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URBAN ROAD CONGESTION CHARGING: THE CASE OF PORTO

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To my parents and brother

If a man takes no thought about what is distant, he will find sorrow near at hand

Confucius

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RESUMO

O desenvolvimento urbano atingiu certos limites de capacidade, o que levou à saturação das vias para utilização do automóvel. O desperdício de tempo em filas de trânsito é hoje um dos maiores transtornos da vida das pessoas, com elevados custos, nomeadamente perda de tempo, aumento dos gastos com combustível, stress e impactos ambientais.

Urge por isso procurar soluções tendo em vista o desenvolvimento sustentável. Como uma situação de falha de mercado, o congestionamento pode ser regulado pelo mecanismo preço. As portagens urbanas têm sido defendidas como uma política válida, actuando sobre gestão da procura como alternativa ao aumento da oferta.

Após uma pesquisa sobre os casos onde já se implementaram esquemas de taxação do congestionamento, alguns com sucesso e outros não, é feito um estudo para a cidade do Porto. A avaliação do congestionamento no Porto é elaborada através da utilização de um modelo de transportes multimodal.

As políticas de investimento público em infra-estruturas de transportes na Área Metropolitana do Porto têm sido orientadas para o aumento da rede rodoviária e, apenas recentemente, para a criação de uma rede de metropolitano, sendo que só esta ultima se mostrou eficaz no combate à crescente procura automóvel.

Ponderadas todas as premissas, concluímos que a situação actual não justifica a introdução de portagens.

PALAVRAS-CHAVE: Portagens Urbanas, Gestão da Procura, Esquemas de Taxação do Congestionamento, Congestionamento no Porto, Modelo de Transportes.

ABSTRACT

The development of the road network in urban regions reached capacity limits and led to saturation effects. The waste of time in traffic jams is one of the major liabilities of modern life, with high costs, including the cost of lost work and leisure time, increased fuel consumption, stress and environmental costs.

Therefore, it urges to find solutions taking in account a sustainable development. As a situation of market failure, congestion can be regulated by the price mechanism. Urban road pricing is said to be a valid way acting on traffic demand management, rather than raising the supply.

After analysing four implemented congestion charging schemes, Singapore, Oslo, London and Stockholm, some well succeeded others don't, a study for the city of Porto is developed. The evaluation of congestion in Porto is supported by a multimodal transport planning model.

Public investment policies in transport infrastructures for the Metropolitan Area of Porto have been directed to the expansion of the road network and, only recently, to the creation of an underground/tramway network. This last one is the only efficient measure applied to tackle the growth in car usage.

Considered all premises, our main findings were that the present situation does not justify the introduction of a congestion charging scheme in Porto.

KEYWORDS: Road Pricing, Traffic Demand Management, Congestion Charging Schemes, Congestion in Porto, Transport Planning Model.

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SYMBOLS AND ABBREVIATIONS

AC – Average Cost

ALS – Area Licensing Scheme

AMP – Area Metropolitana do Porto

CBD – Central Business District

CCZ – Congestion Charging Zone

Cfit – UK Comission for Integrated Transports

CP – Caminhos de Ferro Portugueses

CS – Consumer Surplus

CSTO – City of Stockholm Traffic Office

DGEG – Direcção-Geral de Energia e Geologia

ECMT – European Conference of Ministers of Transport

EPA – Swedish Environmental Protection Agency

ERP – Electronic Road Pricing

GC – Generalised Cost

GMAP – Greater Metropolitan Area of the Porto

GPD – Gross Domestic Product

INE – Portuguese National Statistics Institute

IU – In-vehicle Unit

K – Road Capacity

LCCS – London Congestion Charging Scheme

LPAC – London Planning Advisory Committee

LTA – Land Transport Authority

m – Monetary Cost

MC – Marginal Cost of Production

MSC – Marginal Social Cost

N – Number of Drivers

NE – Natural Equilibrium

NPRA – Norwegian Public Roads Administration

OCR – Optical Character Recognition

OD – Origin Destination

PNR – Portuguese National Road Plan

ROCOL – Road Charging Options for London

RZ – Restricted Zone

s – Speed

SC – Social Cost

SIKA – Swedish Institute for Transport and Communications Analysis

SNRA – Swedish National Road Administration

SO – Social Optimum

SS – Social Surplus

SSNC – Swedish Society for Nature Conservation

STCP – Sociedade de Transporte Colectivos do Porto, S.A

t – Travel Time

TfL – Transport for London

TR – Toll Revenue

TRB – Transportation Research Board

VCI – Via de Cintura Interna

vdf – Volume-delay Function

VOT – Value of Time

x – Volume

τ – Toll

1

INTRODUCTION

1.1. GENERAL DESCRIPTION

Traffic congestion is one of the major liabilities of modern life. The time lost, not to mention the personal discomfort, form a global diseconomy with a price around 2% of the GPD in the European Union. (Mezghani, 2006)

This phenomenon is the consequence of not having a balance between supply and demand.

In the early sixties, the Buchanan Report suggested a revolutionary strategy to avoid road congestion in urban centres. In fact, it was not possible to raise road capacity in the centre without major intervention, so planners adopted that document solution and connected radial axis by a ring road.

However, that policy which helped the growth of the car usage and the urban sprawl brought, decades later, new congestion problems to cities and new impracticable conditions to raise road network capacity. “Indeed, because demand for travel depends on the cost, improvements in travel conditions induce people to take more trips, and it would probably be impossible to eliminate congestion.” [Lindsey and Verhoef, 1999, pp. 1]

Curiously, Buchanan also had other ideas to deal with the problem. He suggested, for example, a "congestion tax" on car owners and the importance of cheap public transport in city centres. Except to some cases, these proposals were not taken into account.

As a situation of market failure, congestion can be regulated by a price mechanism. Urban road pricing is said to be a valid way acting on the demand, rather than the supply side. This economic measure has been applied to regulate traffic in some cities and single highways around the world.

Pricing this externality, over individual transport with great welfare gains, has always set the discussion about equity effects and social acceptability. The optimum design of an urban road pricing scheme is therefore sought to reduce congestion and provide a better quality public transportation to the community, on the one hand held by the reduction in congestion, imposed by cars on buses and on the other hand by the application of the net revenue, which is seen as the best way to gain public acceptability.

Policies like this provide a sustainable development reducing car dependency and improving global mobility in nowadays agglomerations.

