2013-01-01

Assessing Regional Impacts of Transportation Policies and Traffic Management Solutions in Large Urban Areas

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ASSESSING REGIONAL IMPACTS OF TRANSPORTATION POLICIES AND TRAFFIC MANAGEMENT SOLUTIONS IN LARGE URBAN AREAS

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Dedication

I would like to dedicate this thesis to the special memory of my grandfather, Vaclav Rendl.

I would also like to dedicate this thesis to my entire family and my closest friends who have always stood beside me providing me with support and motivation.

ASSESSING REGIONAL IMPACTS OF TRANSPORTATION POLICIES AND TRAFFIC MANAGEMENT SOLUTIONS IN LARGE URBAN AREAS

by

TOMAS RENDL, Bc.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Civil Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

May 2013

Acknowledgements

I would like to thank my advisors Dr. Ruey Long Cheu and Dr. Ladislav Bina for their guidance, suggestions and feedback. I would also like to thank Dr. Salvador Hernandez, and Tomas Horak for providing me very helpful consultations.

Special thanks belong to my parents for their self-sacrificing support during all of my studies.

Declaration

This thesis is an output of the Transatlantic Dual Masters Degree Program in Transportation Science and Logistic Systems, a joint project between Czech Technical University in Prague, Czech Republic, The University of Texas at El Paso, USA and University of Zilina, Slovak Republic.

This thesis is jointly supervised by the following faculty members:

Ruey Long Cheu, Ph.D., The University of Texas at El Paso

doc. Ing. Ladislav Bina, CSc., Czech Technical University

The contents of this research were developed under an EU-U.S. Atlantis grant (P116J100057) from the International and Foreign Language Education Programs (IFLE), U.S. Department of Education. However, those contents do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government.

This research is co-funded by the European Commission's Directorate General for Education and Culture (DG EAC) under Agreement 2010-2843/001-001-CPT EU-US TD.

Abstract

This thesis introduces the problem of the continually increasing demand for road transportation in large urban areas. Associated problems and their possible solutions have been described and linked together in a wider context. Thereafter, a framework for the application of the multicriterial decision making method is introduced in order to help to find the best solution. The proposed framework evaluates alternatives and their potential impacts with respect to nine criteria. This method has been applied in a case study, using the example of the City of Prague, Czech Republic. Based on the results of two scenarios, the city's superior highway network completion is first recommended. Thereafter, implementation of an urban road pricing system is recommended.

Key words: transportation policy, traffic management, intelligent transportation systems, urban area, externality, congestion, urban road pricing, multicriterial decision making

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Chapter 1: Introduction

Transportation represents one of the essential functions for the humankind; movements of goods and people contribute without doubt to the growth of the global economy and welfare significantly. The total spending of society on transportation usually reaches an amount of more than 10% of Gross Domestic Product (GDP) (Czech Ministry of Transport 2012; National Chamber Foundation 2008). In addition, estimations indicate that private households spend roughly 13% of their total consumption on transportation related items in the United States of America (USA) and in the European Union (EU) (McDonald 2012; European Commission 2011). Also, transportation is understood generally to be one of the factors influencing the quality of life.

The continually increasing demand for transportation needs represents a challenging problem and results in many undesirable side effects and negative consequences. Among the negative impacts are, for example, congested and overloaded infrastructure, enormous energy consumption, infrastructural and environmental damages, traffic accidents, growing financial requirements, and etc. These negative impacts are also called negative externalities from transportation, because they cause external costs.

1.1 Background

According to *EU Transport in Figures 2012* (European Commission 2011), the total Passenger Transportation Activities (PTA) accomplished by any motorized means reached 6,424 billion passenger-kilometers (pkm) within EU in the year 2010; and 7,300 billion pkm within USA in the year 2009. The biggest portion of this load is linked to highway infrastructures, which serves nearly 84% of pkm in EU, and 87% in USA respectively.

As can be seen in Table 1.1, most of the inhabitants in both EU and USA live in urban areas. Therefore, together with the fact that most of PTAs are carried out on highways, we can assume that bigger towns, cities and metropolitan areas are adversely affected by the side effects and negative consequences.

Likewise, Table 1.2 points to the fact that nearly half of the total population of USA lives in metropolitan areas of more than one million inhabitants. Density of population is more concentrated in particular spots than uniformly distributed across the country. Even if there is no equivalent statistics for the whole EU, the trend of living directly in big cities is generally little bit lower (see Table 1.2) as there are fewer cities in EU that have population of more than one million. In spite of this fact cities and their close vicinities still generate a significant number of PTAs.

Table 1.1: Population Statistics for EU, USA, and China

Year 2010	EU	USA	CHINA
population [million]	502	310	1341
urban population [% of total]	76	82	50

Source: (EU transportation in figures 2012)

Table 1.2: Population Living in Metropolitan Areas of More Than One Million in Selected Countries

Year 2010	USA	CZECH REPUBLIC	UNITED KINGDOM	GERMANY	FRANCE	ITALY	CHINA
% of total population	45	11	26	8	22	17	18

Source: (The World Bank, 2010a)

The degree of automobilization (number of passenger cars per thousand inhabitants), and the degree of motorization (number of motor vehicles per thousand inhabitants) have been growing (The World Bank 2010b, The World Bank 2010c). The growth has started to slow down in developed countries. There are two possible reasons for the slower growth. The first one is economic recession. The other one is the so-called point of saturation; that is, the maximal degree of automobilization/motorization has started to be reached (Bruhova-Foltynova 2011). Correlation between the evolution of the degree of automobilization/motorization and deterioration in traffic situation in cities is undeniable. While Figure 1.1 shows that the degree of automobilization has nearly doubled in

the Czech Republic (CZ) during the last 20 years, Figure 1.2 introduces another interesting and indicative parameter about road traffic situation – the number of motor vehicles per kilometer (km) of country's road network. According to these two figures, it can be claimed that the growth of vehicles has exceeded the development of road infrastructure. This situation may not be sustainable.

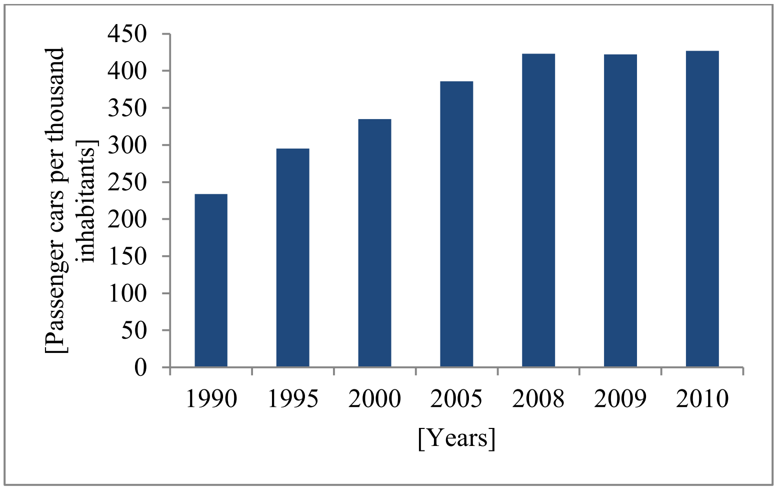


Figure 1.1: History of the Degree of Automobilization in the Czech Republic

Source: (European Commission 2011)

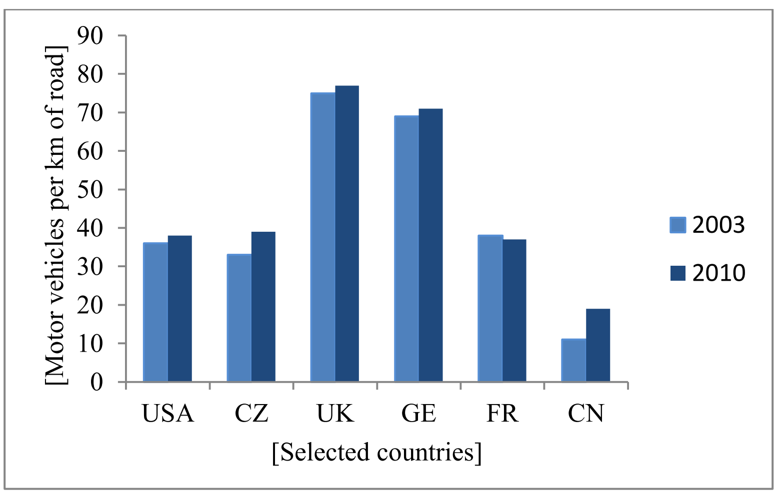


Figure 1.2: Motor Vehicles per km of Road Network in Selected Countries in 2003 and 2010

Source: (The World Bank 2010d)

So far only PTAs have been discussed. In addition to PTAs there are also Goods Transportation Activities (GTA) carried out on highways around the world. Usually the contribution of GTAs to the cities' transportation problems represents just a fragment of the whole pot of issues.

One of the biggest problems caused by GTAs is the movements of Heavy Goods Vehicles (HGV). Usually the origins and destinations of HGVs are not located in the same city; whereas the majority of personal vehicles initiate and terminate their trips within a single one larger urban area. Majority of HGV trips originated from outer areas of one city and end in another city while passing through the cities' road networks. If there is no bypassing possibility, their share on environmental and infrastructural damages can be very significant.

Compared to EU, domestic GTAs are served relatively more by railways in US. The total participation of road infrastructure on carried cargo, measured in ton-kilometers (tkm), was only 32.8% compared to 45.3% of railways in US in 2007 (European Commission 2011). Complications with the railroad network interoperability across EU countries lead to 45.8% of the total EU's domestic GPAs are transported through the road network; compared to only 10.2% served by rails in 2010 (European Commission 2011).

It is obvious that large urban areas attract a lot of PTAs and GTAs traffic activities. As it has been mentioned – transportation activities have grown and most of the load has been carried out through the road network.

Highway transportation differs from the other modes of transport fundamentally in one aspect, which is the decentralization in decision making. In other words most of the users make their independent decisions when, where and how they will travel. They just simply try to follow their own interest and benefits. As a consequence, the temporal and spatial distribution of traffic flow may not be optimal. In some sections of the network, congestion and heavy traffic are typically observed, which causes time losses, inefficiency, and environmental and infrastructural damages. In contrast, in air and sea transport modes, users have to travel according to scheduled flights or voyages with fixed routes.

In urban areas it is very difficult and costly to increase road infrastructure capacity or rebuild the network, because of the limited space or right-of-way. Such a solution would not be fully sustainable

anyway. Therefore, some regulations, policies and innovative technologies may be implemented in urban highway networks in order to ease congestion and to mitigate the undesirable side effects. However, every city's traffic conditions and possible solutions may be unique. Some solutions may work in one city but not in others.

This thesis provides a review of the state of the art policies and traffic management solutions including their impacts. A framework is then proposed as a decision support tool for preliminary-project selection. A case study is then followed which demonstrates via a practical example how policy makers and government/city officers can compare the merits of different possible solutions and make the initial decision for more detailed traffic impact/engineering studies.

1.2 Objective and Scope

This thesis has several objectives:

1. To review the transportation situation and problems in large urban areas in EU and US.
2. To systematically identify and classify the externalities and the negative side effects from urban road transportation.
3. To summarize the major transportation policies and traffic management solutions that will address the negative side effects identified in Objective 2.
4. To propose a framework for evaluation of the transportation policies and traffic management solutions.
5. To demonstrate an application of the framework proposed in Objective 4.

1.3 Organization of Thesis

This thesis is organized into the following chapters:

- Chapter 1 describes the motivation and the background of this thesis.
- Chapter 2 introduces the specific transportation situation and associated problems in large urban areas.

- Chapter 3 reviews and classify the externalities and negative side effects from urban road transportation
- Chapter 4 reviews, summarizes and discusses the major transportation policies, traffic management solutions, and experience with their implementation around the world.
- Chapter 5 proposes the framework for evaluation of transportation policies and traffic management solutions.
- Chapter 6 demonstrates the application of the framework proposed in Chapter 5, using the example of Prague, Czech Republic.
- Chapter 7 concludes this thesis and provides several recommendations for future work.

Chapter 2: Transportation Situation and Problems in Larger Urban Areas

2.1 The Urban Form and Transportation

2.1.1 Spatial Imprint and Spatial Interaction

"Urban form refers to the spatial imprint (see Figure 2.1) of an urban transportation system as well as the adjacent physical infrastructures. Jointly, they confer a level of spatial arrangement to cities" (Rodrigue 2013). Components of the urban transportation system, particularly infrastructures, modes, and users, participate on shaping the urban form. The spatial imprint of every city is different, because of variety in socioeconomic and geographical characteristics. The spatial interactions reflect each city's circulation pattern of passengers or freight (Kotas 2007; Rodrigue et al. 2006; Rodrigue 2013).

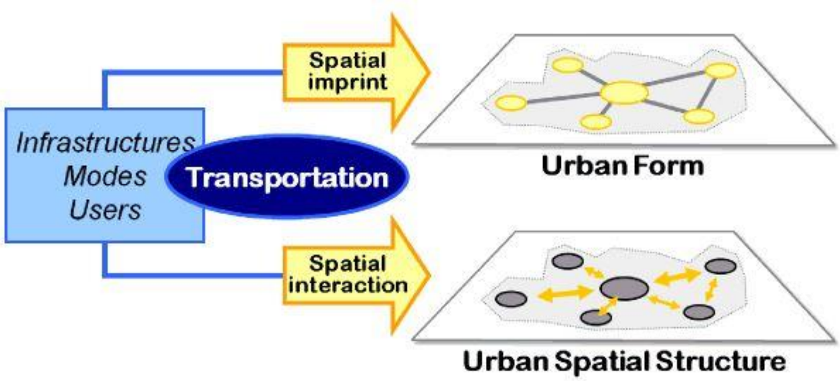


Figure 2.1: Transportation, Urban Form and Spatial Structure

Source: (Rodrigue 2013)

2.1.2 Urban Spatial Structure and Suburbanization

Construction of a city's road network has begun actually at the same time as construction of the city itself, because the city squares, street, and etc. have always been used for transportation and freight movements. However the evolution of the initial city's layout was influenced by many other factors instead of considerations for future transportation needs. This is perfectly visible especially in old European cities. Old historical city centers (usually fortified places in the past) are located in the

midsections and their constrained street networks were built up without any special planned patterns. Then, other urban districts are built around the historical center while struggling to from a transportation friendly spatial structure. Compared to European cities, the United States cities are relatively young and different. Their developments have been planned with respect to transportation needs since the beginning – grid organization of road network for easier orientation and accessibility, higher road transportation capacity, and etc. “North American cites tend to have an urban form that has been shaped by the automobile” (Rodrigue 2013).

From the transportation point of view, the categorization of the urban structure is important. Figure 2.2 shows that there are four possible types of urban spatial structures.

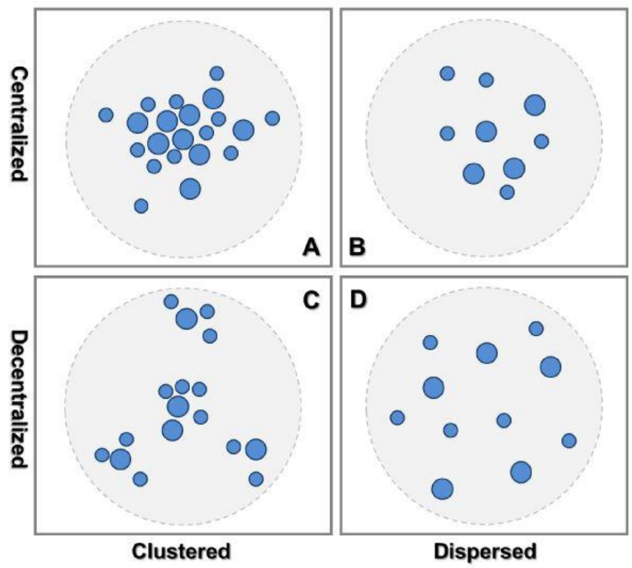


Figure 2.2: Types of Urban Spatial Structures
Source: (Rodrigue 2013)

The cost of land plus commuting from the suburban districts has been usually lower than the cost of land in the central urban areas; therefore households have had an incentive to buy lower-priced housing at the periphery. It contributes to a relationship between urban density and individual transportation (personal vehicles) and public transportation usage. Dispersed areas such as El Paso (type B) lead to higher car use, whereas denser locations such as Prague or New York (types A, C, respectively) offer more alternative modes (Anas et al. 1996; Kotas 2007; Rodrigue et al. 2006).

According to Anas et al. (1996), as heavy traffic and congestion builds near the city center, some centrally located companies respond by moving out of the Central Business District (CBD) and closer to their employees and customers with agglomerative forces, causing some of these employments to become clustered in suburban centers. This can also be called suburbanization. Figure 2.3 shows graphically the idea mentioned above.

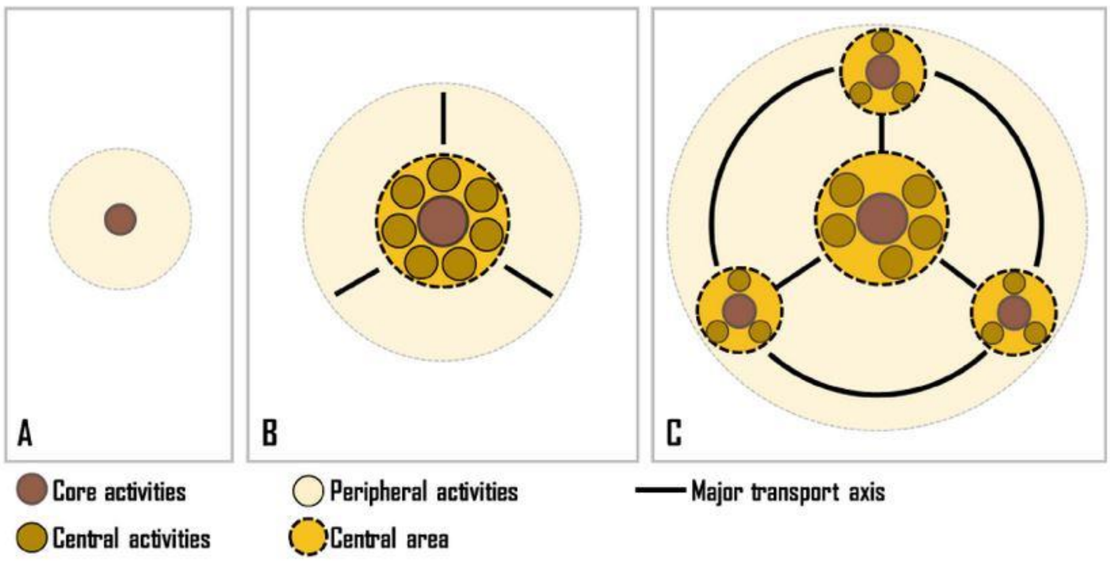


Figure 2.3: Evolution of the Spatial Structure of a City

Source: (Rodrigue et al. 2006)

2.1.3 Essential Functional Zones

Transportation represents the element with conjunctive (synergistic) function and disjunctive (separating) function at the same time. It does not create any zones by itself, but it creates networks composed from linkages (e.g. urban roads or rail/metro lines) and nodes (e.g. intersections, junctions or stations/terminals). Transportation networks, particularly nodal points spur urban development (Kotas 2007).

Several essential functional components exist. Such components tend to be concentrated in specific areas, where they create the so called functional zones. They can be divided with respect to their dominant functions:

- *Residential zones*
- *Industrial zones*
- *Administrative and public facilities zones*
- *Recreational zones*

Aggregation of individual functional components into zones has a lot of positive effects. However it generates more trips and multiplies demand for transportation.

2.2 Structure of Road Network According to Urban Form

It has been mentioned already that the initial road network development was subordinate to historical development of the city most of the time. Then acceptable level of road transportation should be provided by superior and hierarchized highway network.

The three basic schemes of highway network structure defined by Kotas (2007) are described in sections 2.2.1, 2.2.2, and 2.2.3.

2.2.1 Radial-Circular Scheme with By-Pass

The radial-circular scheme is typical for urban areas with around 100,000 – 500,000 inhabitants. Brno, Czech Republic is an example of this scheme.

Pass through traffic by-passes the city through an intercity freeway or highway (see Figure 2.4). The inner urban area is linked with the by-pass through approach roads. If there is another freeway or highway coming to the town in radial direction, its direct penetration into the center area must be avoided. The city center area must not be interconnected to the intercity highways diametrically in order to exclude all non-essential traffic.

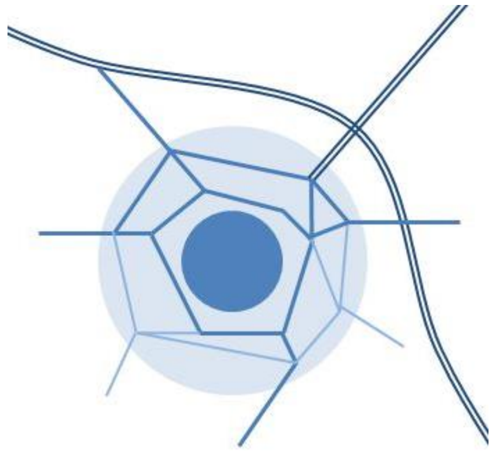


Figure 2.4: Radial-Circular Scheme with By-Pass

Adapted from (Kotas 2007)

2.2.2 Radial-Circular Scheme with Inner and Outer Ring

The radial-circular road network (Figure 2.5) with the inner and outer ring is well suited and typical for large metropolitan areas with population of more than 500,000. Prague, Czech Republic is a typical example of this scheme, when the construction of missing parts of inner and outer ring is completed.

The inner ring should surround the compact build-up area at its boundary. Its function is to serve most of the vehicle movements in the central locations. It should provide faster and smoother travel than passing through central area on the local and service roads with many restriction and limited capacity.

