10% to 90% to pedestrian delay. Since the objective is to minimize the average delay of the whole system, a general formula of the objective function of the enhanced model could be defined as:

$$(1 - w) \cdot Delays_{VEH} + w \cdot Delays_{PED} \quad (2.1)$$

Therefore nine cases are analyzed individually for each one of the enhanced model, plus one case for the basic model, making a total of 19 alternatives studied.

2.1.4. Data Collection and Processing

Several data is required to calibrate and validate the Chicago Model. The existing traffic signal timing plans were obtained for all 875 intersections in the study area from Chicago Department of Transportation (DOT). The latest regional O-D demand data, available for 2001, provided travel demand information required as input.

As for the field traffic data on Interstate, freeway, and expressway mainlines, over six hundred continuous sensor-counting stations along Gary-Chicago-Milwaukee (GCM) corridor for period 2007-2009 were used as a base for model calibration and validation. Intersection Midblock Traffic Data was collected from a Chicago Department of Transportation (DOT) program that collected citywide intersection traffic data in 2006, the input data to the pedestrian model comes from a study of pedestrian traffic conducted in Chicago Loop Area during 2007 summer. All the data collected after 2001 was converted to 2001 counts using extrapolation considering 1 percent as the traffic discount rate.

The models were run separately using TRANSIMS Simulation tool. Extensive documentation has been written regarding TRANSIMS software, for instance Smith *et al.* (1995) or Barrett *et al.* (1995). Without being exhaustive, TRANSIMS is an abbreviation for TRansportation ANalysis and SIMulation System, and is an integrated platform to conduct regional transportation system analysis based on a cellular automata micro simulator. It is capable of conducting large-scale simulation on a second-by-second basis for detailed regional multimodal transportation planning, traffic operations and evacuation planning/emergency management analyses.

Its approach is based on modeling individual travelers and their multi-modal transportation based on synthetic populations and their activities. Compared to

traditional traffic planning approaches, TRANSIMS requires a significant amount of data and computing resources. Further information about how this software was used to create, calibrate and validate a Chicago TRANSIMS model can be found in Li *et al.* (2012). The output data of TRANSIMS provided for each model is composed of data sheets regarding travel speeds, travel times and traffic volumes for base case and alternative scenarios.

2.2 Travel-time User Benefits Analysis

In this section, a general review is conducted on the role of user benefit analysis in the world, the different methodologies employed and the theories on which is based.

2.2.1 Cost-Benefits Analysis

Long-term economic development strongly depends on the availability of good infrastructures, and a transportation network is particularly important. Because the resources available to society are limited, it is very important to make good decisions about which improvement should be implemented. Governments employ benefit-cost analysis to ensure that their regulatory actions and investments in transportation infrastructure will use society's resources most efficiently and to promote transparency in decision-making.

Around 1960, cost-benefit analysis started to be applied for transportation investments, with the planning and construction of the M1 Motorway, the first inter-urban motorway to be completed in the UK; and later on in the London Underground's Victoria Line. Since then, several cost-benefit analysis approaches have been developed and widely used for evaluating transportation projects around the world.

In the United Kingdom, a methodology called the New Approach to Appraisal (NATA) was introduced by the then U.K. Department for Transport,

Environment and the Regions with the publication of the *White Paper* (1998). This methodology has been a cornerstone of transport appraisal in the UK and it has been maintained and lately developed into the *Transport Analysis Guidance* (2014).

In the United States, several handbooks have been published by federal administrations and associations like the Federal Highway Administration (*Economic Analysis Primer: Benefit-Cost Analysis*, 2003), the AASHTO's *Red Book (User Benefit Analysis for Highways*, 2003), Transportation Research Board (*Transportation Benefit-Cost Analysis*, 2013) ; and state agencies like Indiana Department of Transportation (*INDOT Design Manual*, 2002) or Minnesota Department of Transportation (*Benefit-Cost Analysis for Transportation Projects*, 2003), to mention a few.

As for other countries, Canada promoted the analysis for major transport investments with the *Guide to Benefit-Cost Analysis in Transport Canada* (1994). In the European Union, in order to issue common transport appraisal guidance across EU's member states, the European Commission published the *EU Guide to Cost-Benefit Analysis of Major Projects* (2008).

2.2.2. User Benefits

It seems intuitive that there are different types of benefits depending on who receives the impact of transportation improvements. It is commonly accepted in the guides explained previously, that benefits can be separated in two big groups: user benefits and indirect benefits (also known as non-user benefits).

As explained in the *AASHTO Red Book* (2003), user benefits are the ones enjoyed by travelers that are directly affected by a transportation improvement. They are determined by travel costs in three distinct areas: travel time costs (on which this

study is focused), operating costs, and accident costs. Taken together, the total of these costs is essentially the price that travelers must pay to travel.

The user benefit could be defined in a simplistic way as the difference between the costs of traveling in two different scenarios, where one of them offers a reduced travel cost regarding the other one. The benefit consists on making the same trip at a lower cost. In a transportation improvement, this approach is decisive, since most of the projects try to reduce the travel cost perceived by users in many ways (for instance, reducing travel times or accidents). There is an economic interest behind, since a user-friendly infrastructure may improve the economic activities in the area.

Even though it does not seem always obvious, a project will also impact people other than direct users of the facility. These effects are referred to as indirect benefits or non-user benefits. Examples of indirect benefits include environmental impacts, effects on urban growth, economic influences, and the distribution of costs and benefits attached with the project.

Taking these two kinds of concepts in to consideration and comparing them with the project cost, an estimator could determine if a certain improvement would be beneficial or not to the society.

2.2.3. Travel-time User Benefits

When measures are taken to upgrade a transportation system, it is usually forecasted that they will reduce travel time, either by decreasing waiting and/or transfer time, or by incrementing travel speed.

It has been object of study the importance of savings in travel time over the total of transportation user benefits. In the sixties, Beesley (1965) realized that the time

saving can represent a high percentage of the generalized benefits to society obtained from the construction of infrastructure projects. On the basis of his experience, he detected that the time savings resulted from 64% to 78% of the total measured gross benefits (depending on the time unit valuation) in the first operation year of the M1 motorway in the United Kingdom and as far as 80% for the Victoria Line in the London Underground. More recently, the European Conference of Ministers of transport (2003) concluded that Time savings usually account for about four-fifths of the non-monetary benefits of transport policy measures.

These results show clearly that is true the generally accepted idea that savings in travel time often constitute the largest component of transport benefits to society. Therefore it seems right that many methodologies (AASHTO, 2003), Sinha and Labi (2007), European Commission (2008), to mention a few) use this element as their main criterion for planning and development of transportation improvements.

The calculation of travel-time user benefits is performed in almost all previously mentioned manuals in base to two economic concepts: Consumer surplus theory and Value of Time.

2.2.4. Consumer Surplus

User benefits for transport projects can be defined by the concept of the consumer's surplus, as seen in European Commission (2008), Kenneth Small (1999) or Victoria Transport Policy Institute (2012), to name a few.