1.2. OBJECTIVE

This dissertation is intended to study the introduction effect of congestion charging schemes in urban zones appealing to the most recent cases and to study the introduction of this policy for the city of Porto.

The effects have to be predicted attending on the cordon from which the circulation would be taxed, the payment level, impacts in the traffic, acceptability of the community, etc...

1.3. METHODOLOGY

This dissertation started with a convenient bibliographic research focused on the economic theory of congestion and some notes from traffic engineering.

A second moment was the practical analysis of the policy, constructing an overview on the implemented case studies and a comparative study of them.

In order to assess road congestion in the city of Porto, it was acquired knowledge in transport modelling, essentially on modelling road pricing, and hence applied to a multimodal transport model.

To conclude the Porto case, a final reflection moment allowed the exposition of some arguments that aim at the explanation of the model results as well as the current situation of the road traffic in the city.

1.4. STRUCTURE

The structure of this dissertation, apart from the present chapter, follows the methodology employed.

Chapter 2 presents the component of the economic theory of transportation associated to short-run decisions on road traffic management. Overall, some economic principles are analysed, followed by a review on the road pricing theory and a possible approach from this to a congestion charging scheme.

From theory to implemented schemes, chapter 3 presents a summarised analysis on the case studies focusing on their design options and the results obtained. Analogies to the economic theory appear when found opportune and a final synthesis section joins the main aspects of the four analysed cases: Singapore, Oslo, London and Stockholm.

From a general description of transport models to the practical methodology used for evaluating the implementation of a road pricing scheme on the city of Porto, chapter 4 focus on aspects related to modelling flows on road networks and how models can support the decision making.

General data analysis and results from the Porto’s transport model are reviewed in chapter 5. A reflection on a possible introduction of road congestion charging for the city of Porto is also exposed.

A final and single chapter presents the main conclusions.

2

ECONOMIC THEORY OF URBAN TRAFFIC CONGESTION

The present chapter presents a part of the economic theory of transportation associated to short-run decisions on road traffic management. Overall, some economic principles are analysed, followed by a review on the road pricing theory and a possible approach from this to a congestion charging scheme. This chapter was inspired on the book *Principles of Transport Economics* by the authors Emile Quinet and Roger Vickerman.

2.1. General Principles

2.1.1. Generalised Cost of Travelling

In analogy with the consumer behaviour theory the activity travelling itself creates disutility. The utility extension to transport is the generalised cost of making a trip (GC), with a negative sign. This is a price for a good inclusive of not only the monetary cost of travelling but also the time cost and the psychic cost.

Indeed, many elements compose the GC. For example, time costs can be divided in access time, wait time, travel time, interchange time, schedule delay and other costs. Psychic costs can reflect elements such as reliability (dimension of service quality) or significance (prolonged waiting time or missed travel connections). This composes an econometric function that in practice is the basis for transport models software. (Quinet and Vickerman, 2004)

A simplified and more intuitive equation 2.1 includes only the monetary and travel time costs.

$$GC = m + VOT \times t \qquad (2.1)$$

The first member of the equation 2.1 is the monetary cost (m) which can be divided into three groups, not equally perceived by users:

- Fixed costs (insurance, vehicle registration/license fees, vignettes, permits,…) that are irrelevant for a second trip;
- Semi-fixed costs (vehicle depreciation, depending on both age and cumulative distance driven) relatively irrelevant per trip;
- Variable costs (fuel, oil, maintenance, tolls,...) directly dependant on the trip.

In this perspective, an urban congestion charge from its variable character is very well perceived by users. This fact is important for the existence of a price-elastic demand but it is also a lever to public rejection of the policy.

Pricing time has been a valid idea in transport economics. Taking part in the second member of the equation 2.1, the value of time (VOT), also known as value of travel time savings (VTTS) or cost of travel time, is the ratio between the marginal utility of time and the marginal utility of income. In other words this represents the amount an individual is willing to pay to save a unit of travel time. The total time cost is therefore the product between VOT and the total trip time (t).

The generalised cost of travelling is an individual cost. As a public measure, road pricing leads to the notions of social cost and social surplus.

2.1.2. Social Cost

The term social cost (SC) of a transport infrastructure is used to designate the sum of all individual costs plus the total infrastructure cost (F).

$$SC(N,K) = \sum_{n=0}^{N} GC(N,K) + F(K) \quad (2.2)$$

Formula 2.2 particularly expresses the social cost on a road segment. For short-run decisions the road capacity (K) is fixed, meaning that the social cost only depends on the number of users (N).

2.1.3. Social Surplus

One alternative to set an optimal pricing rule can be derived by using a partial equilibrium analysis by maximising social surplus. (*idem*)

Social surplus is given by the area under the demand curve minus the total of all individual costs. For simplicity it is considered the average cost of travelling time multiplied by the number of travellers.

$$SS(N) = \int_{n=0}^{N} p(N)dn - AC(N) \times N \qquad (2.3)$$

In first-best conditions and without externalities, the optimal pricing rule is to set a price of service at its marginal cost of production (MC). However, if we assume externalities, the optimal price equals the marginal social cost (MSC).

First-best conditions subsist when the rest of the economy is operating efficiently and an externality is said to exist when the actions of an agent or agents affect the utility or production possibilities of other agents without a market in which effects are priced.

The concept of social welfare is similar to social surplus. Changes in social surplus are associated to a welfare gain or lost.

2.2. CONGESTION EXTERNALITY

2.2.1. PROBLEM ANALYSIS

Costs related to congestion include the cost of lost work and leisure time, increased fuel consumption, increased vehicle wear and tear, additional air pollution and associated health related problems and unnecessary stress and discomfort. Congestion slows the movement of goods and services, adding to the price of products and reducing the competitiveness of business. (*ibidem*)

However, for practical economic analysis the external cost of congestion is merely linked to the loss in time.

Traffic flow on a given road section is studied in traffic engineering by a speed-flow curve (figure 2.1). Data collected from vehicle counts represents the following curve. It can be divided into congested and hypercongested (as named by economists).