The outer ring should be situated a decent distance from the urbanized area, but not too far away. Otherwise its attractiveness as a tangential and half-circle route would be reduced. If some freeways coming to the city go beyond the outer ring, they should not be directly connected to the inner ring. Roads with radial orientation carry out the biggest portion of traffic volume. Therefore the incoming traffic needs to be split up before reaching the inner ring, in order to disperse the traffic load to more places.

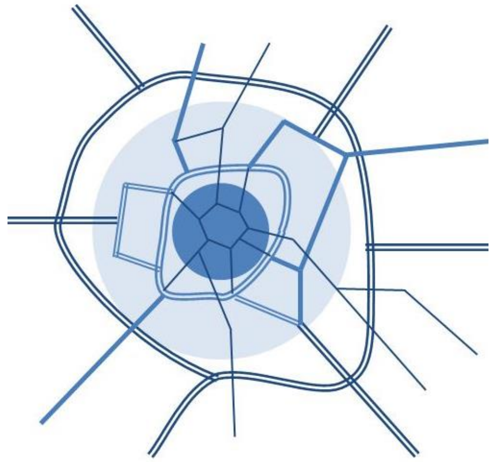


Figure 2.5: Radial-Circular Scheme with Inner and Outer Ring
Adapted from (Kotas 2007)

2.2.3 Grid Scheme with Freeway along Peripherals

The grid scheme (Figure 2.6) is induced by intently founded grid system lay-out, which is very typical for the majority of US cities. The downtown and CBD occupies a relatively small area in the midsection of the city. Compared to both radial-circular scheme with by-pass and radial-circular scheme with inner and outer ring, there is no need to create obstacles preventing the central area from pass through traffic. It does not penetrate central parts at all, because of the disincentive effect of the limited access to high capacity roads along the peripherals.

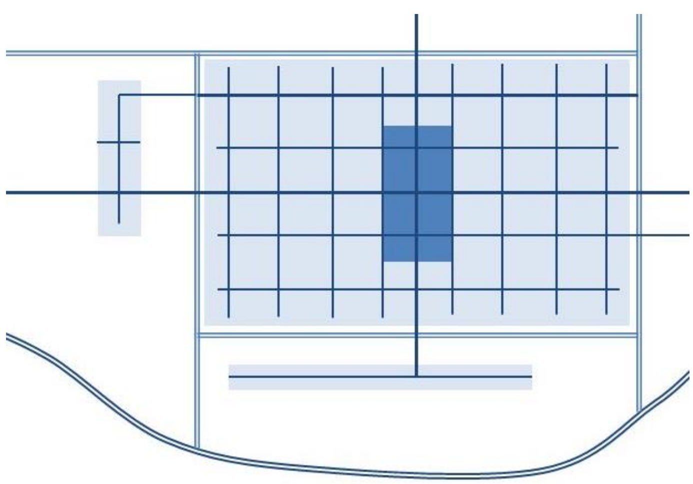


Figure 2.6: Grid Scheme with Freeway along Peripherals
Adapted from (Kotas 2007)

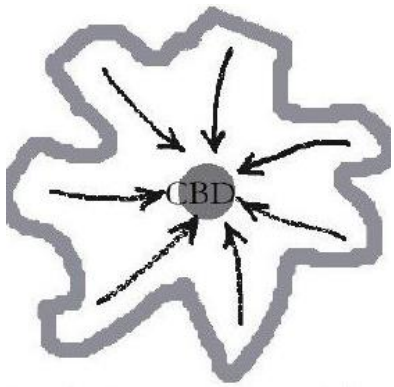
2.3 TRANSPORTATION DEMAND AND BEHAVIOR IN URBAN AREAS

2.3.1 Spatial Trip Patterns

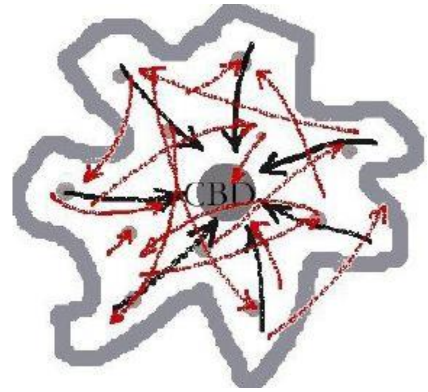
The transportation demand in the city is derived from people's and companies' needs to travel in order to perform some kinds of activity. There are two basic types of transportation demand; *mandatory transportation demand* (derived from the real need to travel) and *original transportation* demand (derived from the personal will to travel). The major transportation relationship within the urban area and its neighborhood is defined by the mandatory demand because of the necessity to move between the place of living and the place of working or studying, and etc. (Bertaud 2002; Kotas 2007; Mahmassani 2002).

Trip patterns within a metropolitan area can be schematically represented according to the urban area's spatial structure described previously (see Figure 2.2). "A polycentric city functions very much in the same way as a centralized city: jobs, wherever they are, attract people from all over the city. However, the pattern of trips is different. In a polycentric city each sub-center generates trips from all over the built-up area of the city (see Figure 2.7). Trips tend to show a wide dispersion of origins and destinations, appearing almost random. Trips in a polycentric city will tend to be longer than in a centralized city, ceteris paribus" (Bertaud 2004).

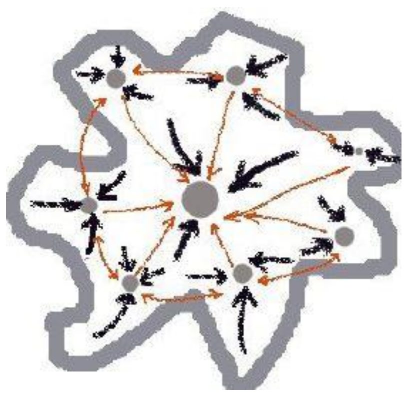
All the possible distributions of trip origins and destinations, according to metropolitan and central districts, are summarized and graphically interpreted in Figure 2.8. Detailed information about such transportation relations is necessary for the implementation of an effective traffic management and policy decision making.



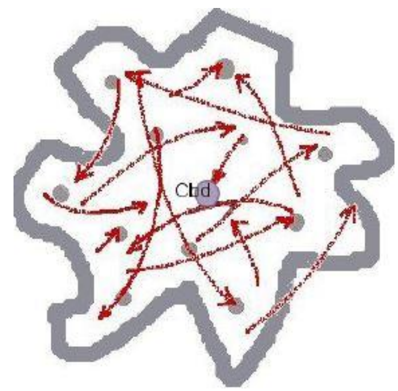
Strongly centralized



Centralized



Polycentric-clustered model



Polycentric-dispersed

Figure 2.7: Schematic Representation of Trips Patterns within a Metropolitan Area

Source: (Bertaud 2004)

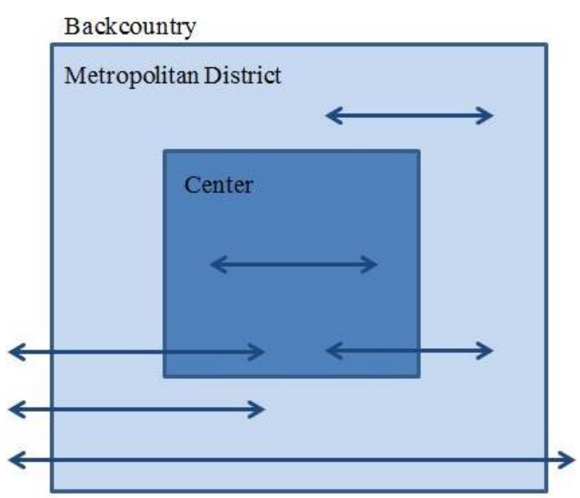


Figure 2.8: Possible Trip Origin and Destination according to Metropolitan District

There are daily, weekly and seasonal variations of transportation demands. In particular, daily and weekly variations are important for trip pattern research in cities.

Concentration of attraction times in trip destinations leads to concentration of traffic flows as well. Therefore, peak hours are observed (see Figure 2.9). In general, morning peaks tend to be higher and narrower as can be seen in Figure 2.9; this fact is very remarkable especially in El Paso. It is because of given initial time of business hours and direct travelling from home places to work, school, and etc., whereas the time is more flexible when returning home in the afternoon. In addition, the end of business hour varies more and people also stopover in public facilities (shopping malls, recreational centers, and etc.) (Mahmassani et al. 1996). The traffic congestion is worst during peak hours and the level of perception of its side effects is the highest. Compared to El Paso, traffic load distribution in Prague is more uniform and a significant saddle cannot be observed between the morning and afternoon peeks. It may also be a sign of transportation demand reaching the capacity of the road network most of the day (Kotas 2007, TSK hl. m. Prahy 2012; U.S. Department of Transportation 2013; El Paso MPO 2005).

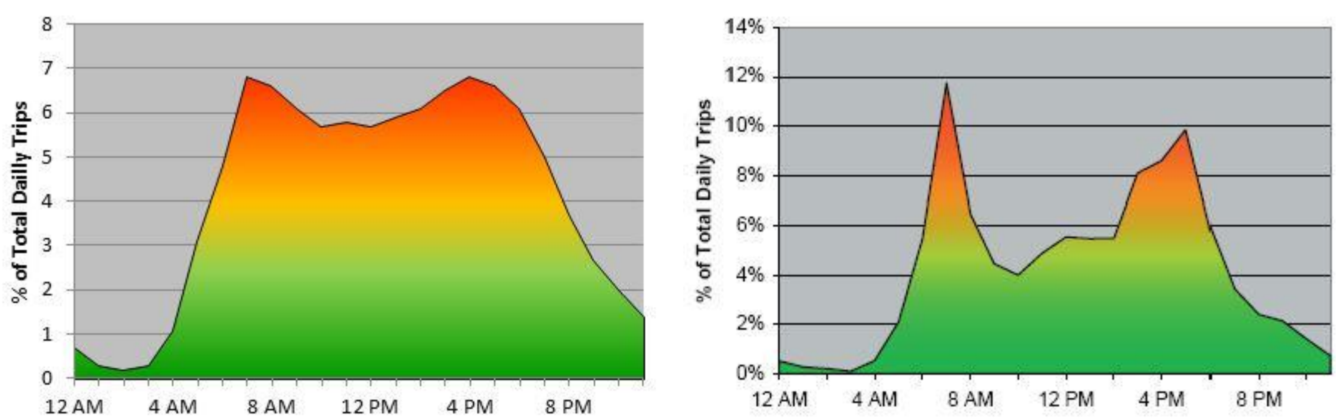


Figure 2.9: Comparison of Daily Variation in Prague (left) and El Paso (right) in Average Work Day
Source: (TSK hl. m. Prahy 2012; El Paso MPO 2012)

2.3.2 Transportation Behavior and Modal Choice

It has been proven that transportation behavior corresponds with the life style of certain population groups (Chliaoutakis et al. 2005; Zhang & Mohammadian 2006). The life style is

a determining factor in profiling household daily schedule, travel patterns and trip generation. Therefore, it is essential to perform life style analysis and categorization in order to recognize basic transportation needs of various groups. This information is important for analyzing and forecasting transportation demand. “The analysis of the lifestyle has also very important implications for policymakers as they are interested to address transportation equity issue and to balance mobility, accessibility, and traffic safety” (Zhang & Mohammadian 2006).

According to the research provided by Zhang & Mohammadian (2006), US’s population groups can be assigned to seven clusters with distinguishable lifestyle and transportation behavior:

- *Mature working-class families*

  (High percentage of mandatory trips per person, not regular usage of public transportation, usage of carpooling if possible)

- *Rural families*

  (High reliance on cars, because of missing alternative)

- *Upper-income outskirts residents*

  (Neither usage of public transport nor carpooling)

- *Yong families*

  (Similar characteristic as mature working-class families, but less traveling)

- *Retirees/Empty nesters*

  (Relying on cars, travelling shorter distances)

- *Manhattan/Downtown Lifestyle*

  (Significant walk and bike usage, public transportation usage, small percentage of private vehicle trips, short distance travel)

- *City low-income*

  (Low rate of car ownership, high public transportation usage)

Young people without children tend to live in central urban areas so that they can save time from long commute to work and other activities. Because of their limited incomes, they tend to rent apartments and use public transportation.

Families with children tend to move and live in the suburbs in a detached house with more space and better environment. As a result, they have to travel longer distances. Their lifestyle pushes them into driving their children to many activities. When the children grow up, these families change their lifestyle and become mature families with more workers and higher income; thus more mandatory trips are generated.

Downtown lifestyle and city low-income generally tend to higher usage of public transport. The implication means that both densely urbanized areas and poor economic attributes result in better public transportation use. In contrast, upper-income outskirts residents use public transportation sporadically; if so they preferably use rail-based systems.

People always search for the most comfortable, safest and fastest form of transport; preferably door-to-door solution. Therefore, car wins most of the time. However, if there is a chance to act differently, traveler will minimally consider other possibilities during the pre-trip decision making. This individual's choice of mode of transport can be possibly stimulated by adopting transportation policies and regulations in order to manage modal-split. Findings mentioned above are very important for urban design and transportation planning. Although they have been discovered in US, they may be transferable for EU's cities as well.

Chapter 3: Externalities and Negative Side Effects from Urban Road Transportation

3.1 Classification of Externalities

According to Buchanan & Stubblebine (1962), an externality can be explained as a cost or benefit which results from an activity or transaction and which affects an otherwise uninvolved party who did not choose to incur that cost or benefit. Newer economic definition of an externality was formulated by Meade (1973): "An external economy (diseconomy) is an event which confers an appreciable benefit (inflicts an appreciable damage) on some person or persons who were not fully consenting parties in reaching the decision or decisions which led directly or indirectly to the event in question."

Transportation generates a lot of externalities. All the means of transportation vary in their characteristics or attributes. Analogically they vary in externalities production. Both positive and negative externalities are produced.

Positive externalities in transportation seem to be a marginalized topic in contrast with anxious debates about negative externalities (or negative side effects). However, two aspects must be respected. Firstly, positive externalities do not harm; there is no need to mitigate them. Secondly, the impact of positive externalities in transportation is highly individualized; external benefits of society are equal to individual benefits (Miskovsky 2011). By contrast, external costs of society are always higher then cost of individuals. According to Bruhova-Foltynova (2009), Rothengatter (1994) and ECMT (2001) among the most beneficial positive externalities in transportation are:

- *Positive stimulation of economy and employment in peripheral and suburban areas*
- *Lower costs of logistic*
- *Travel comfort and time savings, etc.*
- *Advanced availability of Integrated Rescue System*

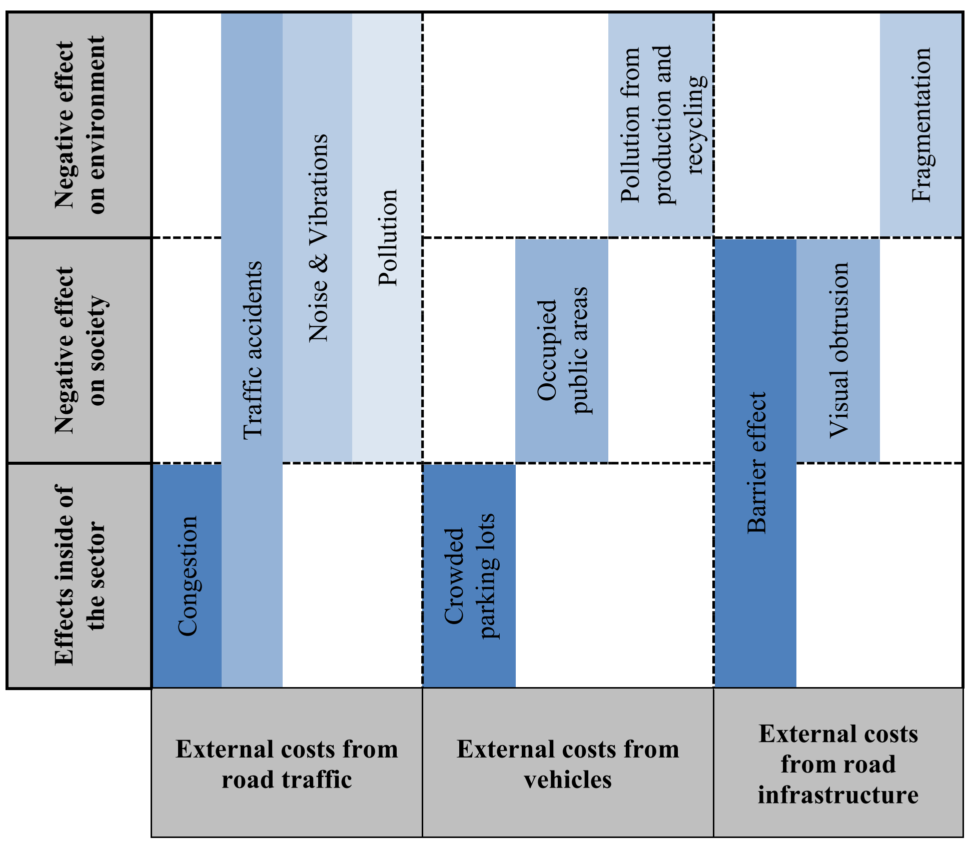
Negative externalities in transportation have more serious consequences. A lot of external cost is generated for the society as a whole, but individual users participate minimally on their reimbursement.

In spite of the fact that some of transportation costs are partly covered by fuel taxes, fares etc.; significant portion of them (external costs) is paid by the society (tax payers) no matter which mean of transportation they use (Miskovsky 2011; Santos et al. 2010).

Users of (urban) road network - individual vehicles, do not face with the full costs of their actions sufficiently. The road transportation demand keeps growing at an almost unsustainable level, inasmuch as prices of using road infrastructure do not reflect real costs they impose on the society.

Among the most serious negative effects of road traffic are *congestion*, *traffic accidents*, *environmental damages* and *infrastructural damages*. Another problem is caused by *parking*, because of an excessive occupancy of public areas. According to Maca (2010) other negative externalities are *barrier effect*, *spatial fragmentation*, and *visual obtrusion*. The relationships between the abovementioned externalities with vehicles, users and road structure can be seen in Table 3.1.

Table 3.1: Negative Externalities in Urban Road Transportation



Adapted from (Maca 2010)

The idea of internalization of externalities is based on the recognition and best possible evaluation of individual external costs and their transfer back to the producer; respecting the principle *user pays* and *polluter pays*. There is no universal internalization tool for all the externalities. Each of them has to be investigated individually. Detailed information about this topic can be found in Miskovsky (2011).

3.2 Congestion

Traffic congestion is known as the largest road transportation externality (Anas & Lindsey 2011). Congestion creates multiplying effects on the entire set of associated problems. Figure 3.1 provides visualized interpretation and relationships of the associated problems. The problems with darker color indicate the higher importance; the solid lines represent direct incidence and the dash lines represents indirect incidence.

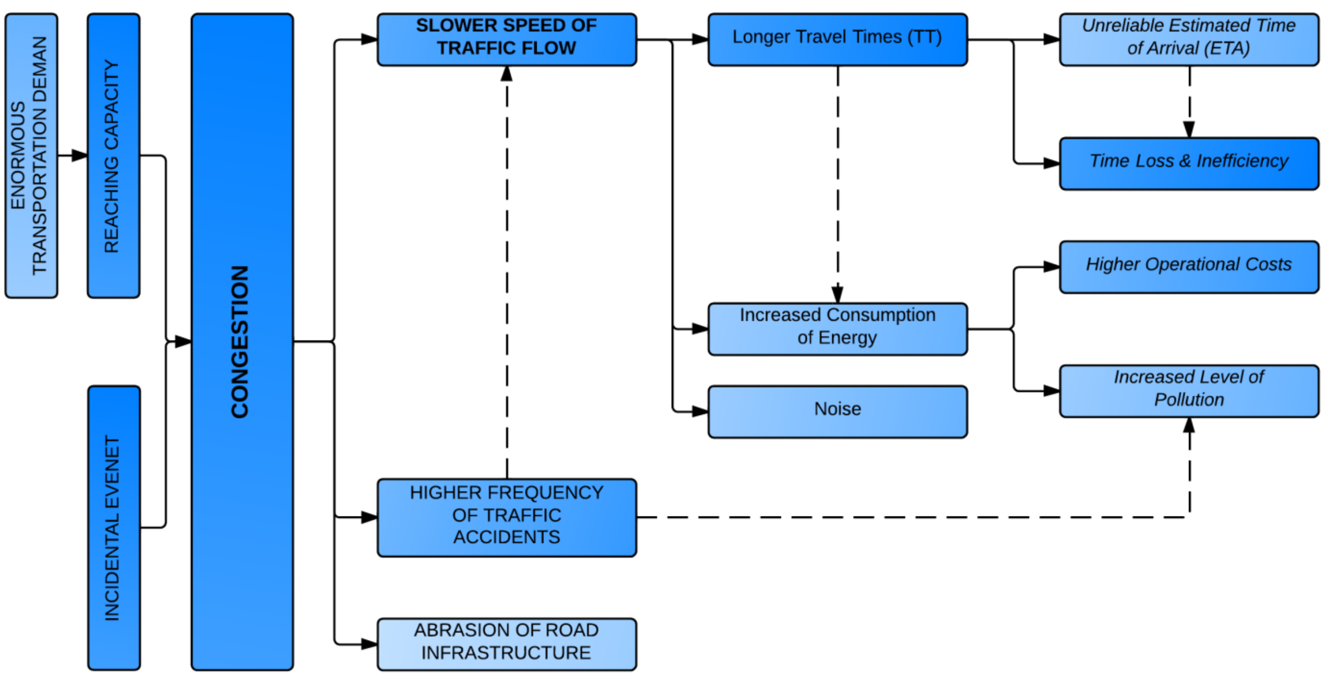


Figure 3.1: Visualization of Relationships among Problems Associated to Congestion

Most of the congestion occurs in accordance with the variations of transportation demand and they both can be predicted. Congestion temporarily and spatially overloads particular parts of a city's road network. Arterially oriented roads and other feeder roads, backbone roads in central areas, and crucial intersections are among the most affected parts of network. Congestion occurs when the highway capacity is incapable to serve the excessive demand. The capacity is determined by its physical parameters and it also slightly influenced by exogenous factors such weather, and etc.