The consumer surplus is defined in transportation economy as the excess of consumers' willingness-to-pay over the prevailing generalized cost of a specific trip. Willingness-to-pay is the maximum amount of money that a consumer would be willing to pay to make a particular trip, and generalized cost is an amount of money

representing the overall inconvenience perceived by the users travelling between a particular origin (i) and destination (j) by a particular mode. The traditional demand curve can be used to understand the concept:

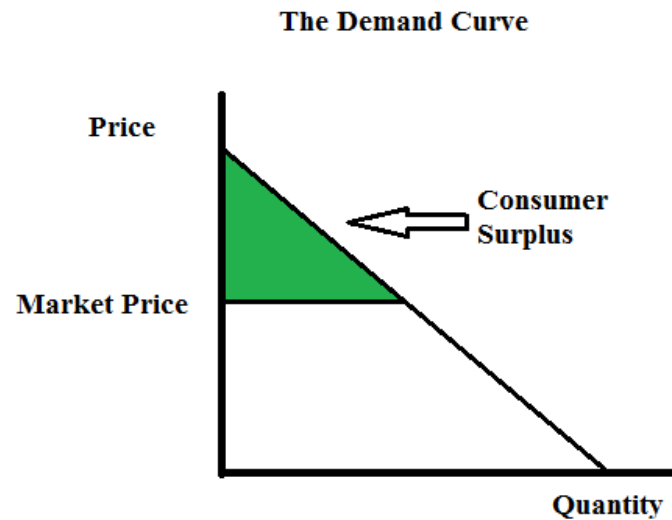


Figure 2.1 Consumer Surplus in the Demand Curve

Consumer surplus is calculated as the green area in figure 2.1 in the traditional demand curve. The surplus associated with making a journey will not be the same for everybody and depends on the benefit each individual derives from making that journey. When analyzing user benefits, two different situations can be observed, as in figure 2.2:

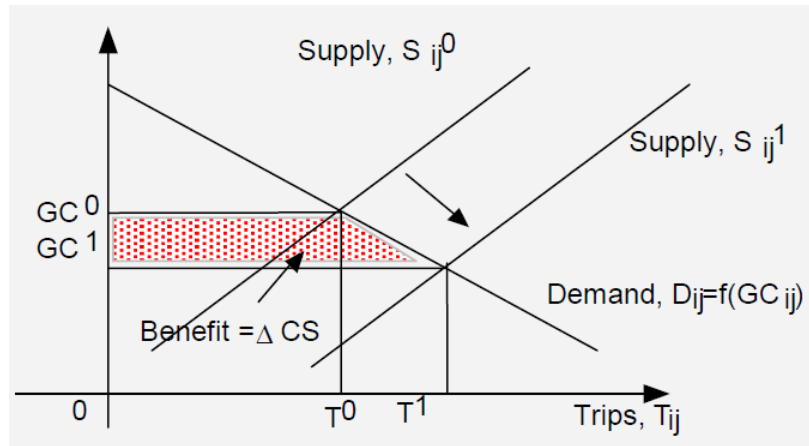


Figure 2.2 Social Consumer Surplus Variation, European Commission (2008)

Here it can be observed that when a new situation arises in which general costs (GC) are reduced (for instance, due to a diminution on travel time), the number of travelers (or trips) increases and therefore, consumer surplus. From this point it seems reasonable that the user benefit will be the difference between the two consumer surplus, or graphically, between two areas.

In the travel time user benefit scenario, the approach is exactly the same, replacing the costs with the travel time required to a certain trip.

2.2.5. Value of Time

Since a value of the cost associated to travel time is required to calculate the travel-time user benefits, the Value of Time (VOT) is one of the most important elements in project appraisal. In neoclassical microeconomics it is defined as the willingness to pay for unit travel time savings (Jiang *et al.*, 2004). Sinha and Labi (2007) defines the value of time as the value of goods, services, or some utility that can be produced within a time interval. Criado *et al.*, 2011) define the same concept as the subjective valuation that a transport user assigns to the time consumed when traveling with a certain mode of transport.

These definitions agree with the idea accepted in all governmental guidebooks reviewed that this value will depend upon the alternative choices that the user may have for the time spent in a transportation facility, also known as the opportunity cost.

Several studies have been conducted on the VOT and the elements on which it depends, in order to obtain an accurate value. The first to consider the idea that the time spent traveling was non-work time was Becker (1965), thus laying the foundations of the wage approach. Pleasant and unpleasant travel conditions were considered later by Johnson (1966). However, some years had to pass until Oort (1969) first evaluated travel time benefits due to travel time reduction in a new infrastructure. Small *et al.* (1999) analyzed different studies on VOT estimation for congested and uncongested situations, deducing that the congested travel time is valued more than uncongested travel time.

With the time, the wage approach gained momentum, being nowadays the cornerstone of the value of time appraisal in many countries around the world. Provided that work is usually the main alternative use of the time, seems intuitive that the value of time will be related to wage. This approach states that the value assigned to an hour of travel time should be a percentage of the after-tax hourly wage, being this percentage dependant on the purpose of the trip (AASHTO, 2003).

Following this, transportation agencies and researchers use different standpoints. In one hand, some of them decided to provide fixed values of value of time for each purpose and mode. (European Commission, 2008; Transport Canada, 1994; Forkenbrock and Weisbrod, 2001).

On the other hand, some agencies prefer to assign fixed percentages to this purposes, and let the analysts and practitioners derive the values of time for each specific project from the users' actual choices, or to re-adjust and to re-weight the estimates from other studies on the basis of income levels (ECONorthwest and Parsons, 2002; VTPI, 2009; AASHTO, 2003; Gwilliam, 1997; Lam and Small, 2001).

CHAPTER 3

METHODOLOGY

When evaluating travel time user's benefit a consistent methodology need to be applied. Since this study includes sensitive socio economic concepts that may vary with the time many formulas, considerations and hypothesis will need to be explained and its use justified.

3.1 Justification of the Chosen Methodology for User Benefit Analysis in terms of Travel Time

Considering the conditions of the project and after studying different alternatives, the methodology found in *Transportation Decision Making: principles of project evaluation and programming* (TDM) by K. Sinha and S. Labi (2007) has been chosen as main guide to develop this study, being based and complemented with the manual *AASHTO User Benefit Analysis for Highways* (2003), also known as *Red Book*.

Three main reasons lead to this selection are as follows:

1. Interoperability: The Sinha and Labi (2007) Method has a perfect interoperability with the AASHTO & HCM manuals and regulations, sharing the very same variables, concepts, procedures and references in both documents. This is also convenient because our input data comes from the transport simulation tool TRANSIMS, used by the U.S. Department of Transportation and completely adapted to the same standards observed in the HCM and AASHTO Red book.

2. Area of application: Being Chicago the zone where the methodology was developed and tested, seems right to develop the analysis using a method approved and used in the State of Illinois.

3. Clarity and structure: The TDM method provides a simple and organized approach to the analysis of benefits that allows a positive understanding of the procedure and easy detection of mistakes. AASHTO approximation gives a comprehensive general vision of the problem, while TDM makes some of AASHTO's scheme simpler.

3.2 TDM Methodology for Calculating Travel Time User Benefits

Sinha and Labi (2007), as well as the *AASHTO User Benefit Analysis for Highways Manual* (2003) focuses on user benefits, meaning benefits that are enjoyed by travelers that are directly affected by a transportation improvement.

The *AASHTO Red Book (2003)* states that the majority of the improvement types related to transportation will affect travel times for users of the facility. As a consequence, the change in travel times for traversing the improved segment is one of the primary components of user costs and benefits to be evaluated. The *Transportation Decision Making: principles of project evaluation and programming* (using the same formulas considered in the *AASHTO User Benefit Analysis for Highways Manual*) provides us with the following procedure:

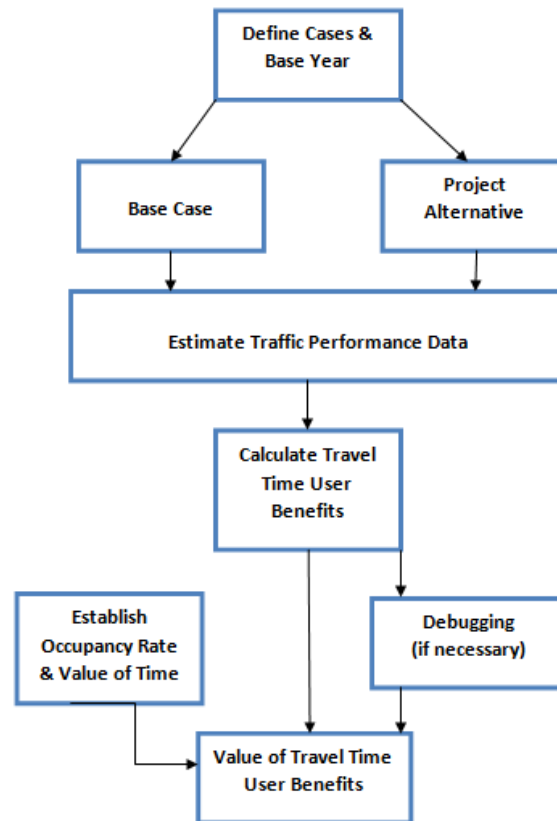


Figure 3.1 Flowchart of the TDM methodology used

The order of the steps has been altered for explanatory purpose, trying to explain in first place the variables that take part in the main formula, knowing that this will not alter the final results.