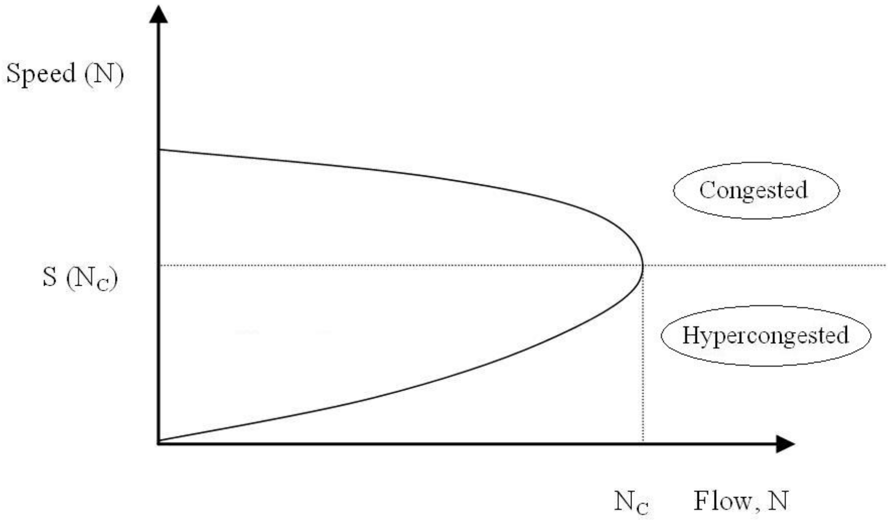

Figure 2.1 - Speed-Flow Curve (Cohen, 1993)

This curve is usually divided in two parts by a point that represents the capacity of the road. The meaning of capacity in traffic engineering is the flow value N_C close to the maximum hourly flow.

The congested branch (the upper part of the curve) reflects a clear relation between speed and flow, and can be analysed by static models. However, for the hypercongested branch, the resource to dynamic models is essential. (*idem*)

"For economic analysis (e.g. Button, 1992), it is common to ignore the hypercongested branch of the speed-flow curve and to specify a functional form for travel cost (C(N)) on the congested branch directly, rather than beginning with a speed-density function and then deriving C(N)" [Lindsey and Verhoef (1999), pp. 4]

The speed-flow curve can be presented as a cost-flow curve by pricing the time. It is common to associate this travel cost curve with an inverse demand function as shows the following figure 2.2.

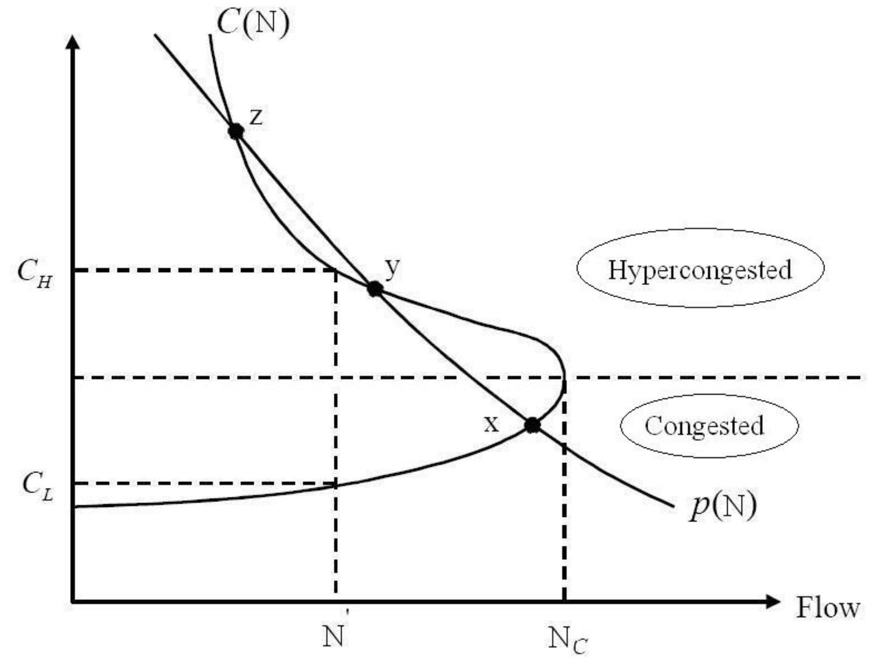

Figure 2.2 – Backward-bending travel cost curve, C(N) , and travel demand curve, p(N)

(Lindsey and Verhoef, 1999)

In this figure the hypercongested branch of the speed flow curve is equivalent to the upper part of the cost curve C(N) from the capacity flow N_C.

In order to analyse the congested part, the first conceptual framework for road pricing policy was introduced by Walters (1961), producing a supply-demand diagram (figure 2.3). This models congestion and congestion pricing by combining the speed-flow curve with a demand curve for trips. (Quinet and Vickerman, 2004)

Assumptions:

- The only endogenous choice is the number of trips;
- Travellers are identical (including their values of time) except for their reservation price for a trip;
- Vehicles are identical in private and external congestion costs;
- Demand for trips is given by a conventional downward-sloping (inverse) demand curve p(N) which represents marginal private and social benefits;
- The generalised cost of making a trip (GC) equals the average cost (AC) and rises with the number of travellers (N);
- The flow represents a stationary state, constant over time;
- Congestion is the only externality.

The link between the individual and the social optimums is well achieved by representing the average cost (AC) and the marginal social cost (MSC) curves. The AC curve expresses the average generalised cost of travelling with the time element given by the speed-flow traffic engineering function. The MSC is derived from differentiating the social cost:

$$MSC = \frac{dSC}{dN} = \frac{d(AC \times N)}{dN} = AC + N\frac{dAC}{dN} \qquad (2.4)$$

Thus, the MSC is equivalent to the AC plus the marginal congestion externality cost defined by the incremental cost of each user in the total cost.