It is necessary to remind that merely increase infrastructure capacity may not solve the problem completely. The Down-Thomson paradox describes the situation when increasing road capacity actually makes congestion on the road even worse. Current users of public transportation may be shifted to private vehicle mode, because of actual reduction in average door-to-door travel speed (Braess et al. 2005).

Besides recurrent (periodic) congestion patterns, randomly occurring congestion are observed too. The time and location of this type of congestion cannot be predicted, because it is caused by stochastic incidents such as traffic accidents.

To eliminate congestion, a complex, systematic and transportation policy must be adopted. It includes reasonable infrastructure construction and maintenance, responsible planning, and traffic management helping to improve traffic flow. It can be achieved through a suitable combination of transportation policies and regulations, Intelligent Transport Systems (ITS) solutions, economical tools, and administrative tools described in next chapters.

3.3 Traffic Accidents

"Accidents are the second largest road transportation externality and result in personal injuries, fatalities, and damage to vehicles and other property" (Anas & Lindsey 2011). Accidents also contribute to pollution by leaked fuels, oils, and etc. from crashed vehicles. Also, there is a correlation between traffic accident and congestion occurrence as can be seen in Figure 3.1.

The financial evaluation of external costs from traffic accidents may be very problematic. Damages to vehicles and other property can be objectively priced; however problems occur when it comes to injuries and fatalities, where many subjective attributes are involved.

Table 3.2: Urban and Rural Traffic Accidents Statistics in the Czech Republic, 2010

Location	No. of Accidents	No. of Fatalities
URBAN	54,024	260
RURAL	21,498	493

Source: (Policie CR 2011)

As can be seen from Table 3.2, nearly 72% of all the traffic accidents in the Czech Republic happened in urban areas. Less than 35% of all the fatalities happened in urban areas. In USA, although less than 19% of the population lived in rural areas in 2010, rural fatalities accounted for 55% of all traffic fatalities in the nation in the same year (NTSHA 2012).

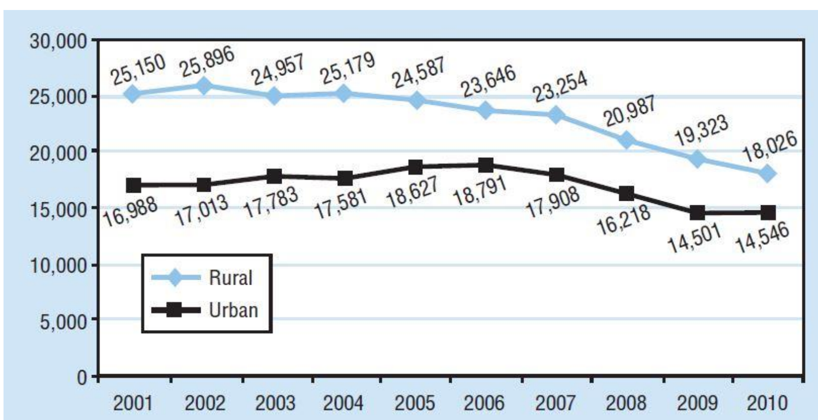


Figure 3.2: Motor Vehicle Traffic Fatalities by Year and Location in USA, 2001 – 2010

Source: (NHTSA 2012)

It can be said that urban areas tend to have higher traffic accident rates but lower ratios of fatalities. There is more traffic in urban areas, but the movements are made with slower speed, which

results in fewer fatalities. It is very likely that when the level of traffic in urban areas is reduced, the frequency of (not only fatal) traffic accidents will decrease.

3.4 Environmental Damages and Health Risks

All types of pollution, noise, vibration, and etc. can be collectively called environmental damages. Such a damaged life environment implies some potential health risks.

Metropolitan areas are mostly exposed to dangerous *air pollutants* from road transportation. "Vehicle emissions depend on fuel type, engine displacement, maintenance, engine temperature, and the driving cycle or time profile of speed. For each pollutant, emissions per kilometer are a flat-bottomed, U-shaped function of speed with a minimum at an intermediate speed that depends on the pollutant. In heavy congestion, speeds are generally well below the minimum" (Anas & Lindsey 2011). Higher concentration of harmful gases produced mainly by motor vehicles such as NO_x, CO_x, SO_x, VOCs (Volatile Organic Compounds), PMs (Particulate Matters), and often existence of smog lead to higher probability of cardiovascular and respiration diseases, decrease in lifetime expectancy, and etc.

Noise is an unpleasant and disturbing sound measured in decibels (dB). Long term exposure of human to noise is harmful. "According to the World Health Organization (WHO), noise from road transport affects the health of almost one third of people in Europe" (Anas & Lindsey 2011). It has negative impact on psychical condition such as pain and hearing fatigue, annoyance, dyssomnia, interferences with social behaviour and etc. It also increases the probability of cardiovascular diseases. Approximately 75% – 85% of the noise experienced by human is caused by road transportation. The average level of noise produced by a vehicle moving in urban areas is around 50 dB. The level of noise produced by a frequently used metropolitan road can reach up to 90 dB (Adamec 2008). As can be seen in Table 3.3, humans start to be annoyed when the level of noise starts to reach 50 dB during the daytime.

Table 3.3: Selected Harmful Effect on Humans According to Level of Noise (Long Time Exposure)

Harmful Effect of Noise	dB						
	40-45	45-50	50-55	55-60	60-65	65-70	70+
hearing damages							
increased risk of cardio-vascular diseases							
strong obtrusion by noise (daytime)							
obtrusion by noise (daytime)							
worse quality of sleeping							
obtrusion by noise (nighttime)							

Source: Adapted from (Adamec 2008)

Vibrations are mainly produced by vehicle movements. There is a close relationship between noise and vibrations. Vehicles movements are the biggest source of vibrations. Noise and vibration magnitudes are derived from many attributes such as vehicle construction, speed of movement, surface condition of pavement, and etc. Vibrations which are periodically perceived for a long time have harmful consequences (Adamec 2008).

Chapter 4: Transportation Policies and Traffic Management Solutions

Transportation policies and traffic management solutions may be viewed as tools for internalization of external costs. They help to mitigate impacts of negative side effects from road traffic in urban areas by improving modal-split, temporal and spatial vehicle trip distribution, and etc. There is no single universal tool for optimal mitigation of all the negative externalities, but the tools can be categorized.

The first category recognizes policies and solutions in accordance to the instruments they use. There are solution based on application of *financial instruments* (e.g. toll, fuel taxes) and solutions based on *administrative instruments* (e.g. restrictions on traffic flow) (Miskovsky 2011).

The second category recognizes policies and solutions in accordance to the way they achieve desired goals. There are *command-and-control* and *incentive-based* policies. Command-and-control policies define some particular instructions, restrictions or rules. The compliance of these rules is supervised by some kind of enforcement system. Users are fined when the rule is violated. In contrast, incentive-based policies motivate users to behave consentingly in desired way (Santos et al. 2010). This chapter describes the most popular policies and solution implemented in major urban areas worldwide.

4.1 Urban Road Pricing

Implementation of a tollways[1] system a source of funds for infrastructure construction and maintenance has been discussed since 1920. The economist A.C. Pigou came up with one of the first concepts of internalization of negative externalities by that time.

The first urban road pricing was implemented in Singapore in 1975. The reason for implementation was transportation demand management. The first application of urban road pricing in Europe was introduced in a few Norwegian cities (Bergen, Oslo, and Trondheim) during 1980s and 1990s.

Implementation of large-scale congestion pricing[2] in London and Stockholm in the beginning of the new millennium represents a milestone. Its implementation has been generally considered successful

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[1] Tollways represent one of the road pricing subset. It can be a road, bridge, tunnel, and etc., where motorists are charged a fee according to a fixed schedule.

in both cities. Many other (not only European) cities struggling with congestion have been considering this solution.

The successes in London and Stockholm have proven that large-scale congestion pricing is a very powerful tool, which can encourage traveler to adjust all aspects of their travel behavior. It affects both short-term decisions (number of trips traveled, destination, mode of transport, initial time of trip, route, and etc.) and long-run decision (where to live, where to work, where to set up business, and etc.) (Palma & Lindsey 2011).

Nevertheless many attempts to implement congestion charging have failed (Richardson & Bae 2008). This could be due to several reasons. A congestion charging project is a very ambitious and challenging problem requiring big investments. A lot of transparent communication and explanation to public is needed to obtain at least partial public support. Richardson & Bae (2008) also mentioned that many US transportation engineers do not think that the solutions applied in EU would work in US, because they assume that congestion in US is less concentrated in city centers and more prevalent on expressways. "With the exception of New York City, no US metropolitan area experiences congestion as severe as London's" (Palma & Lindsey 2011).

The rest of this section provides an overview of urban road pricing, which is considered to be the most powerful and effective toll for congestion management. For detailed information about this topic see Palma & Lindsey (2011), Richardson & Bae (2008), and Anas & Lindsey (2011).

4.1.1 Urban Road Pricing Goals

Reducing the level of congestion is usually the primary objective of the urban road pricing. In congestion pricing, users are charged a higher price to enter or travel within an urban area during rush hours. Therefore, users are encouraged to consider the number of their trips, shift their travel to off-peak times or to different locations, or find alternative modes of travel. The existence of a multi-modal transportation network is assumed.

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[2]Congestion pricing is a subset of road pricing. It is the policy of charging drivers a fee that varies by time of day on a fixed schedule (value pricing) or with the level of traffic (dynamic pricing) on a congested roadway. Congestion pricing is designed to allocate roadway space, a scarce resource, in a more economically feasible manner.

In addition, urban road pricing schemes may have other goals such as revenue generation, reduction of environmental impacts, and encouragement of public transportation use. These additional goals are usually not separated from congestion management. However, the effect of pricing scheme varies for each goal and therefore, the most important goal usually determines the design of a road pricing scheme (Eliasson & Mattias 2002).

Revenue generation is required when there is a need to finance infrastructure. Revenues may be used to fund roads, public transportation, or even other non-transportation related projects. Revenue distribution is often the key factor to obtaining public acceptance of the road pricing scheme, no matter what the primary objective is (Eliasson & Mattias 2002).

Reduction of environmental impacts is associated with reduction of high level of traffic and congestion. It is usually reached automatically as a side benefit with reducing the level of congestion. When reduction of environmental impacts is a major goal of road pricing, pricing is generally derived from the size or weight of the vehicle or its emissions class.

Encouragement of public transportation use is also closely linked with the first case – reducing level of congestion. Users are financially motivated to shift to available public transportation systems.

4.1.2 Major Obstacles Encountered

Although urban road pricing initiatives should aim to generate socially desired benefits, all of the international road pricing initiatives have faced some sort of opposition. At least one group perceives that its members would be made worse off because of the pricing scheme (FHWA 2006). This effect may be called winners and losers theory.

Public acceptance represents an essential item for successful urban road pricing initiatives. Perception of the congestion problem, equity or fairness, success of public outreach efforts, and use of toll revenues are the most important factors influencing the public acceptance (FHWA 2006).

4.1.3 Schemes of Pricing

4.1.3.1 Cordon

In cordon pricing scheme, users are charged when they cross the border of the predefined area. Charges can be applied for entering, exiting or for both (see Figure 4.1). As a result of implementation of this scheme, a reduction of congestion inside of the area is observed. However, new congestion may occur along the cordon border. This situation may be solved by implementing of multi-cordon pricing scheme, which helps to disperse the traffic (Anas & Lindsey 2011).

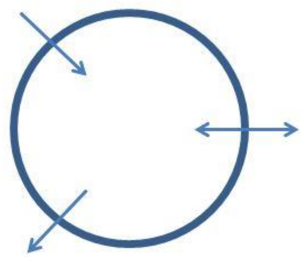

Figure 4.1: Cordon Pricing Scheme

4.1.3.2 Zone

In zone pricing scheme, users are charged when they travel inside of the predefined area, no matter if they enter or leave or if they are already inside of the zone. Therefore, it affects the duration of parking inside the area too. Users are motivated to leave the zone when their permits expire (Anas & Lindsey 2011).

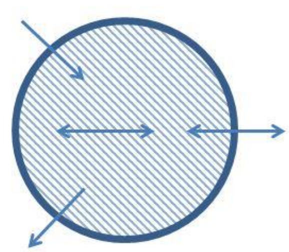

Figure 4.2: Zone Pricing Scheme

4.1.3.3 Distance-Based

Distance-based scheme of pricing reflects Vehicle Miles Traveled (VMT). Miskovsky (2011) mentions this type of road pricing as the most capable tool to motivate users to optimal behavior, because the fee is derived from the real external costs produced by individual users. Therefore it is also suitable from the equity point of view. However, this scheme is better applicable in rural areas then in urban areas, because of the technology required to track every vehicles. This scheme has not been implemented in an urban area so far. Potential privacy issues may also be a main obstacle of implementation (especially in US).

Figure 4.3: Distance-Based Pricing Scheme

4.1.3.4 Facility-Based

Facility-based scheme of pricing is based on charging for usage of specific items of road network such as bridges, tunnels, and etc. This scheme is mostly used for funds collection to recover the cost of construction and maintenance. The fee should be low enough not to discourage users from driving.

Figure 4.4: Facility-Based Pricing Scheme

4.1.4 Amount of Fees and Its Time Differentiation

Determination of the exact amount of the fee is a multi-disciplinary problem. The socio-economical characteristic of the locality must be taken in consideration. Verhoef et al. (2008) describes this topic. Ideally the fee should be derived from the real external costs produced by individual users.

Time differentiation of the fees is important from the transportation engineering point of view, because it enables the system to manage travel demand by time-of-the-day or by day-of-the-week. There are two basic methods of variation:

- *Flat rates*

  (The fee does not change with time, which is suitable for maximizing revenues. It is also easier for users to perform calculation of travel costs.)

- *Differentiated rates*

  (The fee varies with time, which enables dynamic management of traffic. The variation is mostly based on time-of-day schedules. It is used for example in Singapore to maintain desired speed levels. A variant of this is the so called responsive toll, where users are charged according to real-time traffic situation.)

4.1.5 Technology

4.1.5.1 Toll Booth

Toll booths represent the classic pay-and-go places. This system seems to be out of date, because it does not enable free-flow toll collection, which may induce congestion, and requires additional space on roads.

4.1.5.2 Vignettes (Stickers)

System of using vignettes is more advanced and relatively inexpensive solution. It can operate on free-flow principles, but some enforcement system is needed. Vignettes do not enable simple time differentiated rates of fee.

4.1.5.3 Electronic Road Pricing (ERP)

Electronic Road Pricing (ERP) represents the state-of-the-art toll collection project. Such a solution combines advantages of modern technologies with transportation engineering knowledge. In

addition, it enables integration of real-time traffic information and telematics[3] projects based on the data being collected. However, because of the technology and system complexity, it requires huge initial investment (capital costs) and relatively costly maintenance (operating costs). There are three basic technologies to operate an ERP system:

- *ANPR (Automatic Number Plate Recognition)*

  This technology is based on the combination of camera surveillance and Optical Character Recognition (OCR) method. Information from the recognized vehicle license plate is transferred to a central system and analyzed. Cameras also provide the enforcement.

- *DSRC (Dedicated Short Range Communication)*

  This solution requires On Board Units (OBUs) to communicate with road-side infrastructure. Information is transferred from vehicles to road-infrastructure through microwave, which is then transferred to a central system and analyzed. An additional enforcement system is needed.

- *GNNS/CN (Global Navigation Satellite System/Cellular Network)*

  This solution requires OBUs capable to receive and analyze signal from a global navigation satellite system. The OBU tracks the position of a vehicle and sends the information through a cellular data network to a central system. An additional enforcement system is needed. This solution is very suitable for distance-based pricing schemes. However the accuracy of navigation satellite system may be poor in dense urban areas.

4.1.6 Experience from London, Stockholm and Singapore

London, Stockholm and Singapore are the only three cities around the world, where a large-scale road pricing system have been introduced.

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[3] Telematics integrates information and telecommunication technologies with transportation engineering in order to optimize control processes on traffic flow, increase effectiveness of traffic flow, increase safety, and improve comfort of traveling on current road infrastructure.

4.1.6.1 Singapore

Singapore is the first city that implemented urban road pricing (locally called "area license scheme") in 1975. Restraining traffic demand and providing smooth traffic flow have been the main goals of Singapore's road pricing strategies. The toll rates are set up in order to maintain the desired speed levels at least for 85% of time (45-65 km/h for expressways; 20-30 km/h in arterial roads) (Palma & Lindsey 2011). The original paper license system was replaced by automatic ERP gantries (see Figure 4.5) in 1998. See Table 4.1 for more information.

Figure 4.5: Example of ERP Gantry in Singapore
Source: (Land Transport Authority 2013)

4.1.6.2 London

London introduced the congestion charging zone (see Figure 4.6) in 2003 as a result of worsening traffic congestion in the city center. Although London has one of the most advanced public transportation systems, drivers of vehicles spent 1/3 of their travel times stuck in non-moving traffic and another 2/3 of the time moving at average speed lower than 16 km/h. Congestion decreased by 30-40% after the implementation of zone charging (TfL 2013). See Table 4.1 for more information.

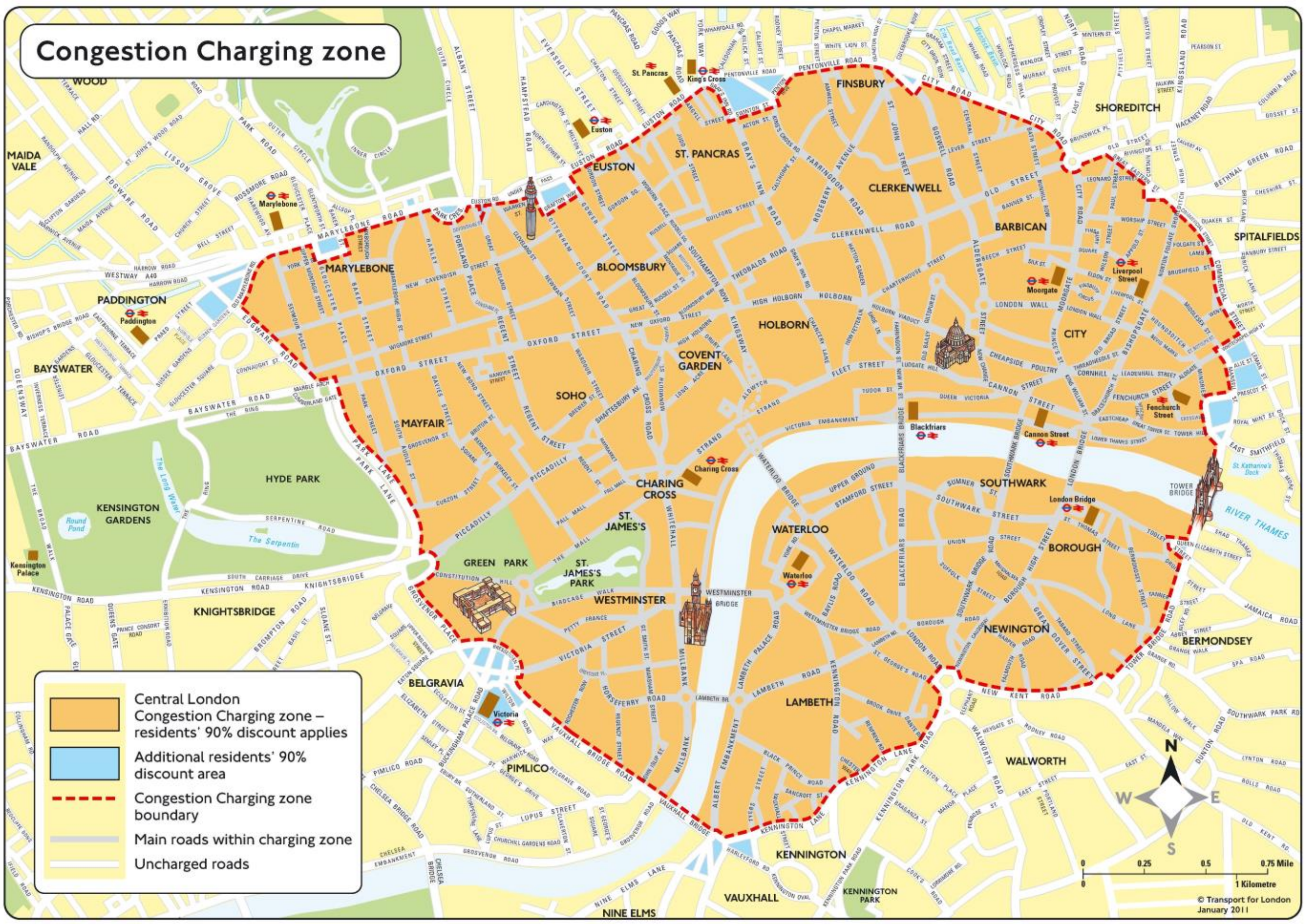

Figure 4.6: Congestion Charging Zone in Central London

Source: (TfL 2013)

4.1.6.3 Stockholm

Stockholm started cordon congestion charging (see Figure 4.7) in 2005. Compared to London, the congestion at Stockholm was not relatively bad. Therefore, fundraising for infrastructure and public transportation were set up as addition goals. The City of Stockholm invested heavily to improve and promote the public transportation systems before the congestion charging project was launched. They bought abound 200 new buses, established new connections and routes, increased the capacity of the metro system and city railways. New P+R (Park and Ride) facilities providing roughly 1,800 new parking spaces were established. However, no effect on traffic flow or modal-split distristribution change was observed until the congestion pricing started (Stockholmsforsoket 2006). See Table 4.1 for more information.