3.2.1. Defining the Project Alternative and the Base Case

The first step in every User Benefit Analysis is to define the Project Alternative and the Base Case against which the project improvements are to be measured. This first move is of significant importance as it identifies exactly what improvement to the road system is being evaluated and which zones and facilities are directly and indirectly affected by its implementation. Calculations will need to be performed on all of the affected road system links or corridors. A base year needs to be established as well in order to have a reference point for time-dependant variables.

3.2.2. Estimation of traffic performance data before and after intervention.

Demand, capacity, travel speeds and travel times; these are the main inputs of Sinha and Labi (2007) and AASHTO (2003) methodologies. Obtaining traffic performance may be the most time-consuming part of project evaluation. It is in this step that the analyst must provide the traffic volume, speed/travel time, and other performance measurements for all of the affected road segments or corridors of both the Project Alternative and the Base Case.

It is not the goal of this study to explain how these estimations can be performed. Proved estimation methodologies can be found in the Highway Capacity Manual (2010) or in Roshandeh *et al.* (2014), just to mention a couple.

For transportation authorities that have well-developed network representations and travel demand modeling suites, the effort required to produce detailed information is much less than in the case where an analyst is making estimates by hand. Even with sophisticated models, however, considerable time, effort, and expense are involved in developing traffic performance data for even simple projects.

3.2.3. Determine occupancy rates before intervention

This data informs us of the average number of people in each vehicle and allows the analyst to convert travel time per vehicle to travel time per vehicle occupant. The occupancy rates (OCC) before and after intervention are not expected to be substantially different in most cases, except those interventions that affect occupancy like HOV, HOT systems or car pooling initiatives.

Although it could be obtained performing field measurements, many local transportation agencies keep a constant study and record of the occupancy rates in their

work areas, as to ensure the accuracy of their studies and provide consistent data to external projects.

3.2.4. Establish the Unit Value of Travel Time

The value that users assign to their travel time is the most challenging and sensitive aspect of the analysis. As commented in chapter 2, it is commonly accepted that this value will depend upon the opportunity cost of that time and the alternative consumption opportunities that the user may have for the time spent in a transportation facility. The AASHTO Red Book continues in that direction and establishes guidelines to give value to this percentage of the wage, as seen in table 3.1.

Table 3.1 AASHTO Guidelines for assigning Values of Time in Highway Projects

Transportation Mode and Trip Purpose	Recommended Value of Time (For Use in Worksheet 5-1 and Worksheet 5.4)
AUTO	
Drive Alone Commute	50% of the wage rate
Carpool Driver Commute	60% of the wage rate
Carpool Passenger Commute	40% of the wage rate
Personal (local)	50% of the wage rate
Personal (intercity)	70% of the wage rate
Business	100% of total compensation
TRANSIT BUS	
In-Vehicle Commute	50% of the wage rate
In-Vehicle Personal	50% of the wage rate
Excess (waiting, walking, or transfer time) Non-business	100% of the wage rate
Business (all time)	100% of total compensation
TRUCK	
In-Vehicle Business	100% of total compensation
Excess (waiting time) Business	100% of total compensation

Source: Authors and U.S. Department of Transportation, 1997. *The Value of Travel Time: Departmental Guidance for Conducting Economic Evaluations*. Washington, D.C.

Information regarding wages is often public access information easy to find.

However many transportation agencies have already established travel-time values that can be updated for use in travel-time impact evaluation, for instance *EU Guide to Cost-Benefit Analysis* (2008). Such updating can be done by using trends in consumer prices

indices (CPI) for Private Transportation, always taking into consideration the local effects of inflation.

3.2.5. Calculate the Travel-time User Benefits

As commented in the literature review, user benefits for transport projects can be defined by the concept of the consumer's surplus. Sinha and Labi (2007) is also based in the approach that benefits result from variations in consumer surplus. This theory can be expressed in a general formula to calculate de User Benefits due to travel time reduction, as follows:

$$STT = \frac{(TT_{v1} - TT_{v2})}{3600} \cdot \left(\frac{V_1 + V_2}{2} \right) \quad (3.1)$$

Where: TT_{v1} is the average vehicle travel time without intervention, in seconds

TT_{v2} is the average vehicle travel time with intervention, in seconds

V_1 is the volume (or number of trips) without intervention.

V_2 is the volume (or number of trips) with intervention.

This step is, although simple, a remarkably laborious part of the procedure. Traffic projects often provide a significant amount of traffic performance information that requires extreme care when operating as to avoid double counting errors and absurd operations.

3.2.6. Debugging of Obtained Results

Usually the traffic performance data provided will consist in a large amount of results from different sources or models. Some models may be capable of generating unusual or even absurd outputs, resulting of accumulated errors or programming bugs. In these cases, a study and further data treatment may be required in order to ensure consistency

in the methodology and remove odd results. General statistic identifying methods may be used, like the Box plot, Chauvenet's criterion, Grubbs' test or Peirce's criterion, just to mention a few.

3.2.7. Calculate the Value of Travel-time User Benefits

Once defined the variables that are going to be used, a general complete formula to calculate de Value of Travel-time User Benefits is issued by Sinha and Labi (2007) in the following way:

$$\Delta H_i = \frac{(TT_{v1} - TT_{v2})}{3600} \cdot \left(\frac{V_1 + V_2}{2} \right) \cdot OCC \cdot VoT \quad (3.2)$$

Where: TT_{v1} is the average vehicle travel time without intervention, in seconds

TT_{v2} is the average vehicle travel time with intervention, in seconds

V_1 is the volume (or number of trips) without intervention.

V_2 is the volume (or number of trips) with intervention.

OCC is the occupancy rate, in persons per vehicle

VoT is the Value of Time for users, in Dollars per hour and person

Since travel-time user benefits have been calculated previously, in this step only a simple multiplication is required, considering the Value of Time and the Occupancy Rates. Then Value of Travel-time User Benefits is obtained for each link and hour. As a result, total daily user benefit in each link and zone can be easily calculated. This step should consider the different area both individually and as a group.

Finally, results must be analyzed to discuss if the methodology proposed by Roshandeh *et al.* (2014) could be an interesting contribution to the citizens' welfare from the time savings point of view.

It is not the goal of this study to consider further steps, but the following steps on considering the total user benefits due to this transportation improvement should include a contrast between the two main remaining travel costs: operating costs and accident costs.

CHAPTER 4

METHODOLOGY APPLICATION

This section contains the specific development and results of the application. Examples are shown to clarify the steps taken and justify decisions taken.

4.1 TDM Methodology application

4.1.1 Basic Information

Following Roshandeh *et al.* (2014) approach for analysis was conducted in Chicago Central Business District (CBD), divided in 4 zones as shown in figure 4.1.