In figure 2.3, where C(N) represents the cost per trip, a simple road is a uniform lane width and no junctions. The same graph can be applied to a given area as a simple model of analysis. (Prod'homme and Bocajero, 2005)

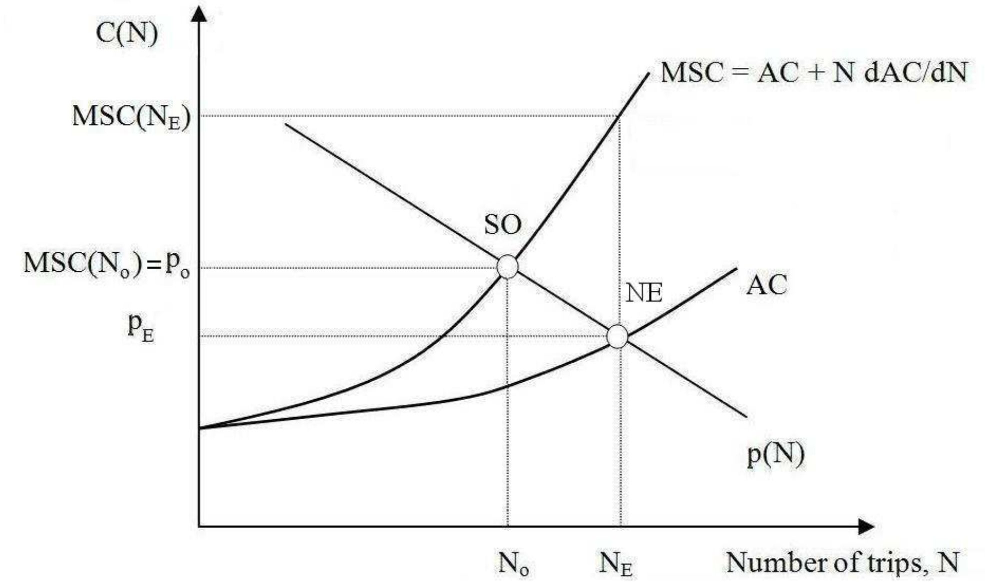

Figure 2.3 – Walters' diagram

The natural equilibrium (NE) on a non-taxed road exists for a number of trips N_E with an average cost of travelling p_E. At this point of road usage, the level of the MSC is extremely high, in accordance to a raised marginal congestion externality cost. N_E is excessive because the marginal benefit to the last traveller, p_E, is less than the MSC (N_E).

The idea behind this diagram is to find a new equilibrium, called social optimum (SO) (check 2.2.3 for further developments) where the demand curve p(N) intercepts the MSC curve. In other words, congestion is always present and the objective, therefore, should not be to eliminate congestion but to make sure that the optimal level of congestion prevails. The toll price to reduce the number of trips from N_E to N_O is known as a 'Pigouvian' tax in honour of its spiritual father Pigou (1920).

2.2.2. Pigouvian Toll, Revenue and Welfare Gain

The optimal toll is calculated by the difference between the MSC and the AC for N_O trips. This graphical interpretation can be formally derived by maximising social surplus. (Quinet and Vickerman, 2004)

$$\tau = N_O \times \frac{dAC(N_O)}{dN} \quad (2.5)$$

The new user cost per trip is equal to $AC(N_O)$ plus τ and the toll revenue results in multiplying the toll price by the number of users N_O.

Congestion costs should be defined as what is lost by society for not being at the optimum. They also equalise the welfare gain associated with the tackle on the number of trips from N_E to N_O. (Prod'homme and Bocajero, 2005)

As said above, the welfare gain reveals an increase in SS that briefly represents the recover in marginal social costs minus the loss derived from a lower demand. Figure 2.4 shows both tax revenue and welfare gain.

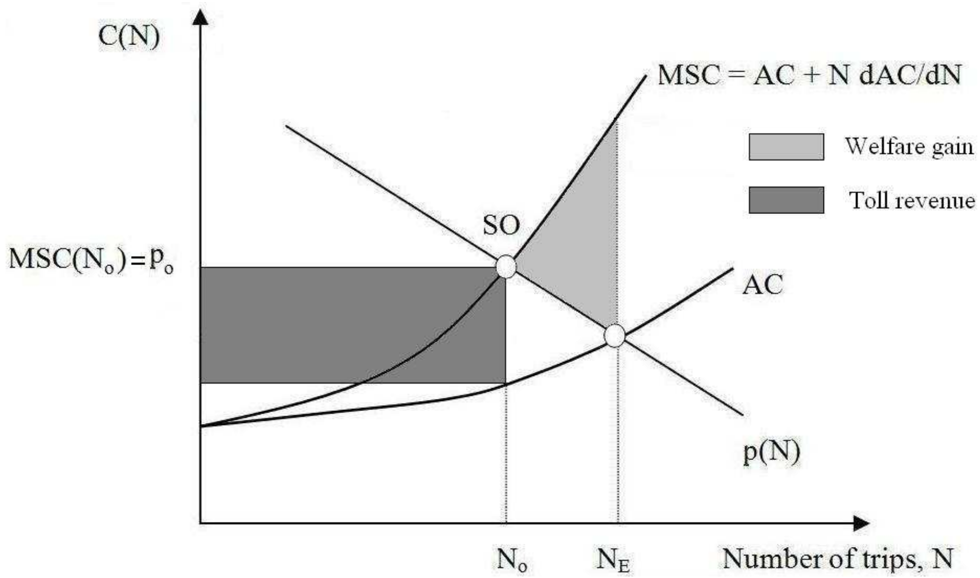

Figure 2.4 – Walters' diagram, Toll revenue and Welfare gain

A condition of natural equilibrium is that consumer surplus (CS) and social surplus (SS) have the same value. In spite of this, on the social optimum equilibrium SS further than retaining CS, sums the total toll revenue (TR). Although there is a decrease in CS from N_E to N_O, the gain in TR exceeds that loss in which forms the main objective of this policy, to maximize SS. (Quinet and Vickerman, 2004)

2.2.3. The Social Optimum Equilibrium

Route choice models in transport are based on two principles presented by Wardrop (1952). The first principle describes network flow equilibrium in the absence of regulation, also called 'user equilibrium' or 'natural equilibrium'. Wardrop's first principle states that "travel cost is the same on all routes there are used and equal or higher on all routes that are not used". (*idem*) "In a Wardrop equilibrium no individual has incentive to change either his route or his decision whether to travel. Wardrop's equilibrium is therefore a Nash equilibrium." [Lindsey and Verhoef (1999), pp. 11]

This user equilibrium is suboptimal to society since social costs are higher than in a 'system optimum', also called 'social optimum' (SO), as described in Wardrop's second principle. It states that in a system optimum, all used routes for an OD pair have identical marginal social costs equal to the marginal benefits for that OD pair, and there are no unused routes with marginal social costs lower than this. (Small and Verhoef, 2007)

The relationship between these two principles forms the key argument for road pricing regulation in what specific matters route choice. Indeed, this policy is essential on a network to reorganize the flow on the links from an individual optimum to a social optimum. This could globally generate a Pareto improvement by the compensation principle although here losers are not directly compensated. (Hau, 1992) In practice, other measures, such as applying the toll revenue on public transports or creating exemptions/discounts to some demand segments, are taken to attempt equity.