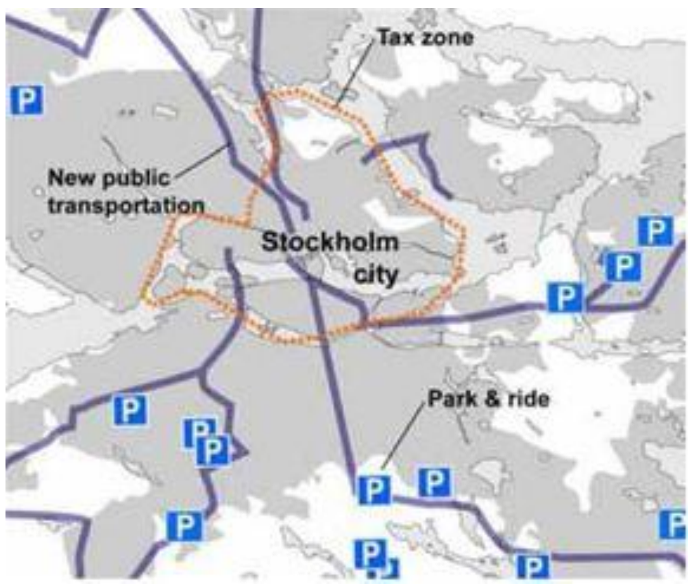

Figure 4.7: Congestion Charging Cordon in Stockholm

Source: (Stockholmsforsoket 2006)

Table 4.1: Facts about Urban Road Pricing in London, Stockholm, and Singapore

	LONDON	**STOCKHOLM**	**SINGAPORE**
Year of introduction	2003	2005	1975 *ERP in 1998*
Goal	Traffic management Reduction of environmental impacts	Traffic management Reduction of environmental impacts	Traffic management Reduction of environmental impacts
Charging method	Cameras with ANPR	DSRC Camera enforcement	DSRC Camera enforcement
Pricing scheme	Zone	Cordon	Zone
Capital costs (approximately)	140 mil EUR	200 mil EUR	100 mil EUR
Annual operating costs (approximately)	140 mil EUR (50% of revenues)	20 mil EUR (25% of revenues)	7 mil EUR (17.5% of revenues)
Annual revenues (approximately)	280 mil	80 mil	40 mil
Fees (approximately)	10 GBP per day (11.50 EUR)	10, 15 or 20 SEK per entering/leaving cordon (1.20, 1.80, 2.40 EUR) maximum 60 SEK in total per day (7.20 EUR)	Variable
Differentiation	By weekdays and responsive	By time-of-day and weekdays	By time-of-day and responsive
Effects	15% less motor traffic, congestion reduced by 30-40%, shorter travel times Investment in public transportation – higher reliability and travel speed, increase of passengers -16% in CO_2 emission -8% in NO_X emission -7% in PM emission *(in 2008, change on 2003)*	22% less motor traffic, shorter travel times Investment in public transportation – higher reliability and travel speed, increase of passengers -13% in CO_2 emission -8.5% in NO_X emission -13% in PM emission *(in 2006, change on 2005)*	10-20% less motor traffic, improvement on traffic flow Investment in public transportation N/A

Adapted from (Palma & Lindsey 2011; European Commission 2010; TfL 2013; TexDOT 2008; Swedish Transport Agency 2013)

4.1.7 Experience from New York City

US Department of Transportation (DOT) announced that it would provide approximately $350 million to New York City (NYC) to implement a congestion charging scheme in 2007. The proposed ERP system is based on a combination of a zone and cordon pricing scheme for Manhattan (see Figure 4.8). “Car drivers entering or leaving Manhattan below 86th Street, on weekdays from 6:00 a.m. until 6:00 p.m., would pay $8 and truck driver would pay $21. For vehicles moving only within the zone, the fee would be $4 per day for cars and $5.50 for trucks” (TxDOT 2008).

However, this plan generated strong opposition. Citizens and local politicians considered it as a punishment for people who work in downtown Manhattan and commute from the surrounding suburbs. Residents in some parts of the city such as Brooklyn complained about a possible negative influence on them. It was not possible to obtain sufficient public acceptance. Therefore the project was put on hold. Shortly thereafter, most of the US DOT budget that was designated for the ERP in NYC was reallocated to other transportation projects in Chicago and Los Angeles (TxDOT 2008, Naparstek 2008).

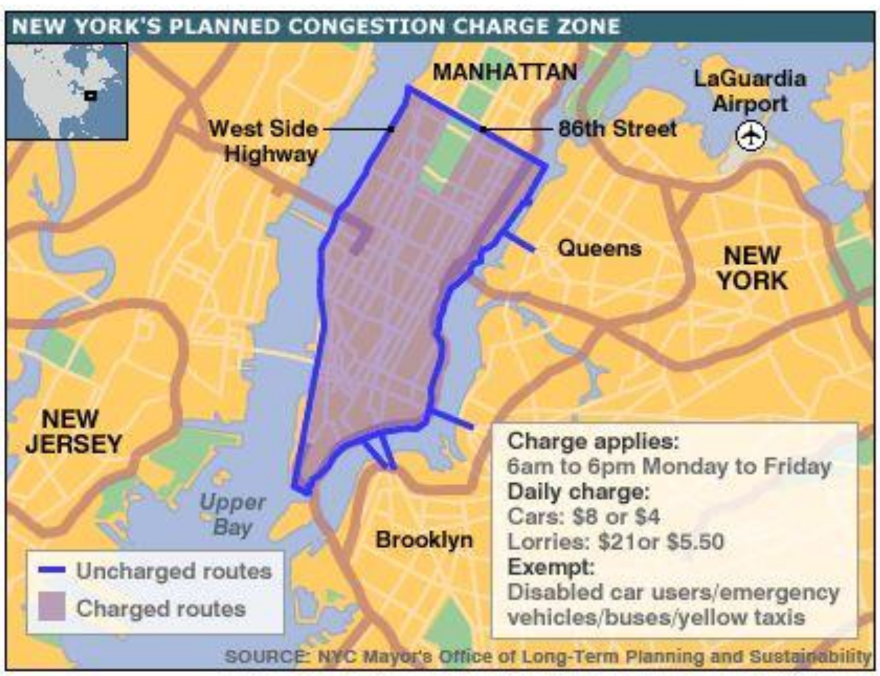

Figure 4.8: Proposed Congestion Charging Zone in NYC

Source: (TxDOT 2008)

4.2 Zones with Limited Access

4.2.1 Environmental Zones

Environmental Zone (EZ) is an administrative and command-and-control policy. Vehicles that want to enter an EZ are required to meet predefined emission limits in order to decrease pollution and establish healthier environment. The limits are usually derived from international or national emission and noise standards and norms. Assuming that the traffic composition is known, pollutant limits may be partly used as parameters to maintain traffic flow in the zones.

In March 1, 2007, big environmental zones project started in more than 40 German cities. Each city in Germany is allowed to establish an EZ in case that the PM air pollutant limit is exceeded at least 35 days in a year. The boundary of an EZ is designated by traffic signs. Only the vehicles certified by a particular "Umweltplakette" (means environmental sticker) can enter the area. There are three kinds of stickers – green, yellow, and red (see Figure 4.9). Certifications are done by an authorized vehicle inspection company and the stickers are assigned according to the vehicle emission category. The price of the certification is 5.50 EUR. The violation of EZ is fined by 40 EUR (Umweltplakette 2013).

Figure 4.9: Environmental Zone System in Germany

Source: (Umweltplakette 2013)

This solution is inexpensive and easy to implement. However its effect seems to be poor. Wichman (2008) consider this solution ineffective, becauase the concentration of PM air pollutant decreased only by 5%. Traffic volumes have indicated no relevant changes as well.

4.2.2 Zones with the Total or Partial Exclusion of Private Road Transportation

Zones with exclusion of private (or eventually other specified) road transportation are possible. Exception can be made for residents, police cars, and etc. However, these zones might not be possible to realize in large-scale. An existence of a sufficient public transportation system is the most important assumption. This solution seems to be relatively easy and inexpensive to implement. In addition, Lindsey & Verhoef (2000) mentioned that some of public opinion research has found that people accept some form of an absolute ban better than the idea of being charged.

4.3 Parking Management

Parking management is primary an administrative command-and-control policy. It can also be a form of financial tool or policy when the system of charging is implemented. Adequate approach to parking management supported by system of public transportation can help to reduce a city's road transportation problems.

Parking needs in a locality can be categorized into three basic groups. Residents and local businesses represent the first group. Regular commuters (people travelling to their jobs, schools, and etc.) represent the second group. Visitors and other trips with non-regular characteristics represent the third group. Assuming that the second and third groups generate a big number of trips and public transport alternative exists, the number of these trips can be reduced through discouraging people from parking in this locality. It can be obtained either by restriction on parking capacity or by implementation of fees. Mobility of the locality has to be preserved and other modes of transport have to satisfy the demand.

Many cities suffer from insufficient parking in the central areas, which can also negatively affect traffic flow. Vehicles arriving to the destination are not able to find parking spaces in the first moment. They are forced to keep moving and therefore they remain in the network traveling additional distances to find a free spot.

Conceptual design of parking management has two approaches. The first possible approach tries to satisfy parking demand by adjusting the capacity. But it can induce unwanted increase of traffic in the locality (see Down-Thomson paradox in Section 3.2). The second and more relevant approach uses

pricing mechanism to control parking demand, combined with incentive to shift travel mode to public transport. The combination of both approaches is also possible. The parking capacity may be increased in order to provide sufficient reserves, but pricing policies can control the demand.

An advanced parking management system also includes the implementation of ITS to provide real-time parking information. Such a system should guide drivers more effectively and provide them information about direction, availability, prices and payments, and etc. (Maccubbin & Hoel 2000).

4.4 Change-Mode Encouragement

Change-mode encouragement is the typical collection of incentive-based policies. Incentive-based policies are not intrusive, which means that their influence on travelers is not enforced. In fact, seeing the advantages resulting from using another mode of transport should make travelers change their mind naturally.

Public transportation represents the essential alternative option for every city. It is impossible to think about any road traffic restraint project until a public transportation system with sufficient capacity is introduced. The benefits of a well-established public transportation system such as time saving, cost saving, vehicle independency, and etc. should overweight the disadvantages such as loss of privacy or less comfort. P+R facilities should be built in order to establish transfer nodes. Evaluation of a P+R facility potential has been researched by Cornejo (2012).

Public transportation should also be promoted and advertised. Its network should be designed with respect to people movement needs. Preferably the public transportation network should compose of more than one mode (bus lines, light rail systems, and etc.) so an integrated system can be created.

Public transportation system benefits from the synergic effect in contrast with personal vehicles, because it groups people traveling the similar directions. Therefore, it is more efficient and environment friendly (less pollution and noise). The efficiency can be furthermore improved by providing preferences in the infrastructure such as dedicated lanes for buses, and etc. On the other hand, it is difficult to plan for the optimal distribution of capacity across the metropolitan area. Last but not the least, public transportation system is usually non-profitmaking and it must be significantly subsidized.

Policy effort to encourage biking and walking should be also mentioned. Besides the positive effect on traffic flow, they help people to stay fit as well. However, the possibility to bike or walk is not equal everywhere. It is also influenced by the actual weather situation, seasons, and geographical dispositions. For example the Benelux area in Europe is famous for mass development of biking in metropolitan areas.

4.5 INFRASTRUCTURE ADJUSTMENTS AND EXPANSION

Adjustments on current infrastructure can be done as the initial step in improving traffic situation. Adjustments should include solutions with low financial requirements. Here are several examples of practical applications of the road infrastructure adjustments:

- *Changes in lanes layout*
- *Excluding pedestrians from crossing streets at the same level as vehicles*

  (Establishing overpasses or underpasses in the most conflicting areas)
- *Modification of some intersections to roundabouts*

  (Roundabouts enable smoother traffic flows)
- *Introduction of dedicated lines*

  (Dedicated lines such as bus lines or High Occupancy Vehicle (HOV[4]) lanes enable to increase number of travelers transported through current road network)

Adjustments can be also done on current public transportation system in order to increase its reliability, performance and capacity (control and safety system upgrades, and etc.).

Right of way is limited for new constructions in metropolitan areas. Therefore, extensive capacity addition is complicated especially in the central parts of a city's road network. According to Down-Thomson paradox (mentioned in Section 3.2) it would not be suitable anyway.

[4] HOV lane means High-Occupancy Vehicle lane. Such lanes should support carpooling. Therefore they are exclusively dedicated to cars occupied by two or more passengers. High-Occupancy Toll (HOT) lanes have been introduced in US as a modification of HOV. Even single-man occupied car are allowed to use this line on condition that they pay a fee.

Road network reconstructions should focus on removing potentially dangerous places or bottlenecks. New road network constructions should be oriented on developing inner and outer rings or by passes.

4.6 Maintenance of Traffic Flow

Traffic flow can be controlled and maintained by the applications of transportation engineering findings. Different kinds of restriction (administrative command-and-control policies) on traffic flow can be applied. It can be for example limitation on speeds. Lower speeds can have several contributions such as keeping traffic flowing at optimal capacity or decreasing of noise and emissions.

Modern traffic flow management is responsive and based on ITS solutions. Telematics devices collect and analyze real-time data about traffic. Based on the processed data, traffic flow is controlled. Variable traffic signs and message boards provides actual information and directions to drivers. Telematic systems also support smother traffic flow by setting up green waves on traffic lights, providing information about estimated travel times, parking possibilities, optional routing possibilities, and etc.

4.7 Other Transportation Policies

Other transportation policies can be derived from individual needs of the city. For example some cities (e.g. Athens, Mexico City) tried to implement policies restricting vehicles movements based on license plate number. The desired effect of traffic situation improvement was not observed. Different kinds of taxes connected with vehicle usage (fuel tax, registration tax, and etc.) belong to other transportation policies.

4.8 Influence of Transportation Policies on Traveler's Decisions

Application of any transportation policies has dual influences. There will be groups being benefited from it and there will be groups being harmed. This is called “losers and winner theory”. Therefore policies should be always chosen with respect to maximizing the benefits. It is also better to

start with a simple solution and observe users' reactions, than to start with implementation of a "heavy-duty-tool" in the beginning.

Figure 4.10 shows the influence of transportation policies on travelers' decisions. Terminators represent possible changes in generated trips after policies implementation. The terminators colored green represent reaching of desired effect of policies. The terminator colored red means no changes. As can be seen from this diagram, implementation of transportation policies can exclude the avoidable trips completely or it can stimulate to change the mode. Change-mode availability/possibility (especially from private vehicles to public transport systems) is assumed if the policies should take an optimal effect.

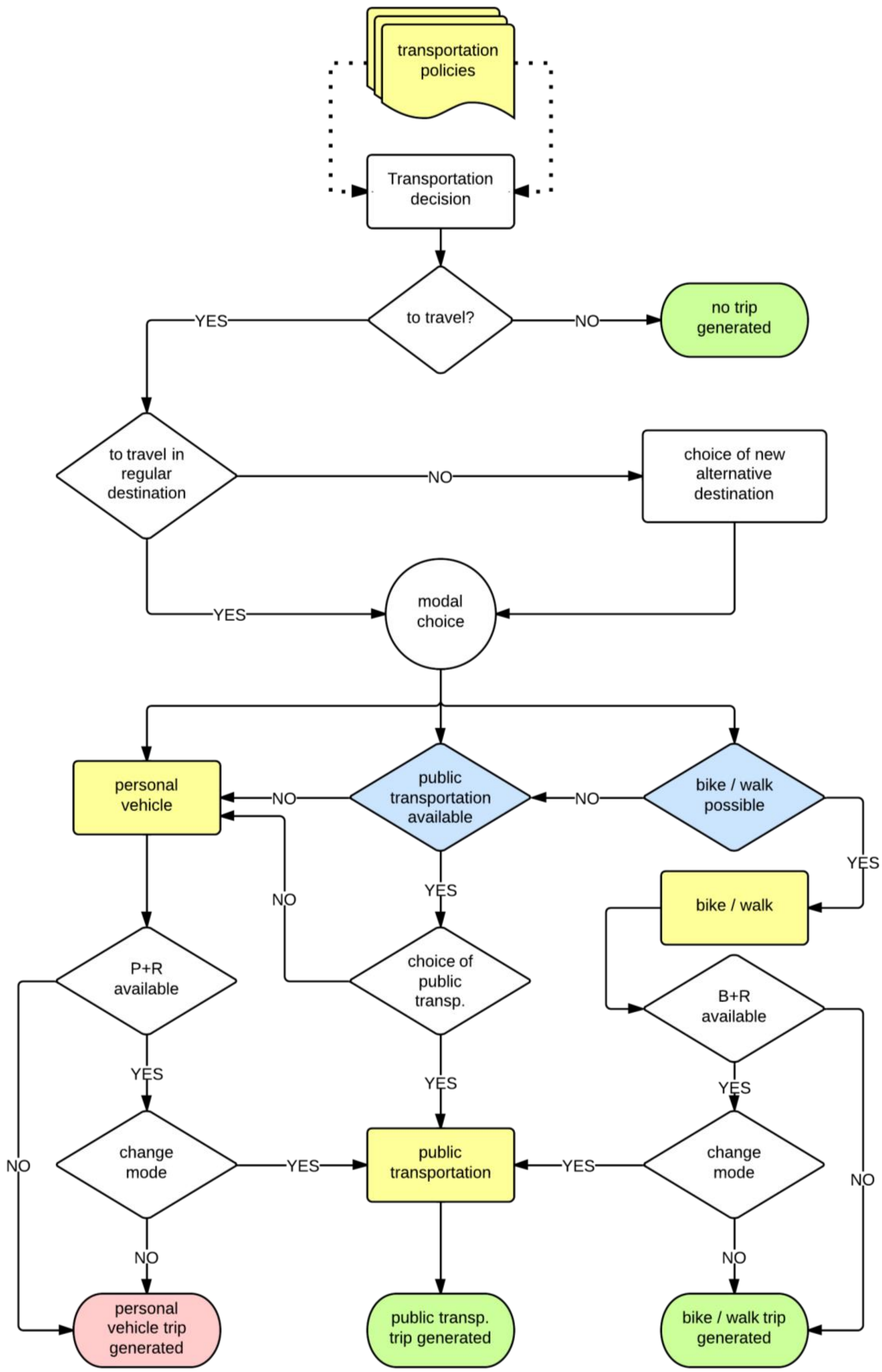

Figure 4.10: Diagram of Transportation Policies Influence on Travelers' Decisions

Chapter 5: Multicriterial Framework for Preliminary Transportation Projects Evaluation and Selection

Transportation projects decision making should be made on basis of a wider range of performance criteria that reflect the concerns of all involved parties. “Decision making mechanism based on multiple criteria can help structure an agency’s decision-making process in a clear, rational, well-defined, documentable, comprehensive, and defensible manner; and help the agency to carry out what-if analyses and to investigate trade-offs between performance criteria” (Sinha & Labi 2007). Therefore, this chapter proposes a basic multicriterial framework for projects evaluation and selection.

Multicriterial decision process consists of five steps. The first step is identification of problems and goals determination. The second step is proposal of alternatives. The third step is establishing of criteria for evaluation of alternatives. The fourth step is evaluation of alternatives. The fifth step is determination of combined impacts for each alternative and selection of the most satisfactory one. Figure 5.1 shows the sequence diagram of this process. Each step is explained in a dedicated section of this chapter.

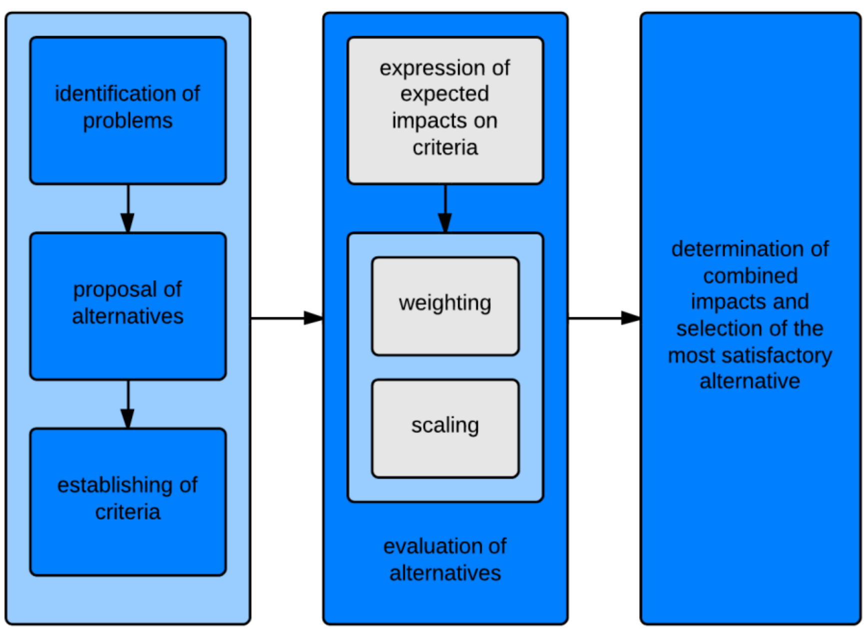

Figure 5.1: Sequence Diagram of a Multicriterial Decision Process

5.1 Identification of Problems and Goals Determination

Transportation decision makers identify and specify problems (described in Chapter 2 and Chapter 3) that need to be mitigated or ideally eliminated. These problems must be prioritized in accordance with their consequences. Then the goals can be formulated.

For example, the decision makers identify that the city struggle with congestion, unsustainable parking situation in the center and worsening air quality. Then they define the problem of congestion as the most important one and they set up the goal that the level of congestion in the investigated area needs to be reduced by at least 10%.