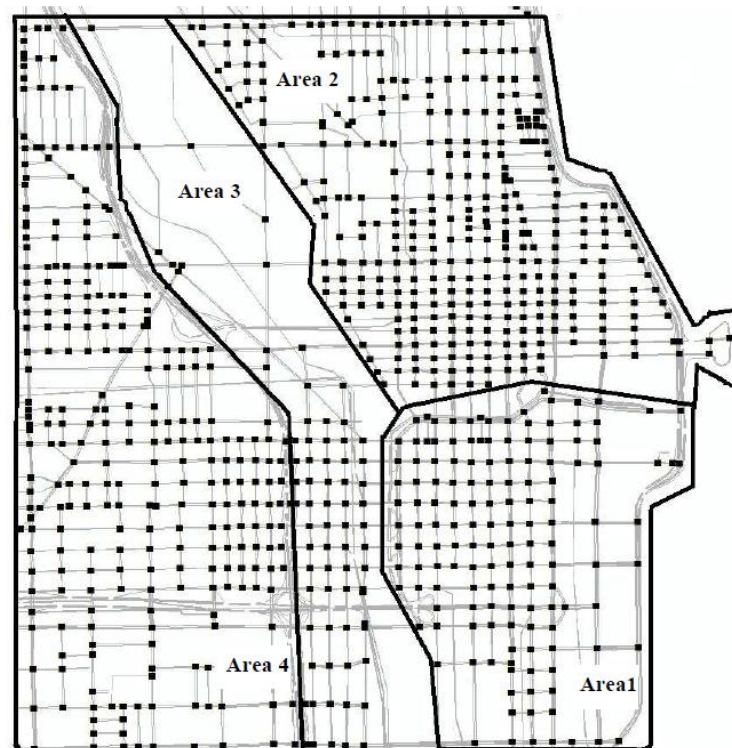


Figure 4.1 Division of the CBD in the four areas of study

Area 1 encompasses the core area of Chicago Loop bounded by Wacker Drive along the Chicago River, Roosevelt Road and Lakeshore Drive; area 2 covers the near north of Loop bounded by the Chicago River, North Avenue and Lakeshore Drive; area

3 includes the Near West Loop bounded by I-90/94, the Chicago River, North Avenue and Roosevelt Road and area 4 contains the West Loop bounded by Ashland Avenue, I90/94, North Avenue and Roosevelt Road.

The total number of links included in CBD is of 1,671. Area 1 is composed of 320 links, 650 links can be counted in area 2, 172 links in area 3 and 532 in area 4. Year 2013 was established as base year for all calculations regarding time and currency.

4.1.2. Base Case and Project Alternatives

Four scenarios were defined in this study: one Base Case and three main Project Alternatives, studied separately. Following AASHTO Red Book (2003) recommendations, the base case is established as the *Status Quo*, meaning a situation in which no interventions have been done.

The three alternative cases consist on situation where the following methods of delay estimation have been used: the Basic Optimized Model, enhanced model using Highway Capacity Manual formulation (HCM, 2010) and a second enhanced Model uses Herbert S. Levinson theory (Levinson, 1971 and Li *et al.*, 2012). However, since the two enhanced optimized models study different situations depending of the relative weight given pedestrian delay (between 10% and 90%.), nine project alternatives have been analyzed individually for each one of them, making a total of 19 project alternatives studied.

4.1.3. Estimation of Traffic Performance Data before and after Intervention

Information about demand, travel speeds and travel times for base case and alternative scenarios was obtained as output data of Roshandeh *et al.* (2014) *New Methodology for Intersection Signal Timing Optimization to Simultaneously Minimize Vehicle and*

Pedestrian Delays, carried out thru TRANSIMS simulation tool (explained in chapter 2). Six data sheets were provided for each model and zone (456 in total) regarding travel speeds, travel times and traffic volumes for base case and alternative scenarios

Information about how this software was used to create, calibrate and validate a Chicago TRANSIMS model can be found in Li *et al.* (2012) and Roshandeh *et al.* (2014).

4.1.4. Occupancy Rates

As explained in the previous chapter, occupancy rates (OCC) give us information about the number of people that is in a vehicle. The information provided by U.S. Department of Transportation, *Energy Intensity of Light Duty Vehicles and Motorcycles (1960-2011)*, states 1.39 people per vehicle as a good approximation for most transportation projects conducted in the United States.

Table 4.1 Occupancy rates. U.S. Department of Transportation (1990-2013)

Average occupancy rate	1990	1995	2000	2005	2009	2010	2011
Light duty vehicle, short wheel base	1.62	1.59	1.59	1.58	1.39	1.39	1.39

As it can be observed, occupancy rates present little variation with time and therefore the consideration that it will not vary significantly in the next years seems reasonable.

If compared with other first world countries it can be considered as a middle value: 1.62 in Canada (Canadian Vehicle Survey 2009), 1.4 in Australia (Stanley et al. 2009), around 1.6 United Kingdom (UK Dept. Trans 2010), 1.3 Austria and Nederland, 1.5 Denmark and Czech Republic, 1.7 in Norway, Italy and Spain (EEA 2008).

4.1.5 Establish the Unit Value of Travel Time

As previously commented, the AASHTO Red Book works with the widely accepted idea that the value of travel time should bear some relationship to the after-tax wage of the traveler, since that is the main alternative use of time in most contexts. Even in a space of time dedicated to leisure, the value of time seems likely to be somehow related to the hourly wage rate since work is still an alternative to leisure.

Different weights of the wage are assigned to different trip purposes as seen in chapter 3, table 3.1. Considering a single trip purpose (and therefore weight) would lead us either to an extremely favorable or to a negative result. In order to consider this diversity of trips, a sensitivity analysis has been conducted, considering the different percentages of each trip purpose along a normal day and using the formula:

$$VoT = (100\% \cdot X_{business} + 60\% \cdot X_{personal} + 50\% \cdot X_{commuter}) \cdot Wage \quad (4.1)$$

Where VoT is the Value of Time and X_i means the percentage of traffic with certain i purpose.

Analyzing daily traffic in Chicago Business Area, the following hypotheses have been considered a fair estimation: In the morning, the vast majority of traffic consists in commuters and minority of personal trips. At noon, seems sensible that the number of commuters will be light while being significant the amount of business trips. Along afternoon-evening, people leave work and it looks acceptable that their transportation plans will include commuting and/or personal trips (as shopping, going to the gym...). At night, it makes sense that transportation would be used mainly for personal trips (leisure, meetings...) and late commutes. These hypotheses have been summarized in table 4.1.

Table 4.2 Trip purposes weights over a working day

	Business trip (100% Wage)	Personal Trip (60% Wage)	Commute trip (50% Wage)	Total to multiply by wage
Morning	20	10	70	0.61
Noon	60	30	10	0.83
Evening	20	20	50	0.63
Night	10	70	20	0.62
Average				0.6725

These calculations lead us to consider the value of time as a 67% of the hourly-wage, which compared to preceding works as Lam and Small (2001) may be observed as conservative. Information regarding wages can be found in U.S. Department of Labor (May 2012) in the following table.

Table 4.3 Occupational employment and wages by major occupational group, United States and the Chicago-Joliet-Naperville Metropolitan Division, May 2012

Major occupational group	Percent of total employment		Mean hourly wage		
	United States	Chicago	United States	Chicago	Percent difference ^[1]
Total, all occupations	100.0%	100.0%	\$22.01	\$23.91 *	9
Management	4.9	6.1 *	52.20	52.07	0
Business and financial operations	4.9	5.6 *	33.44	35.40 *	6
Computer and mathematical	2.7	2.9 *	38.55	38.37	0
Architecture and engineering	1.8	1.3 *	37.98	36.07 *	-5
Life, physical, and social science	0.8	0.5 *	32.87	34.91	6
Community and social service	1.4	1.3 *	21.27	23.26 *	9
Legal	0.8	1.0 *	47.39	53.84 *	14
Education, training, and library	6.4	7.4 *	24.62	27.84 *	13
Arts, design, entertainment, sports, and media	1.3	1.4	26.20	25.55	-2
Healthcare practitioners and technical	5.9	5.5 *	35.35	35.94	2
Healthcare support	3.0	3.0	13.36	13.26	-1
Protective service	2.5	2.8 *	20.70	22.02	6
Food preparation and serving related	8.9	7.6 *	10.28	10.60 *	3
Building and grounds cleaning and maintenance	3.3	3.3	12.34	13.04 *	6
Personal care and service	2.9	2.6 *	11.80	12.58 *	7
Sales and related	10.6	11.2 *	18.26	21.09 *	15
Office and administrative support	16.4	15.6 *	16.54	17.61 *	6
Farming, fishing, and forestry	0.3	0.1 *	11.65	14.42 *	24
Construction and extraction	3.8	3.1 *	21.61	27.41 *	27
Installation, maintenance, and repair	3.9	3.0 *	21.09	22.79 *	8
Production	6.6	7.0 *	16.59	16.66	0
Transportation and material moving	6.7	7.8 *	16.15	17.14 *	6

* The percent share of employment or mean hourly wage for this area is significantly different from the national average of all areas at the 90-percent confidence level.