2.3. Urban Congestion Charging Scheme

The majority of the studies in this policy are based in network models, which have been applied to present cities for empirical estimation. May et al. (2000) applied a network simulation model of the city of Cambridge, U. K., to compute the effects of alternative pricing systems such as cordon pricing, distance-based, congestion-based, etc. They mainly focused on changes in spatial patterns of traffic flow and congestion, and the level of economic welfare was not discussed in detail. Santos, et al. (2001) used a similar network simulation model to obtain the optimal cordon tolls for eight English towns. Alternatively, Verhoef (2002), Zhang and Yang (2004), Sumalee (2004) examined the mathematical problem of obtaining optimal choices of toll levels and locations of toll collection in a network. They mainly determined methods of computing optimal solutions, and presented the numerical results for testing the methods. (Akyama et al, 2004)

"Although network models are useful for practical applications, they are not suitable for investigating the general properties of the problem, since the results depend on the network structures specified for calculations. On the other hand, the continuous space models are useful for theoretical analysis on qualitative properties of traffic pattern and resource allocation under alternative pricing systems." [Akyama et al (2004), pp. 401-402]

Given this academic study, this dissertation is intended to present only a simple model of analysis as suggested by Prud'homme and Bocajero (2005) concerning their economic appraisal to the London Congestion Charging Scheme.

A simplified generalised cost is considered only relative to the congested branch of the cost-flow curve.

$$GC = m + VOT \times t \qquad (2.6)$$

Where, m is the gas price per kilometre [€/km], VOT is the value of time [€/h] and t is the time per kilometre [h/km] so that time is the inverse of the speed.

$$t = \frac{1}{s} \qquad (2.7)$$

Speed can be estimated by a declining and largely linear function of road usage:

$$s(N) = A - B \times N \qquad (2.8)$$

A is the free flow speed (observed for N=0 or for night traffic values) and B equals:

$$B = \frac{A - s^*(N)}{N^*} \qquad (2.9)$$

Note that for the determination of the constant B is considered as fixed speed, s*(N), and flow, N*, values for an observed period as a reference (for example average values of speed and flow observed in a zone).

The next step is to draw an individual cost curve, IC(N), and a marginal social cost curve, MSC(N).

The first, IC(N) is the generalised cost equation (2.6) derived from equations (2.7), (2.8) and (2.9).

The marginal social cost curve equals the individual cost, plus the cost of the additional time spent by all other vehicles because of one extra vehicle on the road.

$$MSC(N) = IC(N) + IC'(N) \times N \qquad (2.10)$$

The Walter's diagram will then be completed with a demand curve, p(N).

$$p(N) = C - D \times N \qquad (2.11)$$

For simplifications this is also linear so that C and D constants can be derived by using just two points. The first point is the one used in (2.9) and the second is the system reaction to a given toll (this can be computed with a transport model or with previous data when the zone was taxed).

Note that in a supply-demand equilibrium, the generalised cost GC(N) equals the demand p(N).

Once the Walters' diagram is completed, it is easier to calculate the Pigouvian toll.

As said, this methodology was used in an economic appraisal of the London Congestion Charging scheme and can help in the way that gives an order of the toll value. From this value many adjustments can be made. For example, in what concerns demand management, the Pigouvian toll figures a third-degree price discrimination when time considerations are taken to reduce peak demand and/or to generate off-peak demand.

2.4. Practical Considerations for Scheme Implementation

The Smeed report of 1964 found that charging vehicles for every mile travelled on congested roads would "yield substantial benefits". (Times Online)

The report, commissioned by the British Ministry of Transport, concluded: "Given the immense growth in the number of vehicles, the present taxation methods do not effectively restrain the use of the roads in the right places at the right times and new methods may have much to contribute in limiting the losses due to traffic congestion." (*idem*)

In order to evaluate road pricing schemes Georgina Santos (2005) listed some criteria based both on the Smeed report (1964) and on May (1992) additional remarks:

"The (expanded) Smeed criteria are a good benchmark for the evaluation of road-pricing policies because they are comprehensive and cover all the concerns that have been raised in the literature, even years after the report was published." [Santos, 2005, pp.513]

To achieve the social optimum equilibrium on a road network, as described in section 2.2.3, charges should relate closely to road usage. As a demand management tool, the price should be variable spatially, temporally and modally. However, in spite of trying to perfectly match this objective, a relatively simple and understandable scheme is preferable so users can perceive the price structure and adjust their travel behaviours as expected by scheme planners.

A good information system is mandatory as prices should be stable and readily ascertainable by road users before embarking on a journey.

Payment in advance should be possible although credit facilities may also be allowed.

The intention of the policy must be understood to provide a progressive public acceptance and the incidence of the system upon motorists should be accepted as fair.

It is expected a high degree of reliability on the installed equipment for a better operating system and the enforcement should be reasonably free from the possibility of fraud and evasion, both deliberate and unintentional.

The same operating system of the scheme should be expandable in terms of capability to be applied in other cities. At the same time, the system should facilitate integration with other technologies.

Foreign motorists, regional and occasional users and other national visitors should be accommodated rapidly and at low cost.

The drivers' privacy should not be violated and should be able to check the balance on their accounts and the validity of the charges levied.

3

CASE STUDIES

From theory to implemented schemes, this chapter presents a summarised analysis on the case studies focusing on their design options and on the results obtained. Analogies to the economic theory appear when found opportune and a final synthesis section connects the main aspects of the four cases.

3.1. SINGAPORE

3.1.1. SCHEME PRESENTATION

In the city of Singapore free space is really scarce, creating one of the biggest problems for the Government. Some radical solutions such as conquering terrain from the sea or allowing the construction of high buildings in the business centre expresses the dimension of this problem.

This is the first case of urban road pricing. Area Licensing Scheme (ALS) was introduced in 1975 when congestion brought less economic advantages to capacity expansions than a demand management policy. ALS was a cordon toll covering an area of about 7 km^2, 1.2% of the city landscape, named Restricted Zone (RZ), figure 3.1, which included the Central Business District (CBD).