5.2 Proposal of Alternatives

Based on the knowledge of local conditions (described in Chapter 2) and desired goals, decision makers come up with a few possible alternatives (such as the transportation policies and solutions described in Chapter 4) and how to achieve them. Figure 5.2 visualizes how the local conditions and attributes influence the process of creating and tailoring of transportation policies and solutions.

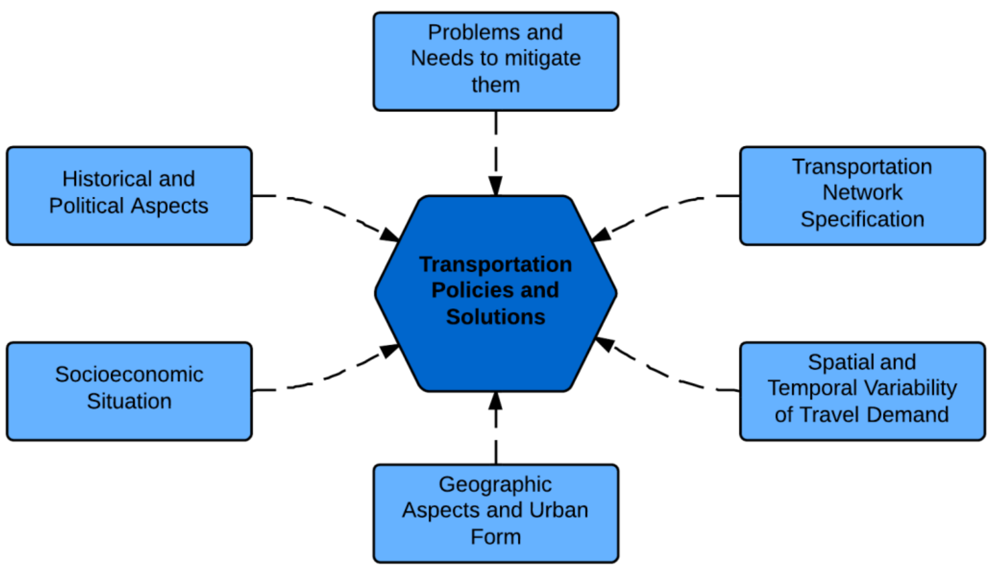

Figure 5.2: Influence of Local Attributes on Development of Transportation Policies and Solutions

From Chapter 4, the prosed projects (alternatives, denoted as A_i) of transportation policies and solutions are:

- *A_1 - Urban Road Pricing (electronic)*
- *A_2 - Parking Management*
- *A_3 - Zones with Limited Access*
- *A_4 - Change-Mode Encouragement*
- *A_5 - Infrastructure Adjustments and Expansion*
- *A_6 - Maintenance of Traffic Flow*

5.3 Establishing of Criteria for Evaluation of Alternatives

Assuming that the transportation policies and solutions are proposed and calibrated for the optimal performance in investigated locality, criteria for ranking of alternatives can be discussed by experts who know the local conditions. The criteria should be established in accordance with the desired goals and performance. They also should take into account other possibilities and consequences resulting from the proposed alternatives. Investment requirements and public opinion should be covered as well.

The criteria used for evaluation as presented in this thesis are established in cooperation with transportation engineering specialists and professors from The University of Texas at El Paso. The criteria can be adjusted with respect to individual and local needs.

The selected criteria (C_j) are:

- *C_1 - Reduction of congestion*

  (Decreasing of number of vehicles in area, faster traffic flow, shorter travel times, higher reliability of estimated travel times)

- *C_2 - Improvement of environment*

  (Decreasing of air pollution, noise and vibration)

- *C_3 - Improvement of safety*

  (Lower frequency of traffic accidents, fewer fatalities, elimination of potentially dangerous events and contributing factors)

- *C_4 - Possibility of revenue collection*

  (Fund raising for improvements and maintenance of infrastructure or alternative mode of transportation)

- *C_5 - Possibility of traffic information collection*

  (Collection of data for traffic analysis and traffic management)

- *C_6 - Public acceptance*

  (Public support for the project)

- *C_7 - Ease of solution*

  (Requirements of additional studies associated with the project, time and effort for successful implementation, requirements of sophisticated maintenance, and etc.)

- *C_8 - Capital costs*

  (Initial investment necessary for the project)

- *C_9 - Operating costs*

  (Costs associated with maintenance and providing of services)

5.4 Evaluation of Alternatives

Proper evaluation of alternatives is a key step in multicriterial decision making. The accuracy of this evaluation process is derived from the amount of information available for each proposed alternative.

5.4.1 Establishing Weights of Criteria

Weights are explicitly or implicitly assigned to each criterion to reflect its importance compared to other criteria. For example, to what extent is reduction of congestion more important than budget, public acceptance, and etc.? Sinha & Labi (2007) introduces a few commonly used methods for

assigning weights. These methods are equal weighting, direct weighting, Delphi technique, regression-based observer-derived weighting, Gamble method, pairwise comparison of the performance criteria, and value swinging method.

This study involves fifteen members of Institute of Transportation Engineers (ITE) Student Chapter at The University of Texas at El Paso to weight the selected criteria. They were asked to score each criterion with an integer value from interval of 1 to 5 according to their experience, judgment and preference. Higher score reflects the higher importance of the criterion. The respondents' weights for each criterion can be view in Table 5.1. The mean value calculated from the obtained scores is the adopted weight of criteria used in subsequent evaluation.

Table 5.1: Criteria Importance Definition

	Proposed weights of criteria by 15 respondents (scoring interval 1 - 5)															**Mean**	Standard Deviation
Reduction of congestion	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	**4.9**	*0.258*
Improvement of environment	3	3	3	4	4	4	3	4	3	4	3	2	3	3	4	**3.4**	*0.617*
Improvement of safety	4	3	4	5	3	4	4	3	4	4	5	4	4	4	4	**3.3**	*0.594*
Possibility of revenue collection	3	2	2	3	3	4	4	3	3	4	2	1	2	2	2	**2.7**	*0.900*
Possibility of traffic information collection	3	3	3	4	3	4	4	3	5	4	3	4	3	5	3	**3.6**	*0.737*
Public acceptance	5	4	4	4	5	4	5	4	3	4	3	3	3	1	4	**3.7**	*1.033*
Ease of solution (complexity)	1	2	2	3	4	4	4	3	1	3	1	3	3	4	2	**2.7**	*1.113*
Capital costs	5	4	5	5	5	5	4	5	3	4	4	5	4	5	4	**4.5**	*0.640*
Operating costs	3	3	4	4	2	4	3	3	1	3	2	5	4	3	2	**3.1**	*1.033*

Figure 5.3 expresses the weights in terms of their mean values, and plus and minus one standard deviation. These relatively narrow ranges demonstrate the respondents' consistent opinion in assigning the scores.

Very high opinion consistency is observed for the criterion of congestion reduction. Relatively high opinion consistency is observed with improvement of environment, improvement of safety, possibility of traffic information collection, and capital costs. Medium opinion consistency is observed with possibility of revenue collection. Various points of view at public acceptance, operation cost, and ease of solution can be seen. The reasons for various points of view at public acceptance and operating cost might be individual. However, the may be several reasons for the relatively non-consistent opinion on the ease of solution may. For example it might be, because respondents do not agree that complex solutions are always better.

Respondents have not been asked to prioritize any goal, so that the results shown in Table 5.1 and Figure 5.3 are general. The (mean) weights are not obligatory and can always be adjusted.

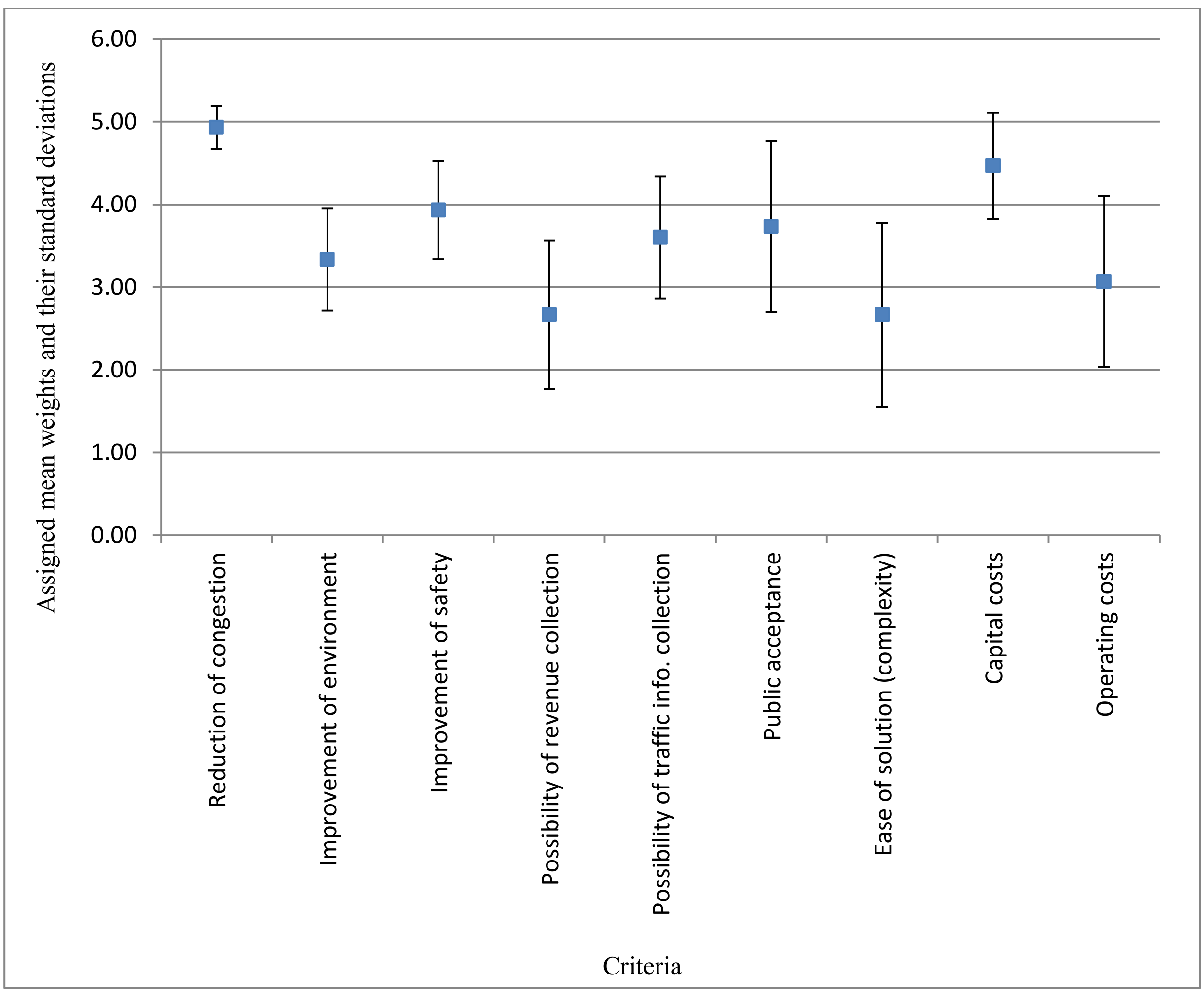

Figure 5.3: Respondents' Opinion Consistency about General Weights of Criteria

5.4.2 Expression of Expected Impact on Performance Criterion due to Alternative

Each alternative varies in its possible impacts. These impacts with respect to the evaluation criteria can be measured and expressed in numeric values if sufficient information and quantitative data are available. However, if the impacts are either too difficult to be expressed numerically or only descriptive data and decision maker's experience are available, indexing method may be applied.

This study uses the indexing method, because only the descriptive data and decision maker's experience and judgments are available in the initial project selection stage, or the measures of impacts for different alternatives are not compatible.

Similar to establishing the mean weights of criteria w_j, the potential impact of an alternative A_i on criteria j (X_{ij}) is scored from interval of 1 to 5. Index assignment in this study is performed by the single decision maker (the author). Positive values are assigned to benefit criteria and negative values are assigned if the criterion represents costs or potential complications (namely capital costs, operating costs, and ease of solution). Table 5.2 summarizes the available information about proposed alternatives. It should help the decision maker to come up with indices. Indices X_{ij} should not be expected to apply universally to all localities, because the specific condition in each locality (city) shall be taken into consideration. In addition, the indices may vary with possible scenarios. Table 5.3 shows how to arrange the criteria j, mean assigned weights of criteria w_j and enter data on indices X_{ij} for alternative A_i.

Table 5.2: General Evaluation of the Most Important Transportation Policies

	CORE BENEFITS	CORE DRAWBACKS
URBAN ROAD PRICING ***(Electronic)***	• Strong potential to optimize transportation behavior (generally) • Strong impact on most problematic externalities (the best method for congestion decreasing) • Internalization of externalities based on real external cost produced by users • Possible revenue generation • Possible added technological value (ITS) • Advanced, complex state-of-the-art solution	• Very high capital and operating costs • Problematic public acceptance • Complex large-scale project, not simple to implement • Possibility of disruptive road-side infrastructure • Possible shifting of traffic problems out of the charged locations
ZONES WITH LIMITED ACCESS	• Enabled filtration of predefined vehicles • Positive impact on air pollution • Low capital costs and minimal operating costs • Simple to implement	• Relatively low efficiency of environmental impact • Possible setback of traffic situation along the zone border
PARKING MANAGEMENT	• Some potential to optimize transportation behavior (change-mode perspective) • Less parking vehicles in the road network • Possible positive impact on road traffic flows • Possible added technological value (ITS) • Possible revenue generation	• Necessity to invest in new parking capacities outside the regulated area to satisfy uncovered demand • Possible high capital costs (P+R facilities, ITS)
CHANGE-MODE ENCOURAGEMNT ***(To Public Transportation)***	• Synergic effects (consolidation of travelers with similar origins/destination) • Better energy and economic efficiency of public transportation units • Positive impact on road traffic flows • Positive impact on environment • Lower personal car dependency • Higher safety • Incentives and education instead of restriction	• Incentives may not be sufficient • Very high capital and operating cost (infrastructure, units, change mode facilities) • Needs of subsidies to be competitive to individual vehicle door-2-door transportation
INFRASTRUCTURE ADJUSTMENT AND EXPANSION	• Higher current network efficiency • Higher safety • New capacity	• Limited spatial conditions • High capital costs • Down-Thomson paradox (road)
MAINTANANCE OF ROAD TRAFFIC FLOW	• Simple and inexpensive application of traffic engineering findings • Reduction of environmental impact (noise, pollution) • Possible added technological value (ITS based responsive traffic flow management)	• It may not be sufficient to mitigate problems sufficiently • Capital and operating costs of ITS

Table 5.3: Arrangement of Criteria, Weights, and Indices for Analysis

Criteria (*in total number of j*)	Unit	Mean Weight (w_j)	Expected Impact on Performance Criterion due to Alternative A_i					
			A_1	A_2	A_3	A_4	A_5	A_6
Reduction of congestion	index (+1 to +5)	4.9	X_{11}	…			…	X_{16}
Improvement of environment	index (+1 to +5)	3.4	⋮					⋮
Improvement of safety	index (+1 to +5)	3.3						
Possibility of revenue collection	index (+1 to +5)	2.7						
Possibility of traffic info. collection	index (+1 to +5)	3.6						
Public acceptance	index (+1 to +5)	3.7						
Ease of solution (complexity)	index (-1 to -5)	2.7						
Capital costs	index (-1 to -5)	4.5	⋮					⋮
Operating costs	index (-1 to -5)	3.1	X_{91}	…			…	X_{ij}

5.4.3 Scaling

The performance criteria can be measured in various dimensions with different units. Some criteria can be either expressed or converted in monetary value. However, some of them are not easily monetized. Therefore, each criterion must be converted from its original dimension to one that is uniform and commensurate across all the performance criteria. Detailed information can be found in Sinha & Labi (2007). Scaling does not have to be performed in this study, because only the dimensionless index scores have been used.

5.5 Determination of Combined Impacts for Each Alternatives and Selection of The Most Satisfactory Alternative

The last step is the combination of the impacts for each alternative. This amalgamation of all commensurate and weighted performance criteria is used to yield a combined level of desirability for each alternative, so that the best choice can be identified.

According to Sinha & Labi (2007), among the commonly used techniques for combining performance and using the combined measures to choose the best alternative are mathematical functions

of value, utility, or cost-effectiveness, ranking and rating, maxmin approach, impact index method, pairwise comparisons, mathematical programming, and outranking method. This study uses simplified impact index method. This method has been chosen because it is relatively easy and clear to use while providing outputs with respect to potential errors based on probabilistic approach.

5.5.1 Impact Index Method

This section introduces the application of the impact index method according to Sinha & Labi (2007) and Zieman et al. (1971).

Impact index method is a variation of the ranking and rating method. The procedure of this method considers possible errors or uncertainty associated with the establishing or measurement of the impact. If there are *N* alternatives and *J* performance criteria, the impact index for an alternative *i*, denoted as I_i, is calculated from following formula:

$$I_i = \sum_{j=1}^{J} (R_j S_j X_{ij} + e_j R_j S_j X_{ij}) \tag{5.1}$$

where:

- R_j is the relative weight of performance criterion *j*. It is calculated from all the mean assigned weights w_j (j=1,...,J) of *J* criteria, which can be positive or negative.

  $$R_j = \frac{w_j}{\sum_{j=1}^{J} |w_j|}$$

- X_{ij} is the extent to which an alternative *i* meets a performance criterion *j*.

- S_j is the scaling factor for measurement *X* of the performance criterion *j*.

  $$S_j = \frac{1}{\max(X_{1j}, X_{2j}, \dots, X_{Nj})}$$

- e_j is a random number drawn from a probability distribution. In the absence of a known distribution, an uniform rectangular distribution is considered; assuming ±50% error, the random value of e_j ranges as follows: ($-0.5 \leq e_j \leq +0.5$).

This study does not need to include the scaling factor to the formula, because only the dimensionless score index has been assigned. Therefore, the formula of the impact index can be simplified to

$$I_i = \sum_{j=1}^{J} R_j X_{ij} + e_j R_j X_{ij} \tag{5.2}$$

If e_j is set up to be zero, deterministic values would be obtained for each alternative action. This probabilistic approach uses a uniformly distributed random number generator (assuming a rectangular error distribution) in order to compute impact index values for each alternative (I_i) through Monte Carlo simulation. In a Monte Carlos simulation, *m* instances are generated; each corresponds to a random number. For each instance, I_i is calculated using Equation (5.2). After obtaining m=30 indices (or more) values, the average impact, standard deviation, and confidence interval of I_i can be plotted.

Thereafter, judgments about selecting a desirable alternative can be realized. The more favorable the average impact index value and the smaller the confidence interval, the more likely an alternative is chosen. The confidence interval for the impact of alternative *i* is as follows:

$$\overline{I_i} \pm \left(\frac{STDEV_i}{\sqrt{m}}\right) t_{1-\frac{\alpha}{2}, m-1} \tag{5.3}$$

Where $\overline{I_i}$ is the average of I_i among the *m* instances, $STDEV_i$ is the sample standard deviation of I_i, $1-\alpha$ is the level of confidence, *m* is the number of instances, random impact values or sample size, and *t* is the *t*-distribution statistic. In this thesis, the author recommends

$\alpha = 0.05$	(95% confidence interval)
m=30	(the generation of random number e_j runs 30 times)

$t_{0.975,\ 29}$ = -2.0452 (this value can be found in t-distribution tables)

All the calculations and plots can be performed in Microsoft Excel. The Excel program also enables the generation of random numbers e_j on prescribed conditions by using function 'RAND()*(0.5+0.5)-0.5'.

Chapter 6: Case Study

6.1 BACKGROUND

A practical application of the framework proposed in Chapter 5 is shown in this Chapter, using the example of *Prague, Czech Republic*. Several proposed alternatives have been specified according to Prague's local conditions and their estimated potential impacts have been indexed. The indices are not particular and can be modified and be more specific when more detailed data and information are available.

The example shown in this chapter assumes two possible scenarios for estimation of the most preferable alternative to mitigate identified problems (see Section 6.1.1). The first scenario works with the current state of the city's superior highway infrastructure; i.e., the inner and outer city rings have not been fully completed. The second scenario assumes the situation when the rings are fully or almost constructed (at least the inner ring is operational). Figure 6.1 shows the existing (black lines) and planned (other colors) states of the core transportation infrastructure of Prague.

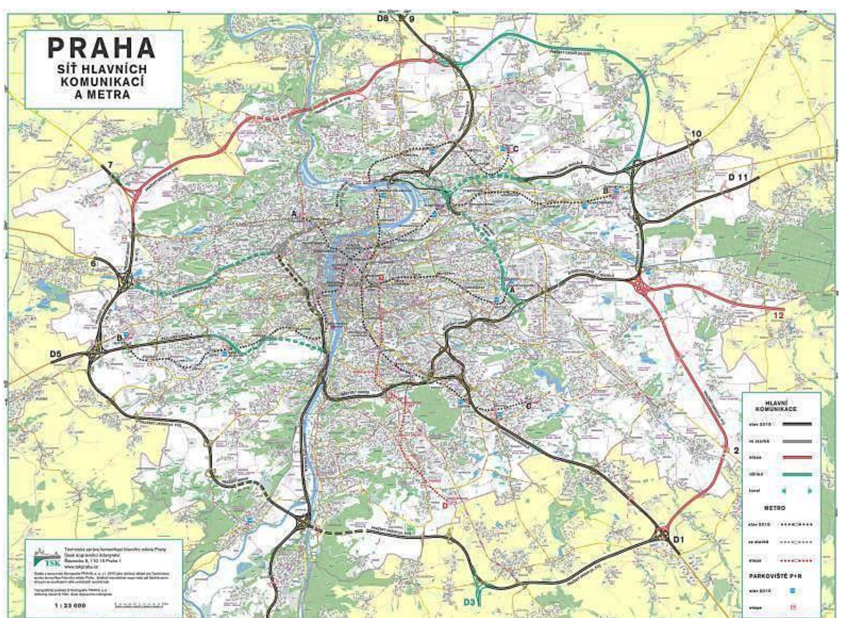

Figure 6.1: Superior Transportation Infrastructure in Prague

Source: (TSK hl. m. Prahy 2013)

6.1.1 Identification of Transportation Problems in Prague

The City of Prague is a metropolitan area with very centralized spatial structure. The central area has a very high concentration of job opportunities, whereas the surrounding areas are residential (CSU 2012). This arrangement attracts lot of radial traffic (from the suburbs to the center and vice versa). As can be seen in Figure 6.2, origin-destination surveys made on the main roads in the central area in 2004 and 2009 discovered almost identical findings that roughly 70% of trips have both the origins and destinations in Prague, roughly 25% of trips have either origins or destinations in Prague, and the last 5% of trips were pass through traffic (TSK hl. m. Prahy 2013).