[1] A positive percent difference measures how much the mean wage in Chicago is above the national mean wage, while a negative difference reflects a lower wage.

As we can see, the average wage was 23.91\$ per hour in 2012, which must be updated to 2013 dollars. As a way to consider inflation, trends in consumer price indices (CPI)

for Private Transportation can be used as provided by U.S. Department of Labor (Bureau of Labor Statistics 2012-2013).

The calculation is made as follows:

$$Wage_{2013} = Wage_{2012} \cdot \frac{CPI_{Private\ Trans.\ Sept,2013}}{CPI_{Private\ Trans.\ May,2012}} = 24.19 \$ \quad (4.2)$$

Ergo, the final Value of Time that will be used will be the 67% of 24.19\$, thus 16.21 \$.

4.1.6. Calculate the Travel-time User Benefits

Sinha and Labi (2007) formula to calculate de User Benefits due to travel time reduction is based in the change in consumer surplus. It can be expressed in a general way as follows:

$$STT = \frac{(TT_{v1} - TT_{v2})}{3600} \cdot \left(\frac{V_1 + V_2}{2} \right) \quad (4.3)$$

Where: TT_{v1} is the average vehicle travel time without intervention, in seconds

TT_{v2} is the average vehicle travel time with intervention, in seconds

V_1 is the volume (or number of trips) without intervention.

V_2 is the volume (or number of trips) with intervention.

As an example, the values of Basic Model, Zone 1, link 16927, AB direction, from 0:00

AM to 1:00AM, will be taken:

			AB_000_100			
LINK	ANODE	BNODE	TT Before (s)	TT After (s)	Volume Before	Volume After
16927	15421	15494	25.1	19.6	64	66

With this data we can apply the formula (4-3):

$$STT = \frac{0.5}{3600} \cdot (25.1 - 19.6) \cdot (64 + 66) = 0.099305 \text{ h} \quad (4.4)$$

In this case we see a positive value which means that users will save time with the new intervention. However we find also negative values, for example between 11 and 12 AM in link 35011:

AB_1100_1200						
LINK	ANODE	BNODE	TT Before (s)	TT After (s)	Volume Before	Volume After
35011	16063	50005	12.8	12.9	40	52

$$STT = \frac{0.5}{3600} \cdot (12.8 - 12.9) \cdot (40 + 52) = -0.0012777 \text{ h} \quad (4.5)$$

In this moment and link, travel time has increased due to the intervention and therefore people is losing time and, as a consequence, money.

If we do this for each link and Hour of the day, and we add them, we get the total STT in a link during a whole day, in both ways (if it's a 2 way street).

This is by far, the most laborious part of the procedure. The Output of TRANSIMS consists in 8 data sheets per area containing speeds, travel times, volumes and queues before and after the improvement. These sheets have been converted to Excel Sheets, merged and afterwards processed to implement the previous formula. Each link and time has to be considered separately in order to avoid double counting errors and absurd operations between non related data, making around 1,5 million values calculated for all models and zones.

4.1.7. Debugging of Obtained Results

Since the TRANSIMS output data used to our calculations may contain bugs inherent to the very nature of this simulation tool, a data treatment is executed in order to remove all unreasonable results obtained. To achieve this, a comprehensive analysis is performed to detect “Outliners”, using a Box plot exclusion criteria.

Using the method presented in *Understanding Statistics* Upton and Cook (1996), a lower fence and an Upper fence are established using quartiles and interquartile range (IQR =Q1-Q3):

$$\text{Lower fence} = 1\text{st Quartile} - 1.5 \cdot \text{IQR}, \text{ being } \text{IQR} = \text{Q1} - \text{Q3}$$

$$\text{Upper fence} = 3\text{rd Quartile} + 1.5 \cdot \text{IQR}$$

As a conservative decision, all values not contained within these fences were removed from calculation. Other methods regarding the use of Interquartile range using different constants were considered, but lately refused for inconsistency of the results obtained.

4.1.8. Calculate the Value of Travel-time User Benefits

The final step of the methodology consists in multiplying travel-time user benefits by the Value of Time and the Occupancy Rate. Then we obtain the Value of Travel-time User Benefits for each link and hour.

Using previous example:

$$STT = \frac{0.5}{3600} \cdot (25.1 - 19.6) \cdot (64 + 66) \cdot 24.19 \cdot 0.67 = 1.61 \$ \quad (4.6)$$

Ergo, for the Basic Model in Zone 1, link 16927, from 0:00 AM to 1:00AM, users are saving 1.61\$. Doing this for every hour and link, we can find the total daily user benefit in each zone.

4.2. Analysis of Results

The obtained results of average daily benefits for the different models and situations are shown and analyzed in different in separated parts. For drawings reasons Basic Model and HCM Model are shown in Table 4.4, while HSL Model is shown in Table 4.5. A scale of colors has been used to give a qualitative idea of the results, being red the negative ones and blue the positives.

Table 4.4 Value of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using the Basic and the HCM Model

	Relative Weight of Pedestrian Delays Ranging from 0 to 90%									
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%
Model	Basic	Enhanced Model Using 2010 HCM Method								
Area	Value of Travel-time User Benefits (in USD \$)									
Zone 1	56,530.55	80,709.77	72,178.38	64,444.24	51,712.74	47,429.04	39,692.93	35,718.42	12,741.40	67,285.64
Zone 2	-25,750.43	19,596.94	11,528.86	80.05	-14,512.32	-25,107.24	-26,183.79	-60,950.63	-74,664.16	-2,012.54
Zone 3	14,387.52	17,724.48	5,066.66	6,475.00	11,656.01	-6,181.65	-7,526.28	-8,777.13	-13,332.04	2,404.89
Zone 4	3,760.35	8,716.81	3,425.54	-13,752.06	-15,942.42	-17,861.81	-23,897.13	-35,986.88	-36,108.34	117.24
12	30,780.13	100,306.71	83,707.24	64,524.29	37,200.42	22,321.80	13,509.14	-25,232.21	-61,922.76	65,273.09
13	70,918.07	98,434.25	77,245.04	70,919.24	63,368.76	41,247.39	32,166.65	26,941.29	-590.64	69,690.52
14	60,290.90	89,426.58	75,603.92	50,692.18	35,770.32	29,567.23	15,795.80	-268.46	-23,366.95	67,402.87
23	-11,362.91	37,321.42	16,595.51	6,555.05	-2,856.31	-31,288.89	-33,710.07	-69,727.76	-87,996.20	392.35
24	-21,990.08	28,313.76	14,954.40	-13,672.01	-30,454.75	-42,969.05	-50,080.92	-96,937.51	-110,772.50	-1,895.31
34	18,147.86	26,441.29	8,492.19	-7,277.06	-4,286.41	-24,043.46	-31,423.41	-44,764.02	-49,440.38	2,522.12
123	45,167.65	118,031.19	88,773.90	70,999.29	48,856.44	16,140.15	5,982.86	-34,009.34	-75,254.80	67,677.98
124	34,540.47	109,023.52	87,132.78	50,772.23	21,258.00	4,459.99	-10,387.99	-61,219.09	-98,031.10	65,390.33
134	74,678.42	107,151.06	80,670.58	57,167.18	47,426.33	23,385.58	8,269.52	-9,045.59	-36,698.98	69,807.76
234	-7,602.56	46,038.24	20,021.05	-7,197.01	-18,798.73	-49,150.70	-57,607.20	-105,714.64	-124,104.54	509.58
1234	48,927.99	126,748.00	92,199.43	57,247.23	32,914.01	-1,721.66	-17,914.27	-69,996.22	-111,363.14	67,795.22

4.2.1 Basic Model

As it can be observed in Table 4.1, results using Basic model vary depending on the area, being zone 2 the most inefficient. Values in zones 3 and 4 are positive but not high. However, extremely positive results on zone 1 lead to a global positive result of almost 50,000 \$. average daily benefits.