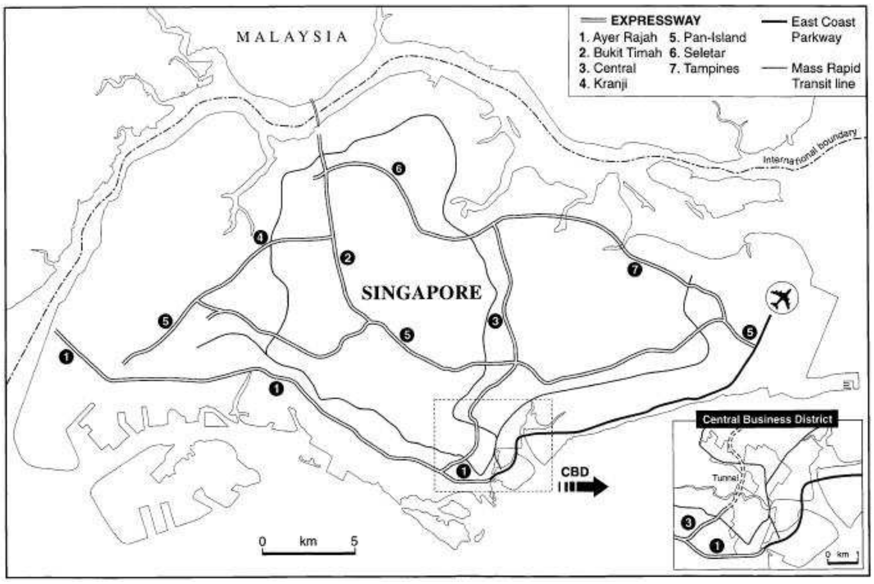

Figure 3.1 – Republic of Singapore and Charging Zone [Goh, 2006, pp. 30]

The scheme was followed by a process of price-demand adjustment and other minimal changes till 1995 when some expressways were included and later, in 1998, when a new controlling system was placed, the Electronic Road Pricing (ERP). (Santos, 2005)

There as been a gradual increase in the elasticities for ERP for both the city roads and the expressways with the latter increasing at a faster rate, since its implementation in 1998. This trend of increasing elasticity suggests that motorists seem to have entered in a learning process and become more conscious of the change in ERP prices over the years and are today more willing to change their travel patterns and behaviour when they are confronted with a higher ERP charge. In other words, the ERP has made the drivers more aware of the true cost of their journey and encouraged them to make travel-related decisions based on cost, the importance of the trip, the alternative routes and alternative transport modes available. (ECMT, 2005)

In May 1999, Land Transport Authority (LTA) announced that the ERP system would be progressively expanded beyond the RZ to relieve traffic congestion along roads in the Outer Cordon area under Phase 2 of the ERP plan.

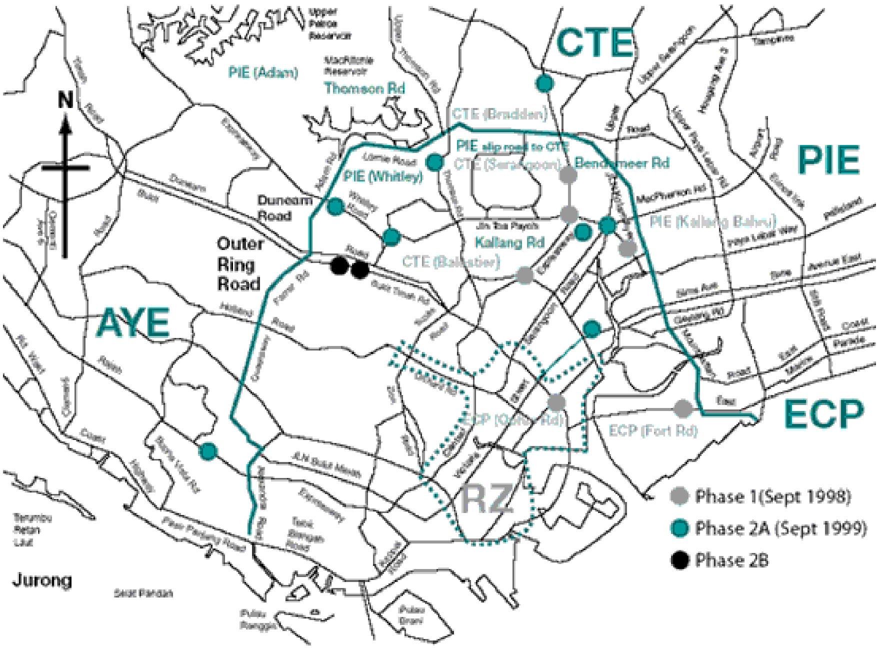

Figure 3.2 – Expansion beyond the RZ in Singapore (Cfit, 2006)

Figure 3.3 – Present ERP gantries in Singapore (LTA)

Figure 3.2 shows the spatial design of the cordon and some ERP points. Total present ERP gantries are represented in figure 3.3. The introduction of this electronic system not only leaves the enforcement more efficient but also makes it possible to graduate the price as a function of the congestion periods of time, which is a remarkable improvement to correctly apply the economic theory of congestion. Vehicles are charged automatically each time they cross a gantry, instead of the previous manual payment method which was only feasible for a day charge.

Table 3.1 characterizes the scheme before and after 1998.

Table 3.1 – Singapore's Scheme Characteristics

	Just Before 1998 Changes	After 1998 Changes
Objective	Reduce traffic congestion and increase average speed in the CBD	Average speed ranging between 20 and 30 kph on arterial roads and between 45 and 65 kph on expressways
Charging Zone	CBD (33 entry points) and 3 expressways	Idem plus expansion (gantries in April 2008, 9 on arterial roads,13 on expressways and 31 at the RZ)
Car Tariff (1)	S$ 3 (€1.5) per day S$ 60 (€30)per month	Between S$ 0,5 and S$ 5 for crossing a gantry (€ 0.25 - 2.5)
Charging Period	Week days from 7.30am to 7pm Saturdays from 7.30am to 2pm Except public holidays	Variable (depending on the road) (2)
Technology	Paper area license displayed on the windscreen	In-vehicle units (IUs) (a cash-card must be properly inserted in the IU)
Enforcement	Manually, by enforcement officers	Automatic, with video cameras

Exemptions	Public transport buses and emergency vehicles	Emergency vehicles only

(1) Vehicle type price discrimination toll cars = 2 toll motorcycle = 2/3 toll heavy vehicle goods and small busses = ½ toll very heavy vehicle goods, approximately €1 = S$ 2 (1999 exchange rate values)

(2) Annex A.1 for price table by gantry and by time of the day

As mentioned above, ERP puts the economic theory of congestion into practice. A research on the optimal toll was directed by the Government of Singapore. The price structure, as illustrates figures 3.4 and 3.5, expresses a charge variation as function of the entrance time, characteristic of a demand management policy. The level of toll increases gradually until the maximum peak period and then bends, in order to reach the optimal toll and to ensure a better average speed ranging between 20 and 30 kph on arterial roads and between 45 and 65 kph on expressways, varying the charge value each half an hour. There is also a transition phase, 5 minutes before each change of tariff, to avoid speed up or slow down by drivers.