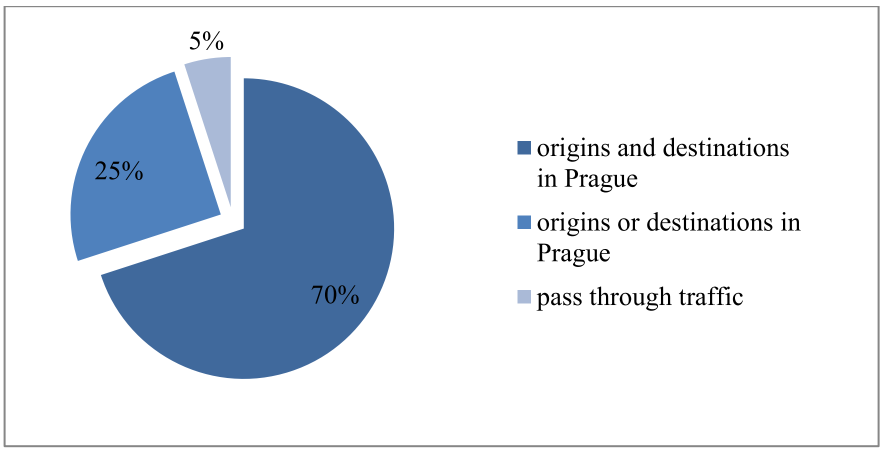

Figure 6.2: Composition of Trips on the Main Roads in the Center of Prague
Adapted from (TSK hl. m Prahy 2013)

The construction of the superior highway network has not been finished yet. Having only a few routing possibilities, the main roads in the central area are congested (mostly by private vehicles). Such a situation worsens air quality and increases noise levels in the center (ENVIS 2013). Therefore, significant reduction of personal vehicle trips into the center has been determined as the main goal of the proposed alternatives.

6.1.2 Proposed Alternatives and Their Specification with Respect to Local Conditions

The existence of an alternative transportation mode to personal vehicles may positively and reasonably influence the impacts of the proposed projects. The City of Prague offers relatively advanced

and reliable systems of public transportation with rail-based backbone as suitable alternatives to personal vehicles.

6.1.2.1 Electronic Urban Road Pricing

Several studies about implementation of an electronic urban road pricing have been made. They predicted significant reduction of personal vehicle trips within the charged zone (cordon scheme does not seems to be suitable for Prague, because of the geographical dispositions) (Magistrat hl. m. Prahy 2008). However, because the superior road network has not been completed, currently there are limited routes for users to avoid the central area. The potential of the urban road pricing system might be higher for funds collection than for congestion reduction. Another possible problem may be insufficient capacity of P+R facilities and a shift of traffic problems to outside of the charged zone. Last but not least, especially in the Czech Republic, this project would have a minimal public acceptance.

6.1.2.1 Parking Management

The parking management policy currently applied in Prague has been facing some criticisms. Its upgrade, adjustments and innovation might help to support change-mode and discourage personal vehicle travelers from some trips in the areas (TSK hl. m. Prahy 2013).

6.1.2.3 Zones with Limited Access

Prague currently restrains access for some vehicles in predefined zones. This policy works on the very basic principal of a low emission zone. Its upgrade and adjustments might help to mitigate some impacts on the environment and to exclude unwanted groups of vehicles from the controlled areas (LEZ in Europe 2013).

6.1.2.4 Change-Mode Encouragement

Change-mode encouragement might have a potential in Prague. It can be supported by investment in developing and improving the public transportation systems in order to make them more

competitive to personal vehicles. However, the experience from Stockholm shows that the effects of incentive-based policies and projects may not be that remarkable.

6.1.2.5 Infrastructure Adjustments and Expansion

Infrastructure adjustments in Prague could remove some problematic bottlenecks and contribute to safety. As described by the Down-Thomson paradox, road infrastructure expansion in cities is not recommended. However, the City of Prague has been missing the key parts of the strategic superior highway network, the completion of which could significantly improve traffic situation in the city center.

6.1.2.6 Maintenance of Traffic Flow

Introduction of a complex and systematic policy (e.g. responsive speed limits) to maintain smooth flow of traffic may help to optimize the performance of city's current highway network, improve safety and mitigate environmental impacts. Solutions based on ITS could also collect important information for transportation engineering.

6.2 EVALUATION OF ALTERNATIVES

6.2.1 Scenario 1

Scenario 1 evaluates alternatives with respect to the current state of transportation infrastructure in Prague. For this scenario, the author has proposed the scores of potential impact (X_{ij}) of an alternative A_i on criteria j. The scores (integer values of 1 to 5) can be seen in the highlighted area in Table 6.1.

Table 6.1: Evaluation Table for Scenario 1

				Expected Impact (X_{ij}) on Performance Criterion due to Alternative A_i						
C_j	Unit	w_j	R_j	A_1	A_2	A_3	A_4	A_5	A_6	
C_1	index (+1 to +5)	4.9	0.15361	4	3	2	3	4	2	Reduction of congestion
C_2	index (+1 to +5)	3.4	0.10658	4	2	2	3	4	2	Improvement of environment
C_3	index (+1 to +5)	3.3	0.10345	2	2	1	3	3	3	Improvement of safety
C_4	index (+1 to +5)	2.7	0.08464	5	3	2	1	1	1	Possibility of revenue collection
C_5	index (+1 to +5)	3.6	0.11285	3	2	1	1	1	5	Possibility of traffic info. collection
C_6	index (+1 to +5)	3.7	0.11599	1	3	3	5	5	3	Public acceptance
C_7	index (-1 to -5)	2.7	0.08464	-5	-2	-2	-3	-4	-3	Ease of solution (complexity)
C_8	index (-1 to -5)	4.5	0.14107	-5	-3	-2	-3	-5	-3	Capital costs
C_9	index (-1 to -5)	3.1	0.09718	-3	-2	-1	-4	-1	-2	Operating costs
				Electronic Urban Road Pricing	Parking management	Zones with limited Access	Change-mode encouragement	Infrastructure adjustment and expansion	Maintenance of traffic flow	

When the potential impacts (X_{ij}) have been established, all the variables for the impact index method are known and calculation can be performed. Table 6.2 shows the results of one out of the 30 iterations (instances) of Monte Carlo simulation. Random numbers generated for the iterations can be found in Appendix A. The tables for all the 30 iterations in Scenario 1 can be found in Appendix B.

Table 6.2: Example of the First Iteration of the Simulation in the Scenario 1

	iteration 1					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.324	0.243	0.162	0.243	0.324	0.162
	0.225	0.113	0.113	0.169	0.169	0.113
	0.109	0.109	0.055	0.164	0.164	0.164
	0.223	0.134	0.089	0.045	0.045	0.045
	0.179	0.119	0.060	0.060	0.060	0.298
	0.061	0.184	0.184	0.306	0.306	0.184
	-0.223	-0.089	-0.089	-0.134	-0.179	-0.134
	-0.372	-0.223	-0.149	-0.223	-0.372	-0.223
	-0.154	-0.103	-0.051	-0.205	-0.051	-0.103
I_i	0.372	0.487	0.372	0.424	0.465	0.505

Table 6.3: Results of Scenario 1

	A_1	A_2	A_3	A_4	A_5	A_6
$\overline{I_i}$	0.667	0.871	0.667	0.759	0.833	0.904
$\left(\frac{STDEV_i}{\sqrt{m}}\right)t_{1-\frac{\alpha}{2},m-1}$	±0.074	±0.096	±0.074	±0.084	±0.092	±0.100

Table 6.3 summarizes the results of the Monte Carlo simulation. It provides information about the average total impact index of each alternative, and the deviations from the mean to construct the 95% confidence interval. Figure 6.3 visualizes the data from Table 6.3 in the graph.

It can be seen in Table 6.3 that Alternative 6 has the highest average total impact index. However, as Alternative 2 and Alternative 5 have significant overlaps in their confidence intervals, any explicit decision cannot be made. Also, Alternative 4 (change-mode encouragement) has a significant overlap of the confidence interval with the three alternatives mentioned above. If it is possible, all these

four alternatives (Alternatives 6, 2, 5 and 4) can be supported. In the situation when only a single project can be supported, an additional criterion may be introduced and the evaluation process repeated.

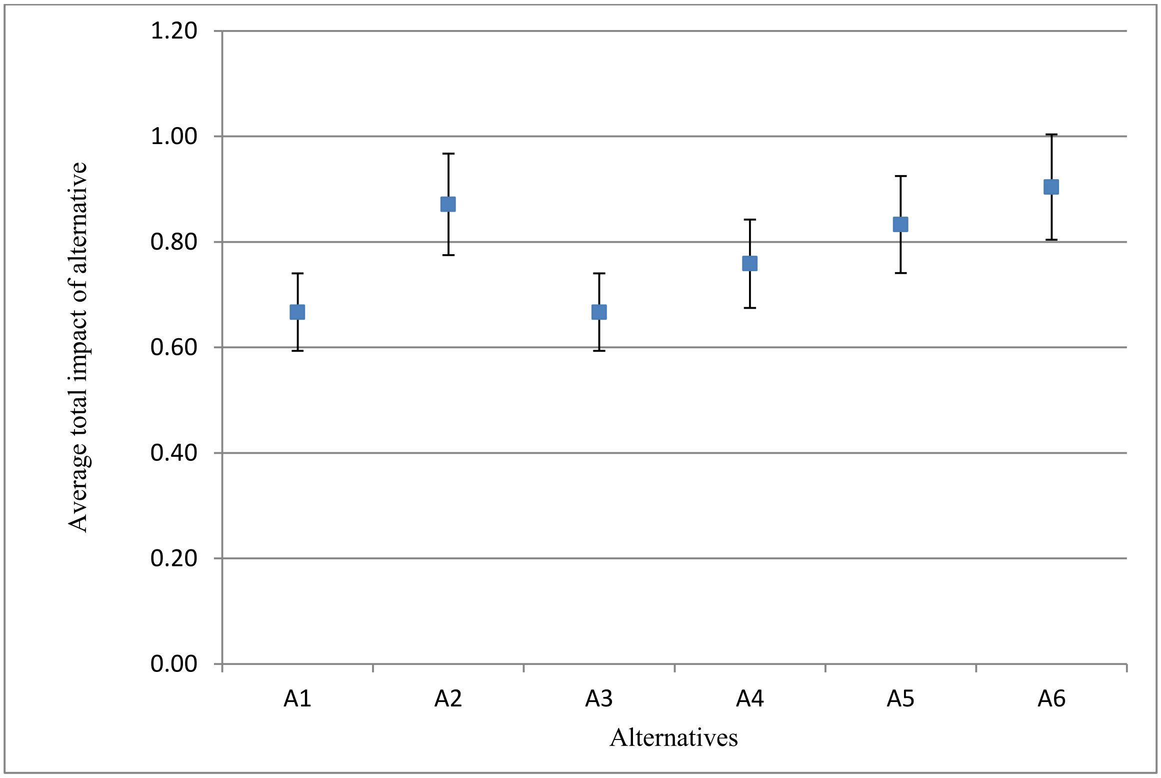

Figure 6.3: Average Total Impact Indices of Alternatives with 95% Confidence Intervals (Scenario 1)

6.2.2 Scenario 2

Scenario 2 evaluates alternatives on the assumption that the construction of the planned superior highway infrastructure has been finished or almost finished (at least the inner ring is fully completed). The scores proposed by the author in Table 6.1 have been adjusted in Table 6.4 with respect to the mentioned assumption. The cells highlighted in green in Table 6.4 represent increases in scores. The cells highlighted red represent decreases in score.

Table 6.4: Evaluation Table for Scenario 2

				Expected Impact (X_{ij}) on Performance Criterion due to Alternative A_i						
C_j	Unit	w_j	R_j	A_1	A_2	A_3	A_4	A_5	A_6	
C_1	index (+1 to +5)	4.9	0.15361	5	3	2	3	2	2	Reduction of congestion
C_2	index (+1 to +5)	3.4	0.10658	4	2	2	3	2	2	Improvement of environment
C_3	index (+1 to +5)	3.3	0.10345	3	2	1	3	3	3	Improvement of safety
C_4	index (+1 to +5)	2.7	0.08464	4	3	2	1	1	1	Possibility of revenue collection
C_5	index (+1 to +5)	3.6	0.11285	3	2	1	1	1	5	Possibility of traffic info. collection
C_6	index (+1 to +5)	3.7	0.11599	3	3	3	5	5	3	Public acceptance
C_7	index (-1 to -5)	2.7	0.08464	-5	-2	-2	-3	-4	-3	Ease of solution (complexity)
C_8	index (-1 to -5)	4.5	0.14107	-5	-3	-2	-3	-5	-3	Capital costs
C_9	index (-1 to -5)	3.1	0.09718	-3	-2	-1	-4	-1	-2	Operating costs
				Electronic Urban Road Pricing	Parking management	Zones with limited Access	Change-mode encouragement	Infrastructure adjustment and expansion	Maintenance of traffic flow	

The calculations for the Scenario 2 are performed in the same way as in Scenario 1. The random numbers and all the iterations can be found in Appendices A and C, respectively. The results of the Monte Carlo simulation are summarized in Table 6.5 and visualized in Figure 6.4.

Compared to the Scenario 1, the situation is more explicit in the Scenario 2. Alternative 1 can be claimed as the winner with the highest average total impact index and minimal overlap of the confidence interval with Alternative 6.

Table 6.5: Results of Scenario 2

	A_1	A_2	A_3	A_4	A_5	A_6
$\overline{I_i}$	1.049	0.871	0.667	0.759	0.442	0.904
$\left(\frac{STDEV_i}{\sqrt{m}}\right) t_{1-\frac{\alpha}{2},m-1}$	±0.116	±0.096	±0.074	±0.084	±0.049	±0.100

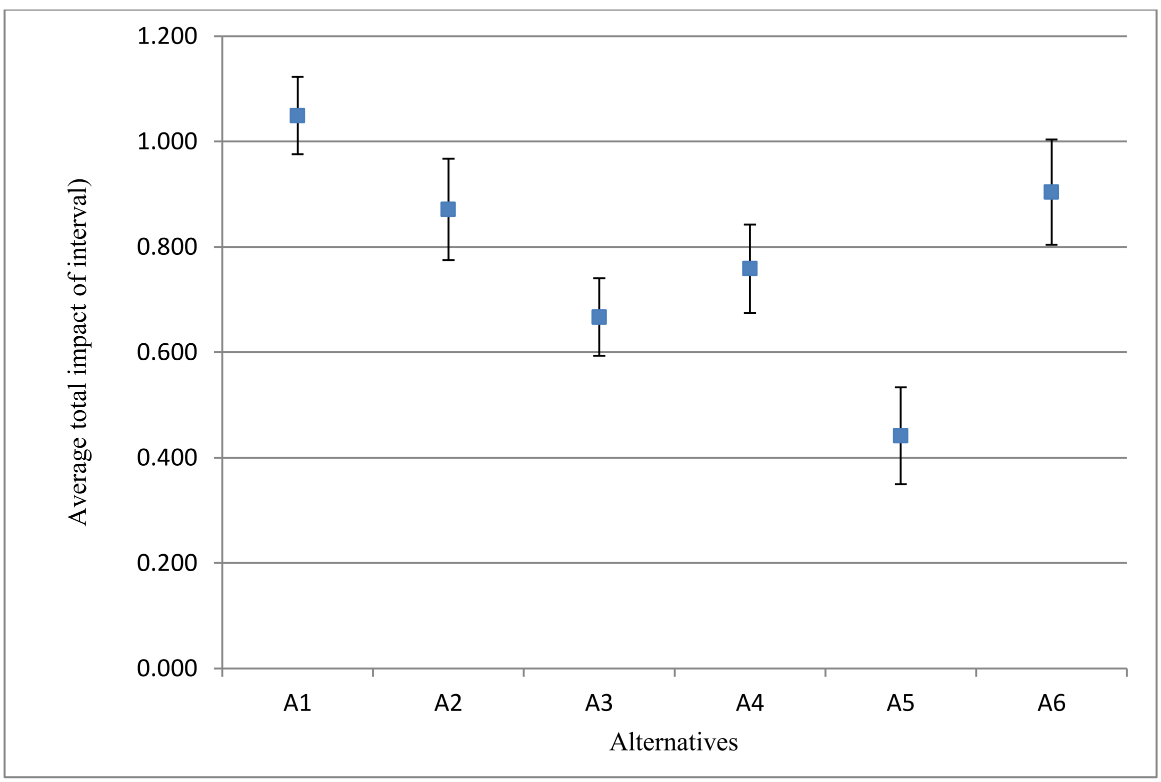

Figure 6.4: Average Total Impact Indices of Alternatives with 95% Confidence Intervals (Scenario 2)

6.3 DISCUSSIONS

The results in Scenario 1 do not indicate a clear preference to any alternative. The average total impacts of Alternative 2 (parking management), Alternative 5 (infrastructure adjustment and expansion), and Alternative 6 (maintenance of traffic flow) are nearly the same. Also, Alternative 4 (change-mode encouragement) has a significant overlap in the confidence interval with the three alternatives mentioned above. All of these projects could be supported. If it is not possible and only a single project may be selected, the evaluation process should be repeated for these four alternatives with an additional criterion.

The assumption of the completed superior highway network influences the evaluation outcome significantly. Alternative 1 (electronic urban road pricing) becomes remarkably dominant in Scenario 2, although it has one of the lowest average total impact in Scenario 1. Also, Alternative 5 (infrastructure adjustment and expansion) loses its appeal and therefore its average total impact is reduced. The evaluation results of both scenarios are compared in Figure 6.5.

Based on the results of Scenario 1 and Scenario 2, infrastructure expansion may be supported until the superior highway network is completed. Thereafter, an electronic urban road pricing may be implemented.

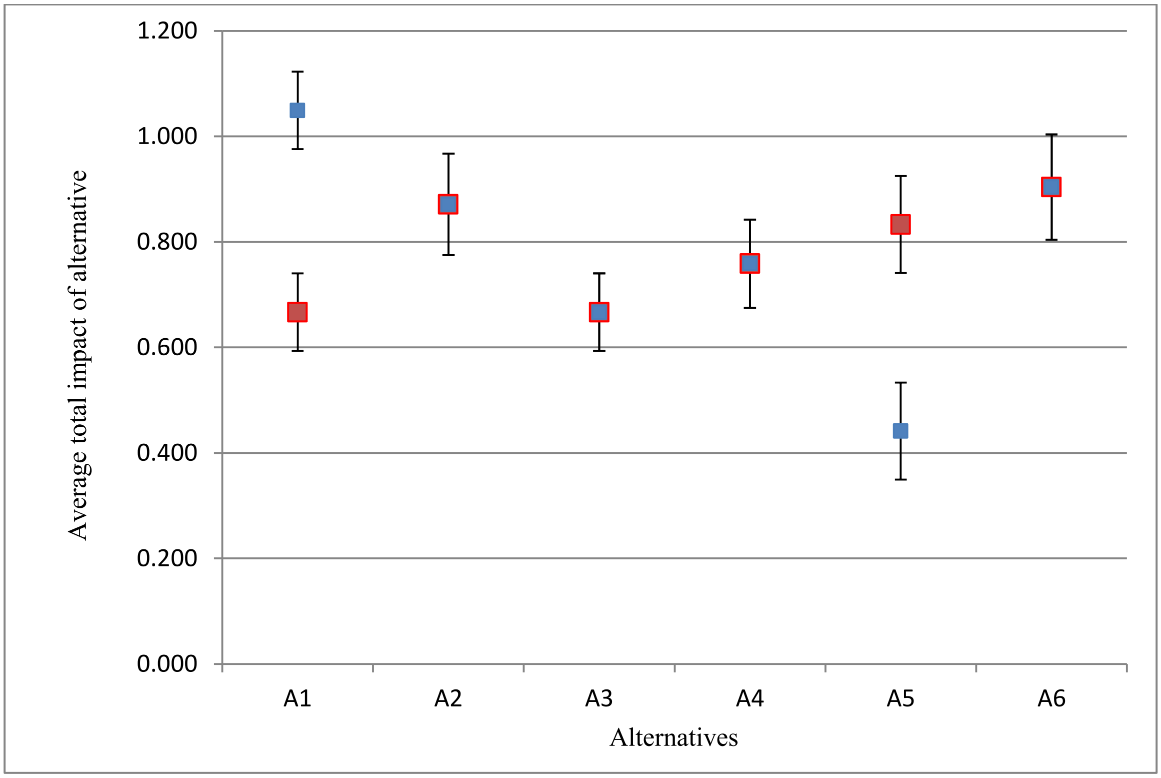

Figure 6.5: Comparison of Scenario 1 (red) and Scenario 2 (blue)

Chapter 7: Conclusions

7.1 Summary of Research

The research, which has been done in this thesis, introduces the problem of continually increasing demand for road transportation in large urban areas. The associated problems have been described and linked together in a wider context. Thereafter, the potential solutions mitigating the identified problems have been reviewed and evaluated via a proposed multicriterial decision making framework.