4.2.2 First Enhanced Model

The HCM enhanced model offers the most polarized results of all three models. Depending on the weight given to the pedestrian delay the highest and the lowest daily results may be found, from 126,748 \$ to -111,363 \$. Best results are obtained for 10% of pedestrian delay's weight. The results then decrease until a minimum is reached for 80% of pedestrian delay, as shown in figure 4.2. The result for 90% is, however, positive.

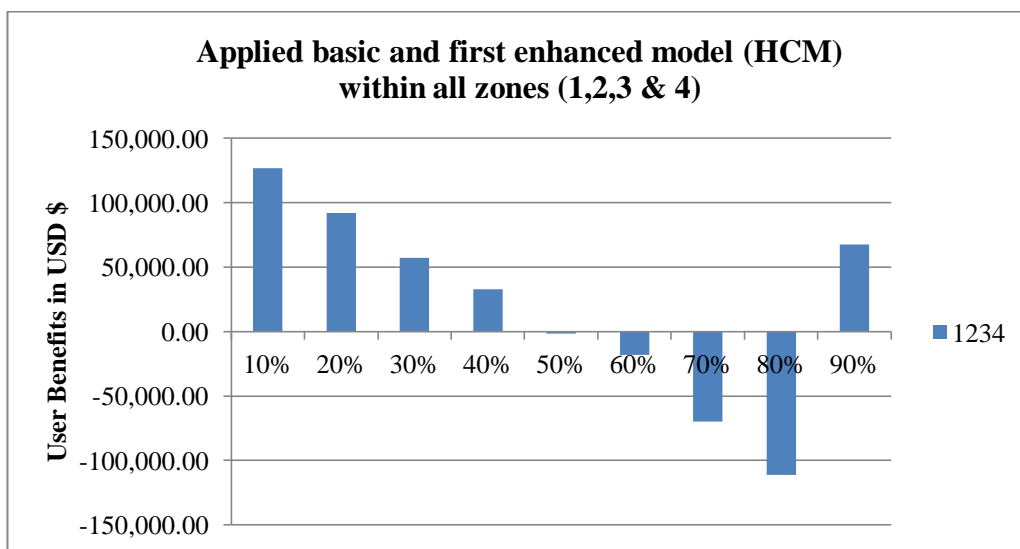


Figure 4.2 Accumulated value of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using the HCM Model within All Four Zones

When calculating the average of all pedestrian weights, a value of 19,545.40 \$ is obtained. This shows that this method provides extreme results. The contribution of each zone can be analyzed in figure 4.3:

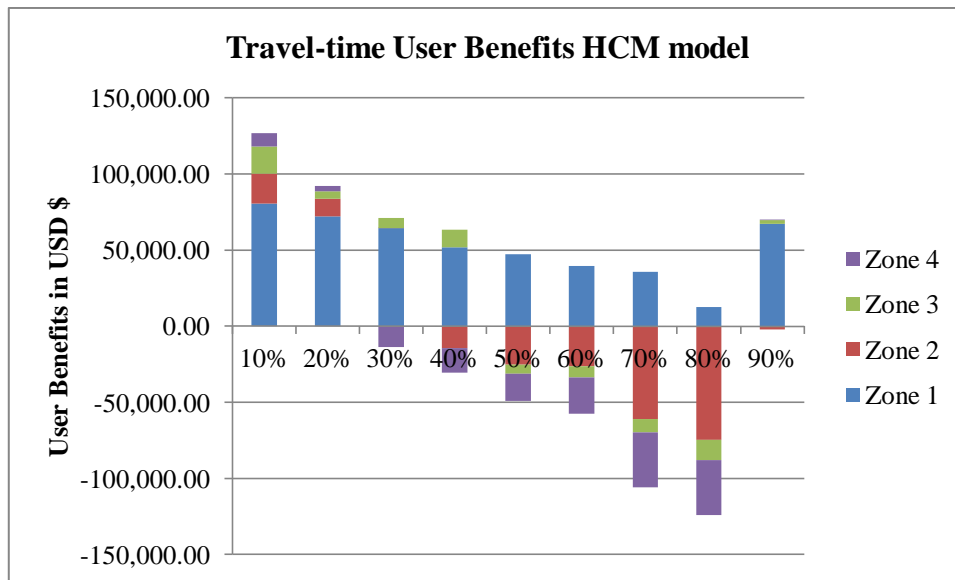


Figure 4.3 Stack up Zone values of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using the HCM Model

In this figure, the tendency in each area is shown. As observed in the basic model, area 2 stands as the most inefficient, being extremely sensitive to changes in pedestrian weights. The performance of zone 1 could be considered quite stable, holding a positive average value around the 50,000 \$, in contrast with zone 2, with -19,000\$. Zone 3 contribution

4.2.3 Second Enhanced Model

Contrary to the HCM, the HSL enhanced model stands as a extremely stable model, with a positive performance for all weights and an average daily benefit of 63,920 \$ for all zones. The highest values may not be as high as in HCM, but it stand over HCM's values in 6 of 9 cases.

Table 4.5 Value of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using HSL Model

	Relative Weight of Pedestrian Delays Ranging from 0 to 90%								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Model	Enhanced Model Using Levinson Method								
Area	Value of Travel-time User Benefits (in USD \$)								
Zone 1	69,157.79	67,593.52	66,728.31	66,482.42	67,857.56	67,069.41	67,481.88	56,978.07	42,764.27
Zone 2	-1,890.56	-495.41	-281.66	-107.51	-1,000.96	-420.47	-175.64	-990.59	-91.03
Zone 3	4,246.66	-1,706.14	526.13	2,011.14	1,145.78	685.09	115.37	-298.75	1,159.13
Zone 4	261.39	-86.03	94.07	-14.53	145.63	-57.08	51.65	206.71	141.31
12	67,267.23	67,098.12	66,446.65	66,374.90	66,856.60	66,648.94	67,306.23	55,987.48	42,673.24
13	73,404.45	65,887.39	67,254.45	68,493.56	69,003.34	67,754.50	67,597.24	56,679.33	43,923.40
14	69,419.18	67,507.49	66,822.38	66,467.89	68,003.19	67,012.33	67,533.53	57,184.78	42,905.58
23	2,356.10	-2,201.55	244.47	1,903.63	144.82	264.62	-60.28	-1,289.34	1,068.10
24	-1,629.17	-581.44	-187.59	-122.04	-855.33	-477.56	-123.99	-783.88	50.28
34	4,508.05	-1,792.17	620.20	1,996.62	1,291.41	628.01	167.02	-92.03	1,300.43
123	71,513.90	65,391.98	66,972.78	68,386.05	68,002.38	67,334.03	67,421.60	55,688.73	43,832.37
124	67,528.63	67,012.08	66,540.72	66,360.38	67,002.23	66,591.85	67,357.89	56,194.19	42,814.55
134	73,665.85	65,801.35	67,348.51	68,479.03	69,148.97	67,697.42	67,648.90	56,886.04	44,064.70
234	2,617.50	-2,287.58	338.54	1,889.10	290.45	207.54	-8.62	-1,082.63	1,209.40
1234	71,775.29	65,305.94	67,066.85	68,371.52	68,148.01	67,276.95	67,473.25	55,895.44	43,973.68

It is remarkable the difference between the contribution of area 1 with the rest of the areas, as perceived in figures 4.4 and 4.5, contributing to the total results with over 95% of the final result.