The toll for each type of vehicle is indicated in electronic panels located before the gantries. It is also possible to take note of all information on the evolution of the tariffs, according to the gantry used, on the Internet site of Land Transport Authority (LTA) (http://www.lta.gov.sg/).

In order to confirm the link between Singapore's price structure and demand management, the ERP rates from two random checkpoints follow.

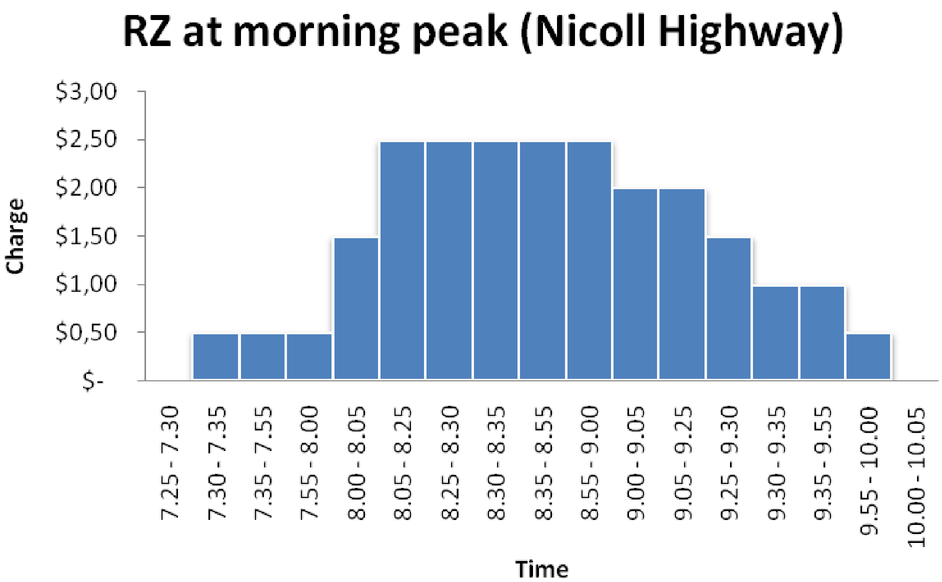

Figure 3.4 – Price-Time variation at a gantry in Singapore's RZ

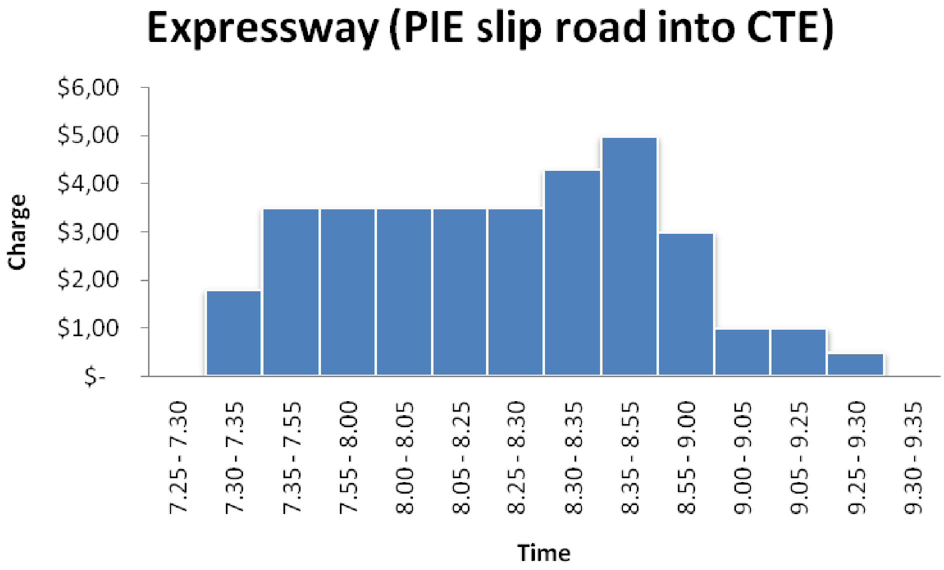

Figure 3.5 – Price-Time variation at a gantry in a Singapore expressway

Notice that these are charge values for cars, indeed the tax varies with vehicle type, location of the gantry and time of day. Furthermore, to ensure optimal use of road space price, structures are reviewed every three months.

3.1.2. Results

3.1.2.1. Traffic and Congestion

There have been substantial modifications from the original ALS to today's ERP such as sequential adjustments made to control demand, changes in the charging period, changes in vehicle type charged, introduction of new gantries and others, that disable a timescale comparative traffic analysis.

On the other hand, a summary from the main periods and some remarkable points seems interesting. The introduction of this first urban road pricing system created an impact somewhat above the previously desired. "By the fourth week of ALS, traffic flow during peak hours had fallen by 45.3%, number of cars dropped by 76.2%, and percentage of commuters travelling by public transportation rose from 35.9% to 43.9%. (Phang and Toh, 1977, Yap 1986) The average speed increased from 18 to 35 kph (Willioughby, 2000)" [Dhakal, 2002, pp. 6]

The implementation of the ERP, as described above, brought new choices to transport users inducing changes on their behaviour and creating new travel patterns.

The first major demand adjustment was a decrease on morning peak and off-peak traffic flow by about 7-8% as compared to the ALS era, and an increase of 28% during the evening peak. This increase could be justified by the lower cross gantry cost in the evening when compared to the previous ALS. Nevertheless, this raise was controlled and might intentional for the reason that capacity on the RZ roads was sufficient enough to deal with this traffic volumes during the evening peak hours. (ECMT, 2005)

3.1.2.2. Costs and Funds Application

One of the Singapore's ALS major success factors was its financial results, directly related to low running costs.