7.2 Contribution

This thesis can help to orient policy-makers in the complex problem of transportation in large urban areas as it a concise description of the problems, their impacts and potential solutions. The main contribution of this thesis is the universal application of the multicriterial evaluation method in preliminary transportation project selection, which can be used in any city around the world.

7.3 Future Research

The future research could be focused on collection of the data, which would help to set up weights and impact indices with higher accuracy.

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Appendix A: Random Numbers Used for Monte Carlo Simulation

iteration	value of generated e_i
1	-0.47199
2	-0.28016
3	-0.03350
4	0.19717
5	-0.33628
6	0.11618
7	0.40223
8	-0.27664
9	-0.24559
10	-0.06526
11	0.23934
12	0.18205
13	0.32991
14	-0.03925
15	0.35211

iteration	value of generated e_i
16	-0.25858
17	-0.47016
18	-0.33836
19	-0.01488
20	0.10422
21	-0.17792
22	0.23393
23	-0.26793
24	0.37149
25	0.32269
26	-0.48061
27	-0.00830
28	-0.28108
29	-0.35354
30	-0.08458

Appendix B: Calculations of Total Impact Indices of Alternatives for 30 Random Numbers in Scenario 1

	iteration 1					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.324	0.243	0.162	0.243	0.324	0.162
	0.225	0.113	0.113	0.169	0.169	0.113
	0.109	0.109	0.055	0.164	0.164	0.164
	0.223	0.134	0.089	0.045	0.045	0.045
	0.179	0.119	0.060	0.060	0.060	0.298
	0.061	0.184	0.184	0.306	0.306	0.184
	-0.223	-0.089	-0.089	-0.134	-0.179	-0.134
	-0.372	-0.223	-0.149	-0.223	-0.372	-0.223
	-0.154	-0.103	-0.051	-0.205	-0.051	-0.103
I_i	0.372	0.487	0.372	0.424	0.465	0.505

	iteration 2					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.442	0.332	0.221	0.332	0.442	0.221
	0.307	0.153	0.153	0.230	0.230	0.153
	0.149	0.149	0.074	0.223	0.223	0.223
	0.305	0.183	0.122	0.061	0.061	0.061
	0.244	0.162	0.081	0.081	0.081	0.406
	0.083	0.250	0.250	0.417	0.417	0.250
	-0.305	-0.122	-0.122	-0.183	-0.244	-0.183
	-0.508	-0.305	-0.203	-0.305	-0.508	-0.305
	-0.210	-0.140	-0.070	-0.280	-0.070	-0.140
I_i	0.508	0.663	0.508	0.578	0.634	0.688

	iteration 3					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.594	0.445	0.297	0.445	0.594	0.297
	0.412	0.206	0.206	0.309	0.309	0.206
	0.200	0.200	0.100	0.300	0.300	0.300
	0.409	0.245	0.164	0.082	0.082	0.082
	0.327	0.218	0.109	0.109	0.109	0.545
	0.112	0.336	0.336	0.561	0.561	0.336
	-0.409	-0.164	-0.164	-0.245	-0.327	-0.245
	-0.682	-0.409	-0.273	-0.409	-0.682	-0.409
	-0.282	-0.188	-0.094	-0.376	-0.094	-0.188
I_i	0.682	0.891	0.682	0.776	0.851	0.924

	iteration 4					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.736	0.552	0.368	0.552	0.736	0.368
	0.510	0.255	0.255	0.383	0.383	0.255
	0.248	0.248	0.124	0.372	0.372	0.372
	0.507	0.304	0.203	0.101	0.101	0.101
	0.405	0.270	0.135	0.135	0.135	0.676
	0.139	0.417	0.417	0.694	0.694	0.417
	-0.507	-0.203	-0.203	-0.304	-0.405	-0.304
	-0.844	-0.507	-0.338	-0.507	-0.844	-0.507
	-0.349	-0.233	-0.116	-0.465	-0.116	-0.233
I_i	0.844	1.103	0.844	0.961	1.055	1.145

	iteration 5					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.408	0.306	0.204	0.306	0.408	0.204
	0.283	0.141	0.141	0.212	0.212	0.141
	0.137	0.137	0.069	0.206	0.206	0.206
	0.281	0.169	0.112	0.056	0.056	0.056
	0.225	0.150	0.075	0.075	0.075	0.375
	0.077	0.231	0.231	0.385	0.385	0.231
	-0.281	-0.112	-0.112	-0.169	-0.225	-0.169
	-0.468	-0.281	-0.187	-0.281	-0.468	-0.281
	-0.193	-0.129	-0.064	-0.258	-0.064	-0.129
I_i	0.468	0.612	0.468	0.533	0.585	0.635

	iteration 6					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.686	0.514	0.343	0.514	0.686	0.343
	0.476	0.238	0.238	0.357	0.357	0.238
	0.231	0.231	0.115	0.346	0.346	0.346
	0.472	0.283	0.189	0.094	0.094	0.094
	0.378	0.252	0.126	0.126	0.126	0.630
	0.129	0.388	0.388	0.647	0.647	0.388
	-0.472	-0.189	-0.189	-0.283	-0.378	-0.283
	-0.787	-0.472	-0.315	-0.472	-0.787	-0.472
	-0.325	-0.217	-0.108	-0.434	-0.108	-0.217
I_i	0.787	1.029	0.787	0.896	0.983	1.067

	iteration 7					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.862	0.646	0.431	0.646	0.862	0.431
	0.598	0.299	0.299	0.448	0.448	0.299
	0.290	0.290	0.145	0.435	0.435	0.435
	0.593	0.356	0.237	0.119	0.119	0.119
	0.475	0.316	0.158	0.158	0.158	0.791
	0.163	0.488	0.488	0.813	0.813	0.488
	-0.593	-0.237	-0.237	-0.356	-0.475	-0.356
	-0.989	-0.593	-0.396	-0.593	-0.989	-0.593
	-0.409	-0.273	-0.136	-0.545	-0.136	-0.273
I_i	0.989	1.292	0.989	1.125	1.235	1.341

	iteration 8					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.444	0.333	0.222	0.333	0.444	0.222
	0.308	0.154	0.154	0.231	0.231	0.154
	0.150	0.150	0.075	0.224	0.224	0.224
	0.306	0.184	0.122	0.061	0.061	0.061
	0.245	0.163	0.082	0.082	0.082	0.408
	0.084	0.252	0.252	0.420	0.420	0.252
	-0.306	-0.122	-0.122	-0.184	-0.245	-0.184
	-0.510	-0.306	-0.204	-0.306	-0.510	-0.306
	-0.211	-0.141	-0.070	-0.281	-0.070	-0.141
I_i	0.510	0.667	0.510	0.581	0.637	0.692

	iteration 9					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.464	0.348	0.232	0.348	0.464	0.232
	0.322	0.161	0.161	0.241	0.241	0.161
	0.156	0.156	0.078	0.234	0.234	0.234
	0.319	0.192	0.128	0.064	0.064	0.064
	0.255	0.170	0.085	0.085	0.085	0.426
	0.088	0.263	0.263	0.438	0.438	0.263
	-0.319	-0.128	-0.128	-0.192	-0.255	-0.192
	-0.532	-0.319	-0.213	-0.319	-0.532	-0.319
	-0.220	-0.147	-0.073	-0.293	-0.073	-0.147
I_i	0.532	0.695	0.532	0.605	0.665	0.721

	iteration 10					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.574	0.431	0.287	0.431	0.574	0.287
	0.399	0.199	0.199	0.299	0.299	0.199
	0.193	0.193	0.097	0.290	0.290	0.290
	0.396	0.237	0.158	0.079	0.079	0.079
	0.316	0.211	0.105	0.105	0.105	0.527
	0.108	0.325	0.325	0.542	0.542	0.325
	-0.396	-0.158	-0.158	-0.237	-0.316	-0.237
	-0.659	-0.396	-0.264	-0.396	-0.659	-0.396
	-0.273	-0.182	-0.091	-0.363	-0.091	-0.182
I_i	0.659	0.861	0.659	0.750	0.823	0.894

	iteration 11					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.761	0.571	0.381	0.571	0.761	0.381
	0.528	0.264	0.264	0.396	0.396	0.264
	0.256	0.256	0.128	0.385	0.385	0.385
	0.524	0.315	0.210	0.105	0.105	0.105
	0.420	0.280	0.140	0.140	0.140	0.699
	0.144	0.431	0.431	0.719	0.719	0.431
	-0.524	-0.210	-0.210	-0.315	-0.420	-0.315
	-0.874	-0.524	-0.350	-0.524	-0.874	-0.524
	-0.361	-0.241	-0.120	-0.482	-0.120	-0.241
I_i	0.874	1.142	0.874	0.995	1.092	1.185

	iteration 12					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.726	0.545	0.363	0.545	0.726	0.363
	0.504	0.252	0.252	0.378	0.378	0.252
	0.245	0.245	0.122	0.367	0.367	0.367
	0.500	0.300	0.200	0.100	0.100	0.100
	0.400	0.267	0.133	0.133	0.133	0.667
	0.137	0.411	0.411	0.686	0.686	0.411
	-0.500	-0.200	-0.200	-0.300	-0.400	-0.300
	-0.834	-0.500	-0.333	-0.500	-0.834	-0.500
	-0.345	-0.230	-0.115	-0.459	-0.115	-0.230
I_i	0.834	1.089	0.834	0.949	1.041	1.130

	iteration 13					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.817	0.613	0.409	0.613	0.817	0.409
	0.567	0.283	0.283	0.425	0.425	0.283
	0.275	0.275	0.138	0.413	0.413	0.413
	0.563	0.338	0.225	0.113	0.113	0.113
	0.450	0.300	0.150	0.150	0.150	0.750
	0.154	0.463	0.463	0.771	0.771	0.463
	-0.563	-0.225	-0.225	-0.338	-0.450	-0.338
	-0.938	-0.563	-0.375	-0.563	-0.938	-0.563
	-0.388	-0.258	-0.129	-0.517	-0.129	-0.258
I_i	0.938	1.226	0.938	1.067	1.171	1.272

	iteration 14					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.590	0.443	0.295	0.443	0.590	0.295
	0.410	0.205	0.205	0.307	0.307	0.205
	0.199	0.199	0.099	0.298	0.298	0.298
	0.407	0.244	0.163	0.081	0.081	0.081
	0.325	0.217	0.108	0.108	0.108	0.542
	0.111	0.334	0.334	0.557	0.557	0.334
	-0.407	-0.163	-0.163	-0.244	-0.325	-0.244
	-0.678	-0.407	-0.271	-0.407	-0.678	-0.407
	-0.280	-0.187	-0.093	-0.373	-0.093	-0.187
I_i	0.678	0.885	0.678	0.771	0.846	0.919

	iteration 15					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.831	0.623	0.415	0.623	0.831	0.415
	0.576	0.288	0.288	0.432	0.432	0.288
	0.280	0.280	0.140	0.420	0.420	0.420
	0.572	0.343	0.229	0.114	0.114	0.114
	0.458	0.305	0.153	0.153	0.153	0.763
	0.157	0.470	0.470	0.784	0.784	0.470
	-0.572	-0.229	-0.229	-0.343	-0.458	-0.343
	-0.954	-0.572	-0.381	-0.572	-0.954	-0.572
	-0.394	-0.263	-0.131	-0.526	-0.131	-0.263
I_i	0.954	1.246	0.954	1.085	1.191	1.293

	iteration 16					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.456	0.342	0.228	0.342	0.456	0.228
	0.316	0.158	0.158	0.237	0.237	0.158
	0.153	0.153	0.077	0.230	0.230	0.230
	0.314	0.188	0.126	0.063	0.063	0.063
	0.251	0.167	0.084	0.084	0.084	0.418
	0.086	0.258	0.258	0.430	0.430	0.258
	-0.314	-0.126	-0.126	-0.188	-0.251	-0.188
	-0.523	-0.314	-0.209	-0.314	-0.523	-0.314
	-0.216	-0.144	-0.072	-0.288	-0.072	-0.144
I_i	0.523	0.683	0.523	0.595	0.653	0.709

	iteration 17					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.326	0.244	0.163	0.244	0.326	0.163
	0.226	0.113	0.113	0.169	0.169	0.113
	0.110	0.110	0.055	0.164	0.164	0.164
	0.224	0.135	0.090	0.045	0.045	0.045
	0.179	0.120	0.060	0.060	0.060	0.299
	0.061	0.184	0.184	0.307	0.307	0.184
	-0.224	-0.090	-0.090	-0.135	-0.179	-0.135
	-0.374	-0.224	-0.149	-0.224	-0.374	-0.224
	-0.154	-0.103	-0.051	-0.206	-0.051	-0.103
I_i	0.374	0.488	0.374	0.425	0.467	0.507

	iteration 18					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.407	0.305	0.203	0.305	0.407	0.203
	0.282	0.141	0.141	0.212	0.212	0.141
	0.137	0.137	0.068	0.205	0.205	0.205
	0.280	0.168	0.112	0.056	0.056	0.056
	0.224	0.149	0.075	0.075	0.075	0.373
	0.077	0.230	0.230	0.384	0.384	0.230
	-0.280	-0.112	-0.112	-0.168	-0.224	-0.168
	-0.467	-0.280	-0.187	-0.280	-0.467	-0.280
	-0.193	-0.129	-0.064	-0.257	-0.064	-0.129
I_i	0.467	0.610	0.467	0.531	0.583	0.633

iteration 19						
	A_1	A_2	A_3	A_4	A_5	A_6
	0.605	0.454	0.303	0.454	0.605	0.303
	0.420	0.210	0.210	0.315	0.315	0.210
	0.204	0.204	0.102	0.306	0.306	0.306
	0.417	0.250	0.167	0.083	0.083	0.083
	0.334	0.222	0.111	0.111	0.111	0.556
	0.114	0.343	0.343	0.571	0.571	0.343
	-0.417	-0.167	-0.167	-0.250	-0.334	-0.250
	-0.695	-0.417	-0.278	-0.417	-0.695	-0.417
	-0.287	-0.191	-0.096	-0.383	-0.096	-0.191
I_i	0.695	0.908	0.695	0.791	0.868	0.942

iteration 20						
	A_1	A_2	A_3	A_4	A_5	A_6
	0.678	0.509	0.339	0.509	0.678	0.339
	0.471	0.235	0.235	0.353	0.353	0.235
	0.228	0.228	0.114	0.343	0.343	0.343
	0.467	0.280	0.187	0.093	0.093	0.093
	0.374	0.249	0.125	0.125	0.125	0.623
	0.128	0.384	0.384	0.640	0.640	0.384
	-0.467	-0.187	-0.187	-0.280	-0.374	-0.280
	-0.779	-0.467	-0.312	-0.467	-0.779	-0.467
	-0.322	-0.215	-0.107	-0.429	-0.107	-0.215
I_i	0.779	1.018	0.779	0.886	0.973	1.056

iteration 21						
	A_1	A_2	A_3	A_4	A_5	A_6
	0.505	0.379	0.253	0.379	0.505	0.253
	0.350	0.175	0.175	0.263	0.263	0.175
	0.170	0.170	0.085	0.255	0.255	0.255
	0.348	0.209	0.139	0.070	0.070	0.070
	0.278	0.186	0.093	0.093	0.093	0.464
	0.095	0.286	0.286	0.477	0.477	0.286
	-0.348	-0.139	-0.139	-0.209	-0.278	-0.209
	-0.580	-0.348	-0.232	-0.348	-0.580	-0.348
	-0.240	-0.160	-0.080	-0.320	-0.080	-0.160
I_i	0.580	0.758	0.580	0.660	0.724	0.786

iteration 22						
	A_1	A_2	A_3	A_4	A_5	A_6
	0.758	0.569	0.379	0.569	0.758	0.379
	0.526	0.263	0.263	0.395	0.395	0.263
	0.255	0.255	0.128	0.383	0.383	0.383
	0.522	0.313	0.209	0.104	0.104	0.104
	0.418	0.279	0.139	0.139	0.139	0.696
	0.143	0.429	0.429	0.716	0.716	0.429
	-0.522	-0.209	-0.209	-0.313	-0.418	-0.313
	-0.870	-0.522	-0.348	-0.522	-0.870	-0.522
	-0.360	-0.240	-0.120	-0.480	-0.120	-0.240
I_i	0.870	1.137	0.870	0.990	1.087	1.180

iteration 23						
	A_1	A_2	A_3	A_4	A_5	A_6
	0.450	0.337	0.225	0.337	0.450	0.225
	0.312	0.156	0.156	0.234	0.234	0.156
	0.151	0.151	0.076	0.227	0.227	0.227
	0.310	0.186	0.124	0.062	0.062	0.062
	0.248	0.165	0.083	0.083	0.083	0.413
	0.085	0.255	0.255	0.425	0.425	0.255
	-0.310	-0.124	-0.124	-0.186	-0.248	-0.186
	-0.516	-0.310	-0.207	-0.310	-0.516	-0.310
	-0.213	-0.142	-0.071	-0.285	-0.071	-0.142
I_i	0.516	0.675	0.516	0.587	0.645	0.700

iteration 24						
	A_1	A_2	A_3	A_4	A_5	A_6
	0.843	0.632	0.421	0.632	0.843	0.421
	0.585	0.292	0.292	0.439	0.439	0.292
	0.284	0.284	0.142	0.426	0.426	0.426
	0.580	0.348	0.232	0.116	0.116	0.116
	0.464	0.310	0.155	0.155	0.155	0.774
	0.159	0.477	0.477	0.795	0.795	0.477
	-0.580	-0.232	-0.232	-0.348	-0.464	-0.348
	-0.967	-0.580	-0.387	-0.580	-0.967	-0.580
	-0.400	-0.267	-0.133	-0.533	-0.133	-0.267
I_i	0.967	1.264	0.967	1.101	1.208	1.311

	iteration 25					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.813	0.610	0.406	0.610	0.813	0.406
	0.564	0.282	0.282	0.423	0.423	0.282
	0.274	0.274	0.137	0.410	0.410	0.410
	0.560	0.336	0.224	0.112	0.112	0.112
	0.448	0.299	0.149	0.149	0.149	0.746
	0.153	0.460	0.460	0.767	0.767	0.460
	-0.560	-0.224	-0.224	-0.336	-0.448	-0.336
	-0.933	-0.560	-0.373	-0.560	-0.933	-0.560
	-0.386	-0.257	-0.129	-0.514	-0.129	-0.257
I_i	0.933	1.219	0.933	1.061	1.165	1.265

	iteration 26					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.319	0.239	0.160	0.239	0.319	0.160
	0.221	0.111	0.111	0.166	0.166	0.111
	0.107	0.107	0.054	0.161	0.161	0.161
	0.220	0.132	0.088	0.044	0.044	0.044
	0.176	0.117	0.059	0.059	0.059	0.293
	0.060	0.181	0.181	0.301	0.301	0.181
	-0.220	-0.088	-0.088	-0.132	-0.176	-0.132
	-0.366	-0.220	-0.147	-0.220	-0.366	-0.220
	-0.151	-0.101	-0.050	-0.202	-0.050	-0.101
I_i	0.366	0.479	0.366	0.417	0.458	0.497

	iteration 27					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.609	0.457	0.305	0.457	0.609	0.305
	0.423	0.211	0.211	0.317	0.317	0.211
	0.205	0.205	0.103	0.308	0.308	0.308
	0.420	0.252	0.168	0.084	0.084	0.084
	0.336	0.224	0.112	0.112	0.112	0.560
	0.115	0.345	0.345	0.575	0.575	0.345
	-0.420	-0.168	-0.168	-0.252	-0.336	-0.252
	-0.699	-0.420	-0.280	-0.420	-0.699	-0.420
	-0.289	-0.193	-0.096	-0.385	-0.096	-0.193
I_i	0.699	0.914	0.699	0.796	0.874	0.948

	iteration 28					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.442	0.331	0.221	0.331	0.442	0.221
	0.306	0.153	0.153	0.230	0.230	0.153
	0.149	0.149	0.074	0.223	0.223	0.223
	0.304	0.183	0.122	0.061	0.061	0.061
	0.243	0.162	0.081	0.081	0.081	0.406
	0.083	0.250	0.250	0.417	0.417	0.250
	-0.304	-0.122	-0.122	-0.183	-0.243	-0.183
	-0.507	-0.304	-0.203	-0.304	-0.507	-0.304
	-0.210	-0.140	-0.070	-0.279	-0.070	-0.140
I_i	0.507	0.663	0.507	0.577	0.633	0.687

	iteration 29					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.397	0.298	0.199	0.298	0.397	0.199
	0.276	0.138	0.138	0.207	0.207	0.138
	0.134	0.134	0.067	0.201	0.201	0.201
	0.274	0.164	0.109	0.055	0.055	0.055
	0.219	0.146	0.073	0.073	0.073	0.365
	0.075	0.225	0.225	0.375	0.375	0.225
	-0.274	-0.109	-0.109	-0.164	-0.219	-0.164
	-0.456	-0.274	-0.182	-0.274	-0.456	-0.274
	-0.188	-0.126	-0.063	-0.251	-0.063	-0.126
I_i	0.456	0.596	0.456	0.519	0.569	0.618

	iteration 30					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.562	0.422	0.281	0.422	0.562	0.281
	0.390	0.195	0.195	0.293	0.293	0.195
	0.189	0.189	0.095	0.284	0.284	0.284
	0.387	0.232	0.155	0.077	0.077	0.077
	0.310	0.207	0.103	0.103	0.103	0.517
	0.106	0.319	0.319	0.531	0.531	0.319
	-0.387	-0.155	-0.155	-0.232	-0.310	-0.232
	-0.646	-0.387	-0.258	-0.387	-0.646	-0.387
	-0.267	-0.178	-0.089	-0.356	-0.089	-0.178
I_i	0.646	0.844	0.646	0.735	0.806	0.875