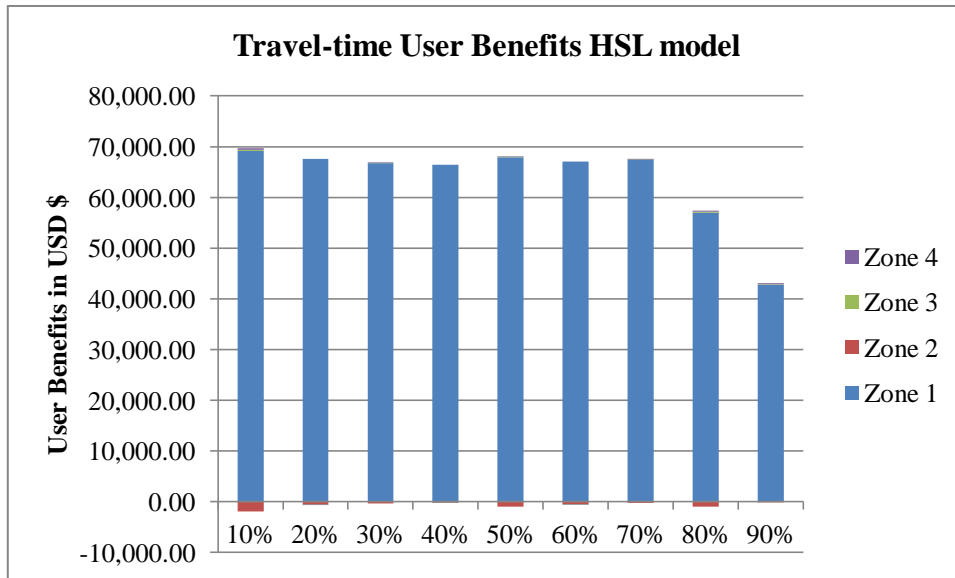


Figure 4.4 Stack up Zone values of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using the HSL Model

In previous cases the contribution of area 4 was low, but in the present is practically inexistent. Areas 2 and 3, also present low absolute values. Figure 4.4 show that the HSL model is unable to change traffic performance in this zones, while working with proefficiency in area 1.

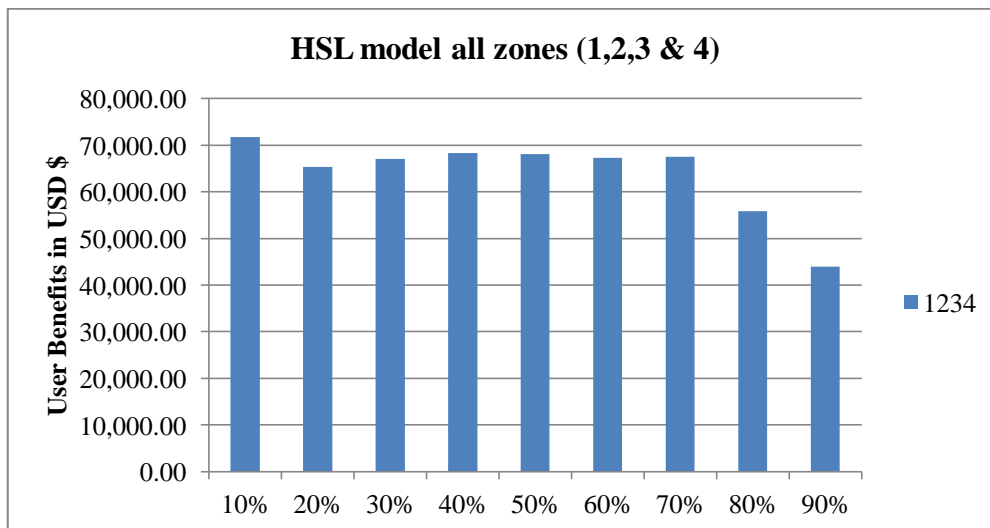


Figure 4.5 Accumulated value of Travel Time User benefits in \$ USD over a 24-Hour Period after Signal Timing Optimization using the Basic and the HCM Model

Figure 4.5 shows that the HSL model is capable of introducing pedestrian delays without affecting notably the efficiency

4.2.4 General Overview

Taking a look at all the results, it is notable the influence of zone 1 results. This may indicate that currently (in the base case), zone 1 is performing inefficiently and that Roshandeh *et al.* (2014) is capable of optimizing it with competence. For zones 2, 3 and 4, results are not as good as in zone 1. This may bear a relationship with size, intersection density or pedestrian-vehicle proportion, since zone 1 is a smaller zone, with a regular distribution of intersections and a high count of both pedestrians and vehicles.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

In the making of this study, a comprehensive travel-time user benefits analysis has been performed over a new methodology, designed by Roshandeh *et al.* (2014), to reduce simultaneously delays experimented by vehicles and pedestrians, optimizing Chicago network's signal timing.

To do so, a base case scenario with no improvement implemented has been compared with three models: a basic model, considering only vehicle delay; and two different enhanced models (HCM model and HSL model) that consider vehicle and pedestrian delay in different proportions. After reviewing different guidebooks, a user benefit calculation method based in Sinha and Labi (2007) and AASHTO (2003) has been developed and applied. Using data resulted from introducing the previous models in TRANSIMS simulation tool and information from federal agencies.

As a result, average daily savings for the different models and vehicle-pedestrian weights have been obtained. Daily profits of almost 50,000 \$ have been obtained for the basic model. If all cases are considered, in average 19,500\$ in HCM model and around 63,900\$ in HSL, could be saved daily using Roshandeh *et al.* (2014). When considering only 10% weight on pedestrian delays, over 126,000 \$ and 71,000 \$ in time savings are obtained for the HCM and HSL models, respectively. This means annual maximum savings close to \$46 Million.

5.2 Conclusions

Discerning whether the application of Roshandeh *et al.* (2014) 's methodology would be economically viable from the point of view of travel time was the main target of this study.

The travel time user benefit appraisal performed lead to the conclusion that the implementation of this new methodology would have a substantial positive effect on Chicago's pedestrians and car users. Optimal pedestrian weights can be found between 10% and 20% for HCM model, ensuring annual savings from \$33 to \$46 millions. When looking for a pedestrian-friendly approach, HSL model offers outstanding results, with annual savings going from \$16 million for 90% of pedestrian weight, to \$26 for 10%. Furthermore, this analysis highlights the fact that zone 1 is a critical area, currently performing far below its optimal.

5.3 Recommendations and Future Work

Since this is only a part of the user benefit analysis and therefore, of the cost-benefit analysis, seems reasonable that further study could develop the benefits observed in operational and crash (accident) costs, as well as indirect costs.

As seen in the results, some zones present unsatisfactory results in many cases. Future works could be conducted in order to analyze the factors that compromise the effectiveness of this methodology, considering area size, intersection density or pedestrian-vehicle proportion.

REFERENCES

AASHTO. (2003). User Benefit Analysis for Highways. *American Association of State Highway and Transportation Officials*, Washington, D.C.

Barrett, C., Berkgigler, K., Smith, L., Loose, V., Beckman, R., Davis, J., Roberts, D., and Williams, M., (1995). "An Operational Description of TRANSIMS", *Los Alamos National Laboratory*, Los Alamos, NM.

Becker, G. S. (1965). "A Theory of the Allocation of Time". *The Economic Journal*, 75(299), 493.

Beesley, M.E. (1965). "The Value of Time Spent in Travelling: Some New Evidence". *Economica*, New Series, 32 (126), 174-185.