Appendix C: Calculations of Total Impact Indices of Alternatives for 30 Random Numbers in Scenario 2

	iteration 1					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.406	0.243	0.162	0.243	0.162	0.162
	0.225	0.113	0.113	0.169	0.113	0.113
	0.164	0.109	0.055	0.164	0.164	0.164
	0.179	0.134	0.089	0.045	0.045	0.045
	0.179	0.119	0.060	0.060	0.060	0.298
	0.184	0.184	0.184	0.306	0.306	0.184
	-0.223	-0.089	-0.089	-0.134	-0.179	-0.134
	-0.372	-0.223	-0.149	-0.223	-0.372	-0.223
	-0.154	-0.103	-0.051	-0.205	-0.051	-0.103
I_i	0.586	0.487	0.372	0.424	0.247	0.505

	iteration 2					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.553	0.332	0.221	0.332	0.221	0.221
	0.307	0.153	0.153	0.230	0.153	0.153
	0.223	0.149	0.074	0.223	0.223	0.223
	0.244	0.183	0.122	0.061	0.061	0.061
	0.244	0.162	0.081	0.081	0.081	0.406
	0.250	0.250	0.250	0.417	0.417	0.250
	-0.305	-0.122	-0.122	-0.183	-0.244	-0.183
	-0.508	-0.305	-0.203	-0.305	-0.508	-0.305
	-0.210	-0.140	-0.070	-0.280	-0.070	-0.140
I_i	0.799	0.663	0.508	0.578	0.336	0.688

	iteration 3					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.742	0.445	0.297	0.445	0.297	0.297
	0.412	0.206	0.206	0.309	0.206	0.206
	0.300	0.200	0.100	0.300	0.300	0.300
	0.327	0.245	0.164	0.082	0.082	0.082
	0.327	0.218	0.109	0.109	0.109	0.545
	0.336	0.336	0.336	0.561	0.561	0.336
	-0.409	-0.164	-0.164	-0.245	-0.327	-0.245
	-0.682	-0.409	-0.273	-0.409	-0.682	-0.409
	-0.282	-0.188	-0.094	-0.376	-0.094	-0.188
I_i	1.073	0.891	0.682	0.776	0.451	0.924

	iteration 4					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.919	0.552	0.368	0.552	0.368	0.368
	0.510	0.255	0.255	0.383	0.255	0.255
	0.372	0.248	0.124	0.372	0.372	0.372
	0.405	0.304	0.203	0.101	0.101	0.101
	0.405	0.270	0.135	0.135	0.135	0.676
	0.417	0.417	0.417	0.694	0.694	0.417
	-0.507	-0.203	-0.203	-0.304	-0.405	-0.304
	-0.844	-0.507	-0.338	-0.507	-0.844	-0.507
	-0.349	-0.233	-0.116	-0.465	-0.116	-0.233
I_i	1.329	1.103	0.844	0.961	0.559	1.145

	iteration 5					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.510	0.306	0.204	0.306	0.204	0.204
	0.283	0.141	0.141	0.212	0.141	0.141
	0.206	0.137	0.069	0.206	0.206	0.206
	0.225	0.169	0.112	0.056	0.056	0.056
	0.225	0.150	0.075	0.075	0.075	0.375
	0.231	0.231	0.231	0.385	0.385	0.231
	-0.281	-0.112	-0.112	-0.169	-0.225	-0.169
	-0.468	-0.281	-0.187	-0.281	-0.468	-0.281
	-0.193	-0.129	-0.064	-0.258	-0.064	-0.129
I_i	0.737	0.612	0.468	0.533	0.310	0.635

	iteration 6					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.857	0.514	0.343	0.514	0.343	0.343
	0.476	0.238	0.238	0.357	0.238	0.238
	0.346	0.231	0.115	0.346	0.346	0.346
	0.378	0.283	0.189	0.094	0.094	0.094
	0.378	0.252	0.126	0.126	0.126	0.630
	0.388	0.388	0.388	0.647	0.647	0.388
	-0.472	-0.189	-0.189	-0.283	-0.378	-0.283
	-0.787	-0.472	-0.315	-0.472	-0.787	-0.472
	-0.325	-0.217	-0.108	-0.434	-0.108	-0.217
I_i	1.239	1.029	0.787	0.896	0.521	1.067

iteration 7

iteration 8

iteration 9

	A1	A2	A3	A4	A5	A6
	1.077	0.646	0.431	0.646	0.431	0.431
	0.598	0.299	0.299	0.448	0.299	0.299
	0.435	0.290	0.145	0.435	0.435	0.435
	0.475	0.356	0.237	0.119	0.119	0.119
	0.475	0.316	0.158	0.158	0.158	0.791
	0.488	0.488	0.488	0.813	0.813	0.488
	-0.593	-0.237	-0.237	-0.356	-0.475	-0.356
	-0.989	-0.593	-0.396	-0.593	-0.989	-0.593
	-0.409	-0.273	-0.136	-0.545	-0.136	-0.273
I_i	1.556	1.292	0.989	1.125	0.655	1.341

	A1	A2	A3	A4	A5	A6
	0.556	0.333	0.222	0.333	0.222	0.222
	0.308	0.154	0.154	0.231	0.154	0.154
	0.224	0.150	0.075	0.224	0.224	0.224
	0.245	0.184	0.122	0.061	0.061	0.061
	0.245	0.163	0.082	0.082	0.082	0.408
	0.252	0.252	0.252	0.420	0.420	0.252
	-0.306	-0.122	-0.122	-0.184	-0.245	-0.184
	-0.510	-0.306	-0.204	-0.306	-0.510	-0.306
	-0.211	-0.141	-0.070	-0.281	-0.070	-0.141
I_i	0.803	0.667	0.510	0.581	0.338	0.692

	A1	A2	A3	A4	A5	A6
	0.579	0.348	0.232	0.348	0.232	0.232
	0.322	0.161	0.161	0.241	0.161	0.161
	0.234	0.156	0.078	0.234	0.234	0.234
	0.255	0.192	0.128	0.064	0.064	0.064
	0.255	0.170	0.085	0.085	0.085	0.426
	0.263	0.263	0.263	0.438	0.438	0.263
	-0.319	-0.128	-0.128	-0.192	-0.255	-0.192
	-0.532	-0.319	-0.213	-0.319	-0.532	-0.319
	-0.220	-0.147	-0.073	-0.293	-0.073	-0.147
I_i	0.837	0.695	0.532	0.605	0.352	0.721

	iteration 10					
	A1	A2	A3	A4	A5	A6
	0.718	0.431	0.287	0.431	0.287	0.287
	0.399	0.199	0.199	0.299	0.199	0.199
	0.290	0.193	0.097	0.290	0.290	0.290
	0.316	0.237	0.158	0.079	0.079	0.079
	0.316	0.211	0.105	0.105	0.105	0.527
	0.325	0.325	0.325	0.542	0.542	0.325
	-0.396	-0.158	-0.158	-0.237	-0.316	-0.237
	-0.659	-0.396	-0.264	-0.396	-0.659	-0.396
	-0.273	-0.182	-0.091	-0.363	-0.091	-0.182
I_i	1.037	0.861	0.659	0.750	0.437	0.894

	iteration 11					
	A1	A2	A3	A4	A5	A6
	0.952	0.571	0.381	0.571	0.381	0.381
	0.528	0.264	0.264	0.396	0.264	0.264
	0.385	0.256	0.128	0.385	0.385	0.385
	0.420	0.315	0.210	0.105	0.105	0.105
	0.420	0.280	0.140	0.140	0.140	0.699
	0.431	0.431	0.431	0.719	0.719	0.431
	-0.524	-0.210	-0.210	-0.315	-0.420	-0.315
	-0.874	-0.524	-0.350	-0.524	-0.874	-0.524
	-0.361	-0.241	-0.120	-0.482	-0.120	-0.241
I_i	1.375	1.142	0.874	0.995	0.579	1.185

	iteration 12					
	A1	A2	A3	A4	A5	A6
	0.908	0.545	0.363	0.545	0.363	0.363
	0.504	0.252	0.252	0.378	0.252	0.252
	0.367	0.245	0.122	0.367	0.367	0.367
	0.400	0.300	0.200	0.100	0.100	0.100
	0.400	0.267	0.133	0.133	0.133	0.667
	0.411	0.411	0.411	0.686	0.686	0.411
	-0.500	-0.200	-0.200	-0.300	-0.400	-0.300
	-0.834	-0.500	-0.333	-0.500	-0.834	-0.500
	-0.345	-0.230	-0.115	-0.459	-0.115	-0.230
I_i	1.312	1.089	0.834	0.949	0.552	1.130

	iteration 13					
	A_1	A_2	A_3	A_4	A_5	A_6
	1.021	0.613	0.409	0.613	0.409	0.409
	0.567	0.283	0.283	0.425	0.283	0.283
	0.413	0.275	0.138	0.413	0.413	0.413
	0.450	0.338	0.225	0.113	0.113	0.113
	0.450	0.300	0.150	0.150	0.150	0.750
	0.463	0.463	0.463	0.771	0.771	0.463
	-0.563	-0.225	-0.225	-0.338	-0.450	-0.338
	-0.938	-0.563	-0.375	-0.563	-0.938	-0.563
	-0.388	-0.258	-0.129	-0.517	-0.129	-0.258
I_i	1.476	1.226	0.938	1.067	0.621	1.272

	iteration 14					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.738	0.443	0.295	0.443	0.295	0.295
	0.410	0.205	0.205	0.307	0.205	0.205
	0.298	0.199	0.099	0.298	0.298	0.298
	0.325	0.244	0.163	0.081	0.081	0.081
	0.325	0.217	0.108	0.108	0.108	0.542
	0.334	0.334	0.334	0.557	0.557	0.334
	-0.407	-0.163	-0.163	-0.244	-0.325	-0.244
	-0.678	-0.407	-0.271	-0.407	-0.678	-0.407
	-0.280	-0.187	-0.093	-0.373	-0.093	-0.187
I_i	1.066	0.885	0.678	0.771	0.449	0.919

	iteration 15					
	A_1	A_2	A_3	A_4	A_5	A_6
	1.038	0.623	0.415	0.623	0.415	0.415
	0.576	0.288	0.288	0.432	0.288	0.288
	0.420	0.280	0.140	0.420	0.420	0.420
	0.458	0.343	0.229	0.114	0.114	0.114
	0.458	0.305	0.153	0.153	0.153	0.763
	0.470	0.470	0.470	0.784	0.784	0.470
	-0.572	-0.229	-0.229	-0.343	-0.458	-0.343
	-0.954	-0.572	-0.381	-0.572	-0.954	-0.572
	-0.394	-0.263	-0.131	-0.526	-0.131	-0.263
I_i	1.500	1.246	0.954	1.085	0.632	1.293

	iteration 16					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.569	0.342	0.228	0.342	0.228	0.228
	0.316	0.158	0.158	0.237	0.158	0.158
	0.230	0.153	0.077	0.230	0.230	0.230
	0.251	0.188	0.126	0.063	0.063	0.063
	0.251	0.167	0.084	0.084	0.084	0.418
	0.258	0.258	0.258	0.430	0.430	0.258
	-0.314	-0.126	-0.126	-0.188	-0.251	-0.188
	-0.523	-0.314	-0.209	-0.314	-0.523	-0.314
	-0.216	-0.144	-0.072	-0.288	-0.072	-0.144
I_i	0.823	0.683	0.523	0.595	0.346	0.709

	iteration 17					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.407	0.244	0.163	0.244	0.163	0.163
	0.226	0.113	0.113	0.169	0.113	0.113
	0.164	0.110	0.055	0.164	0.164	0.164
	0.179	0.135	0.090	0.045	0.045	0.045
	0.179	0.120	0.060	0.060	0.060	0.299
	0.184	0.184	0.184	0.307	0.307	0.184
	-0.224	-0.090	-0.090	-0.135	-0.179	-0.135
	-0.374	-0.224	-0.149	-0.224	-0.374	-0.224
	-0.154	-0.103	-0.051	-0.206	-0.051	-0.103
I_i	0.588	0.488	0.374	0.425	0.247	0.507

	iteration 18					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.508	0.305	0.203	0.305	0.203	0.203
	0.282	0.141	0.141	0.212	0.141	0.141
	0.205	0.137	0.068	0.205	0.205	0.205
	0.224	0.168	0.112	0.056	0.056	0.056
	0.224	0.149	0.075	0.075	0.075	0.373
	0.230	0.230	0.230	0.384	0.384	0.230
	-0.280	-0.112	-0.112	-0.168	-0.224	-0.168
	-0.467	-0.280	-0.187	-0.280	-0.467	-0.280
	-0.193	-0.129	-0.064	-0.257	-0.064	-0.129
I_i	0.734	0.610	0.467	0.531	0.309	0.633

	iteration 19					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.757	0.454	0.303	0.454	0.303	0.303
	0.420	0.210	0.210	0.315	0.210	0.210
	0.306	0.204	0.102	0.306	0.306	0.306
	0.334	0.250	0.167	0.083	0.083	0.083
	0.334	0.222	0.111	0.111	0.111	0.556
	0.343	0.343	0.343	0.571	0.571	0.343
	-0.417	-0.167	-0.167	-0.250	-0.334	-0.250
	-0.695	-0.417	-0.278	-0.417	-0.695	-0.417
	-0.287	-0.191	-0.096	-0.383	-0.096	-0.191
I_i	1.093	0.908	0.695	0.791	0.460	0.942

	iteration 20					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.848	0.509	0.339	0.509	0.339	0.339
	0.471	0.235	0.235	0.353	0.235	0.235
	0.343	0.228	0.114	0.343	0.343	0.343
	0.374	0.280	0.187	0.093	0.093	0.093
	0.374	0.249	0.125	0.125	0.125	0.623
	0.384	0.384	0.384	0.640	0.640	0.384
	-0.467	-0.187	-0.187	-0.280	-0.374	-0.280
	-0.779	-0.467	-0.312	-0.467	-0.779	-0.467
	-0.322	-0.215	-0.107	-0.429	-0.107	-0.215
I_i	1.225	1.018	0.779	0.886	0.516	1.056

	iteration 21					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.631	0.379	0.253	0.379	0.253	0.253
	0.350	0.175	0.175	0.263	0.175	0.175
	0.255	0.170	0.085	0.255	0.255	0.255
	0.278	0.209	0.139	0.070	0.070	0.070
	0.278	0.186	0.093	0.093	0.093	0.464
	0.286	0.286	0.286	0.477	0.477	0.286
	-0.348	-0.139	-0.139	-0.209	-0.278	-0.209
	-0.580	-0.348	-0.232	-0.348	-0.580	-0.348
	-0.240	-0.160	-0.080	-0.320	-0.080	-0.160
I_i	0.912	0.758	0.580	0.660	0.384	0.786

	iteration 22					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.948	0.569	0.379	0.569	0.379	0.379
	0.526	0.263	0.263	0.395	0.263	0.263
	0.383	0.255	0.128	0.383	0.383	0.383
	0.418	0.313	0.209	0.104	0.104	0.104
	0.418	0.279	0.139	0.139	0.139	0.696
	0.429	0.429	0.429	0.716	0.716	0.429
	-0.522	-0.209	-0.209	-0.313	-0.418	-0.313
	-0.870	-0.522	-0.348	-0.522	-0.870	-0.522
	-0.360	-0.240	-0.120	-0.480	-0.120	-0.240
I_i	1.369	1.137	0.870	0.990	0.576	1.180

	iteration 23					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.562	0.337	0.225	0.337	0.225	0.225
	0.312	0.156	0.156	0.234	0.156	0.156
	0.227	0.151	0.076	0.227	0.227	0.227
	0.248	0.186	0.124	0.062	0.062	0.062
	0.248	0.165	0.083	0.083	0.083	0.413
	0.255	0.255	0.255	0.425	0.425	0.255
	-0.310	-0.124	-0.124	-0.186	-0.248	-0.186
	-0.516	-0.310	-0.207	-0.310	-0.516	-0.310
	-0.213	-0.142	-0.071	-0.285	-0.071	-0.142
I_i	0.812	0.675	0.516	0.587	0.342	0.700

	iteration 24					
	A_1	A_2	A_3	A_4	A_5	A_6
	1.053	0.632	0.421	0.632	0.421	0.421
	0.585	0.292	0.292	0.439	0.292	0.292
	0.426	0.284	0.142	0.426	0.426	0.426
	0.464	0.348	0.232	0.116	0.116	0.116
	0.464	0.310	0.155	0.155	0.155	0.774
	0.477	0.477	0.477	0.795	0.795	0.477
	-0.580	-0.232	-0.232	-0.348	-0.464	-0.348
	-0.967	-0.580	-0.387	-0.580	-0.967	-0.580
	-0.400	-0.267	-0.133	-0.533	-0.133	-0.267
I_i	1.522	1.264	0.967	1.101	0.641	1.311

	iteration 25					
	A_1	A_2	A_3	A_4	A_5	A_6
	1.016	0.610	0.406	0.610	0.406	0.406
	0.564	0.282	0.282	0.423	0.282	0.282
	0.410	0.274	0.137	0.410	0.410	0.410
	0.448	0.336	0.224	0.112	0.112	0.112
	0.448	0.299	0.149	0.149	0.149	0.746
	0.460	0.460	0.460	0.767	0.767	0.460
	-0.560	-0.224	-0.224	-0.336	-0.448	-0.336
	-0.933	-0.560	-0.373	-0.560	-0.933	-0.560
	-0.386	-0.257	-0.129	-0.514	-0.129	-0.257
I_i	1.468	1.219	0.933	1.061	0.618	1.265

	iteration 26					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.399	0.239	0.160	0.239	0.160	0.160
	0.221	0.111	0.111	0.166	0.111	0.111
	0.161	0.107	0.054	0.161	0.161	0.161
	0.176	0.132	0.088	0.044	0.044	0.044
	0.176	0.117	0.059	0.059	0.059	0.293
	0.181	0.181	0.181	0.301	0.301	0.181
	-0.220	-0.088	-0.088	-0.132	-0.176	-0.132
	-0.366	-0.220	-0.147	-0.220	-0.366	-0.220
	-0.151	-0.101	-0.050	-0.202	-0.050	-0.101
I_i	0.576	0.479	0.366	0.417	0.243	0.497

	iteration 27					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.762	0.457	0.305	0.457	0.305	0.305
	0.423	0.211	0.211	0.317	0.211	0.211
	0.308	0.205	0.103	0.308	0.308	0.308
	0.336	0.252	0.168	0.084	0.084	0.084
	0.336	0.224	0.112	0.112	0.112	0.560
	0.345	0.345	0.345	0.575	0.575	0.345
	-0.420	-0.168	-0.168	-0.252	-0.336	-0.252
	-0.699	-0.420	-0.280	-0.420	-0.699	-0.420
	-0.289	-0.193	-0.096	-0.385	-0.096	-0.193
I_i	1.101	0.914	0.699	0.796	0.463	0.948

	iteration 28					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.552	0.331	0.221	0.331	0.221	0.221
	0.306	0.153	0.153	0.230	0.153	0.153
	0.223	0.149	0.074	0.223	0.223	0.223
	0.243	0.183	0.122	0.061	0.061	0.061
	0.243	0.162	0.081	0.081	0.081	0.406
	0.250	0.250	0.250	0.417	0.417	0.250
	-0.304	-0.122	-0.122	-0.183	-0.243	-0.183
	-0.507	-0.304	-0.203	-0.304	-0.507	-0.304
	-0.210	-0.140	-0.070	-0.279	-0.070	-0.140
I_i	0.798	0.663	0.507	0.577	0.336	0.687

	iteration 29					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.496	0.298	0.199	0.298	0.199	0.199
	0.276	0.138	0.138	0.207	0.138	0.138
	0.201	0.134	0.067	0.201	0.201	0.201
	0.219	0.164	0.109	0.055	0.055	0.055
	0.219	0.146	0.073	0.073	0.073	0.365
	0.225	0.225	0.225	0.375	0.375	0.225
	-0.274	-0.109	-0.109	-0.164	-0.219	-0.164
	-0.456	-0.274	-0.182	-0.274	-0.456	-0.274
	-0.188	-0.126	-0.063	-0.251	-0.063	-0.126
I_i	0.717	0.596	0.456	0.519	0.302	0.618

	iteration 30					
	A_1	A_2	A_3	A_4	A_5	A_6
	0.703	0.422	0.281	0.422	0.281	0.281
	0.390	0.195	0.195	0.293	0.195	0.195
	0.284	0.189	0.095	0.284	0.284	0.284
	0.310	0.232	0.155	0.077	0.077	0.077
	0.310	0.207	0.103	0.103	0.103	0.517
	0.319	0.319	0.319	0.531	0.531	0.319
	-0.387	-0.155	-0.155	-0.232	-0.310	-0.232
	-0.646	-0.387	-0.258	-0.387	-0.646	-0.387
	-0.267	-0.178	-0.089	-0.356	-0.089	-0.178
I_i	1.016	0.844	0.646	0.735	0.428	0.875

Curriculum Vitae

Tomas Rendl was born in Klatovy, Czech Republic on November 23, 1987. He received his Bachelor Degree of Transportation Engineering in Technology in Transportation and Telecommunications - Transportation Systems and Technology from the Czech Technical University in Prague (CTU) in 2011. The topic of the defended bachelor thesis was Traffic Accidents at Grade Crossing. Afterwards he instantly entered the Transatlantic Dual Master Degree Program in Transportation and Logistic Systems, developed and operated by CTU and The University of Texas at El Paso (UTEP).

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