Belli, P., Anderson, J., Barnum, H., Dixon, J., and Tan, J.-P. (1998). "Handbook on economic analysis of investment operations", *The World Bank*, Washington, D.C.

Benefit-Cost Analysis for Transportation Projects. (2003). *Minnesota Department of Transportation*, St. Paul, MN. Available at <http://www.dot.state.mn.us/planning/program/benefitcost.html> as of Feb. 12, 2014.

Canadian Vehicle Survey. (2009). *Natural Resources Canada*, Ottawa, ON, Canada. Available at <http://oee.nrcan.gc.ca/publications/statistics/cvs09/chapter2.cfm?attr=0> as of Feb. 12, 2014.

Consumer Price Index for All Urban Consumers in the U.S. from 2008 to 2014 (2014). *U.S. Department of Labor, Bureau of Labor Statistics*, Washington, D.C. Available at <http://www.bls.gov/cpi/#tables> as of Feb. 12, 2014.

Criado, O., Sanchez-Borras, M., and Robuste, F. (2011). "Influence of Value of Time on Profitability of Railway Projects: Theoretical Formulation and Case Study". *Transportation Research Record: Journal of the Transportation Research Board*. 2261, 86-94.

Economic Analysis Primer: Benefit-Cost Analysis (2003) US Federal Highway Administration, Washington, D.C. Available at <http://www.fhwa.dot.gov/infrastructure/asstmgmt/primer05.cfm> as of Feb. 12, 2014

ECO Northwest, Parsons Brinckerhoff Quade and Douglas. (2002). "Estimating the benefits and costs of public transit projects: A guidebook for practitioners", *Transit Cooperative Research Program, Report 78. Transport Research Board, Washington D.C.*

EU Guide to Cost-Benefit Analysis of investment projects (2008). *European Commission Directorate General Regional Policy, Brussels, Belgium.*

European Conference of Ministers of transport (2003) "Conclusions of the ECMT Round Table 127: Time and Transport", *ECMT European Conference of Ministers of Transport, Paris, France.*

Forkenbrock, D., Weisbrod, G. E. (2001). "Guidebook for assessing the Social and Economic Effects of transportation Projects", *National Cooperative Highway Research Program, Report 456, Transport Research Board, Washington D.C.*

Guide to Benefit-Cost Analysis in Transport Canada (1994), *Transport Canada, Ottawa, ON, Canada.* Available at http://www.evaluaciondeproyectos.es/EsWeb/Recursos/guias_acb/PDF/3.pdf as of Feb. 12, 2014.

Gwilliam, K. (1997). "The value of time in Economic Evaluation of Transport Projects: Lessons from Recent Research", *World Bank*, Transport No. OT-5, Washington, D.C.

Highway Capacity Manual. (2010). *Transportation Research Board*, Washington D.C.

INDOT Design Manual. (2002). *Indiana Department of Transportation*, Indianapolis, IN. Available at http://www.in.gov/indot/design_manual/design_manual_2013.htm as of Feb. 12, 2014.

Jiang, M., and Morikawa, T. (2004). "Theoretical analysis on the variation of value of travel time savings". *Transportation Research Part A: Policy and Practice*, 38(8), 551-571.

Johnson, M. B. (1966). "Travel Time And The Price Of Leisure". *Economic Inquiry*, 4(2), 135-145.

Lam, T.C. and K.A. Small. (2001) "The value of time and reliability: measurement from a value pricing experiment". *Transport Research Part E*, 37(2-3), 231-251.

Li, Z., Zavatiero, D., Wies, K., Son, Y-J., and Levinson, H.S. (2012). "Development and application of the TRANSIMS toolbox for transportation operations management in and around Chicago central area". Phase I Final Report. *Federal Highway Administration, U.S. Department of Transportation*, Washington, D.C.

Mankiw, N. G. (2012). *Principles of economics* (6th ed.). Mason, OH: South-Western Cengage Learning.

National Travel Survey (2010). *Department for Transport*, London, United Kingdom. Available at

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/8940/nts_2010-09.pdf as of Feb. 12, 2014.

Occupancy rates in the U.S. (2013) *U.S. Department of Transportation, Bureau of Transportation Statistics*, Washington, D.C. Available at http://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/publications/national_transportation_statistics/html/table_04_22.html as of Feb. 12, 2014.

Occupancy rates of passenger vehicles. (2008). *European Environment Agency (EEA)*, Copenhagen, Denmark. Available at <http://www.eea.europa.eu/data-and-maps/indicators/occupancy-rates-of-passenger-vehicles/occupancy-rates-of-passenger-vehicles-1> as of Feb. 12, 2014.

Occupational employment and wages in the U.S. (2012) *U.S. Department of Labor, Bureau of Labor Statistics*, Washington, D.C. Available at <http://www.bls.gov/ro5/oeschi.htm> as of Feb. 12, 2014.

Oort, O. (1969). “The evaluation of traveling time”. *Journal of Transport Economics and Policy*, 3, 219-286.

Roshandeh, A.M., H.S. Levinson, Z. Li, H.P. Bei Zhou. (2014). “A new methodology for intersection signal timing optimization to simultaneously minimize vehicle and pedestrian delays”. *ASCE Journal of Transportation Engineering*. (Accepted, In Press, DOI: 10.1061/(ASCE)TE.1943-5436.0000658)

Schrank, D., Eisele, B., and Lomax, T. (2012) “2012 Annual Urban Mobility Report”. *Texas A&M Transportation Institute, The Texas A&M University*, College Station, TX. Available at <http://mobility.tamu.edu/ums/> as of Feb. 12, 2014.

Sinha, K. C., and Labi, S. (2007). Travel-Time Impacts. *Transportation decision making principles of project evaluation and programming* (p. 98 - 125). Hoboken, N.J.: John Wiley.

Small, K. (1999). "Project Evaluation". *Institute of Transportation Studies, University of California*, Irvine, California. Available at <http://www.uctc.net/papers/379.pdf> as of Feb. 12, 2014.

Small, K.A., Noland, R., Chu, X., and Lewis, D. (1999) "Valuation of Travel-Time Savings and predictability in congested conditions for highway user-cost estimation". *National Cooperative Highway Research Program, Report 431, Transport Research Board*, Washington D.C.

Smith, L., Beckman, R., Anson, D., Nagel, K., and Williams, M. (1995). "TRANSIMS: TRansportation ANalysis and SIMulation System" *Conference: 5, National transportation planning methods applications conference*, Seattle, WA

Stanley, J. K., Hensher, D. A., & Loader, C. (2009). "Road Transport And Climate Change: Stepping Off The Greenhouse Gas". *Transportation Research Part A: Policy and Practice*, 45(10), 1020-1030.

Transport Analysis Guidance (2014) *Department for Transport*, London, United Kingdom. Available at <https://www.gov.uk/transport-analysis-guidance-webtag> as of Feb. 12, 2014

Upton, G., and Cook, I. (1996). *Understanding Statistics* (p. 55). Oxford, United Kingdom: University Press.

Urban traffic congestion. (2011.). *The Washington Post*. Available at <http://www.washingtonpost.com/wp-srv/metro/special/congestion.html> as of Feb. 12, 2014.

Victoria Transport Policy Institute (2012). *Transportation Cost and Benefit Analysis II – Evaluating Transportation Benefits*, *Victoria Transport Policy Institute*, Victoria, British Columbia, Canada.

VTPI (2009). “Transportation cost and benefit analysis”, *Victoria Transport Policy Institute*, Victoria, BC, Canada. Available at <http://www.vtpi.org/tca/> as of Feb. 12, 2014.

White Paper - A new deal for transport: better for everyone (1998) *Department for Transport*, London, United Kingdom. Available at <http://webarchive.nationalarchives.gov.uk/+http://www.dft.gov.uk/about/strategy/whitepapers/previous/aneudealfortransportbetterfo5695> as of Feb. 12, 2014.