"Capital costs associated with the original ALS totalled S$6.6 million in 1975, while capital costs for the revised ALS in 1989 amounted to only S$.17 million. In contrast, revenues from the sale of area licenses amounted to S$47 million in the fiscal year 1993, while expenses related to sales, enforcement, and maintenance were only 9 percent of revenues." [Phang and Toh, 2004, pp. 20]

Transforming the ALS manual system to today's Electronic Road Pricing involved an important financial effort. In October 1995, a project for the design and construction of the new scheme was awarded to a Consortium at about S$197 million. From the S$197 million, about S$100 million covered the initial supply of IUs given to motorists for free during a 10-month period of grace that was given at the time. Since 2004, the payment of this equipment has been addressed to drivers at S$150 including the installation cost. The remaining amount of S$97 million was for the design, development, supply, installation and 1-year warranty of ERP equipment, including gantries and the central computer system. A separate 5-year maintenance contract at about S$39 million was also awarded for 1998–2003, along with the main contract. (Santos, 2005)

As for ERP revenue, Singapore's government collected about S$91 million in financial year 2006. The revenue collected has been managed by the Government's Consolidated Fund, which funds various government programmes for the benefit of all Singaporeans. (LTA website, Parliament Questions and Answers May 2007)

ERP annual operating costs reached S$16 million in 2004, which includes the salary of the staff and administrative expenses so as to manage the system and the department, as well as maintenance of the system. (Santos, 2005)

3.1.3. Acceptability

The rate of violations fell by 40 per cent after the first few months suggesting a decrease in opposition.

A survey found that 75% of respondents felt it was fair to charge vehicles according to the congestion they caused, and more than 60% supported congestion management measures other than high vehicle ownership taxes. (Cfit, 2006)

3.2. Oslo

3.2.1. Scheme Presentation

The use of tolls as a financial instrument for road construction has been successfully used in Norway for over 70 years (Wærsted, 2005). This tradition applied to urban areas was first established in Bergen in 1986 and later in Oslo (1990) and Trondheim (1991).

Oslo faced congestion problems and the plans for better traffic flow needed investment on new infrastructures that could be easily supported by the revenue from tolls. Indeed, the price mechanism, in this situation, was used to maximise the toll revenue rather than achieve the social optimum equilibrium as the already explained Pigouvian toll, chapter 2 of this dissertation. Therefore, the tariff was lower than conventional and the cut-down on demand, expected to tackle congestion, was not so big.

As figure 3.6 shows, a cordon scheme is composed of 19 operating toll stations located in a ring around the city between 3 and 8 km from the centre purely to maximise revenue. (Ieromonachou et al, 2006)

The selection of the Oslo tolling stations was based on a compromise between sites that offered the highest revenues and a small number of collection stations located in areas where the land could be acquired for a reasonable price. (TRB, 2005)

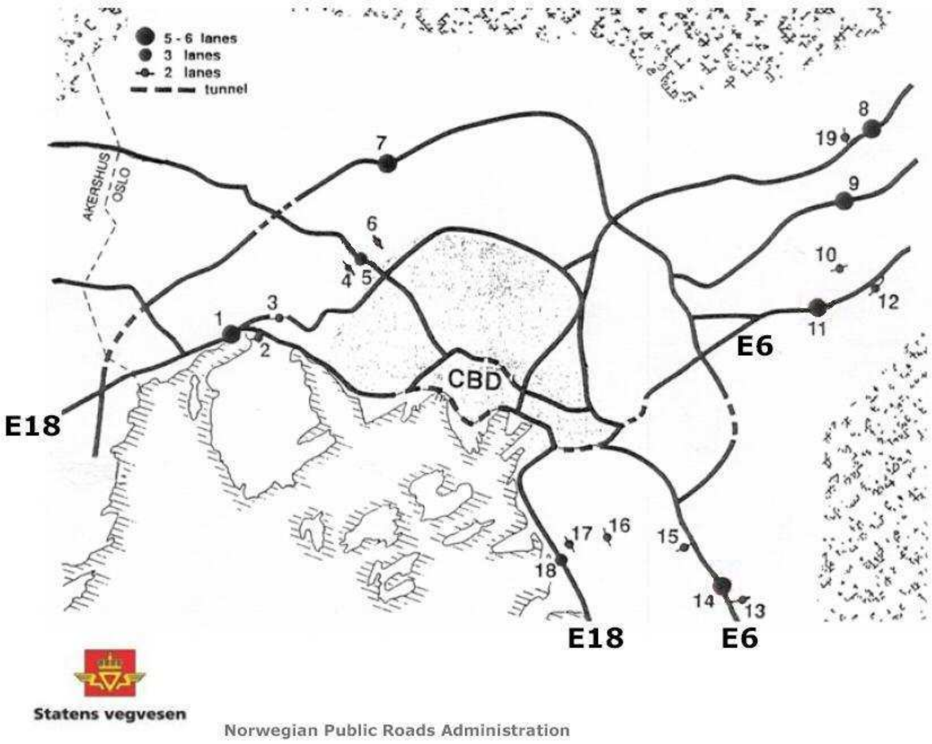

Figure 3.6 – Oslo's cordon scheme (Wærsted, 2005)

Characteristics of the scheme are presented in table 3.2 expressing a weak demand management policy, as the tax of entry is constant throughout the day and hence does not fluctuates with traffic flow. An additional remark in this perspective is that only ingoing traffic is charged for crossing the cordon.

Table 3.2 – Oslo's Scheme Characteristics

	Oslo Package
Objective	Financing Infrastructures
Charging Zone	19 toll stations, about 40km^2 (50% of the residents live inside)
Car Tariff (1)	Constant, NOK 20 (€ 2.4), only for inbound traffic
Charging Period	24hours, 7days a week

Technology	Possible to pay manually at a coin box collection unit or by the AutoPASS system, with a radio transmitter on the windscreen
Enforcement (2)	Automatic, with video cameras
Exemptions	Public transport, MC, EL-cars, ambulances, and handicapped persons

(1) Heavy vehicles (up to 3500kg) pay double. Tariff values on 1st January 2004. Approximately €1 = NOK 8.4 (1st Jan 2004 exchange rates)

(2) An invoice is sent to drivers who do not have an AutoPASS account passing through the AutoPASS lane or for those who do not pay at the coin box collection unit.

3.2.2. Results

3.2.2.1. Traffic and Congestion

The described price structure was not designed to have a major impact neither on road traffic nor on congestion. In a report on road pricing in urban areas by the Swedish Road Administration, it is also stated that in Oslo, "the fees were expressively designed not to change the traffic pattern". Even though there was a slight decrease in the first years, 1990 traffic flow levels returned in 1993 and exceeded in the subsequent years.

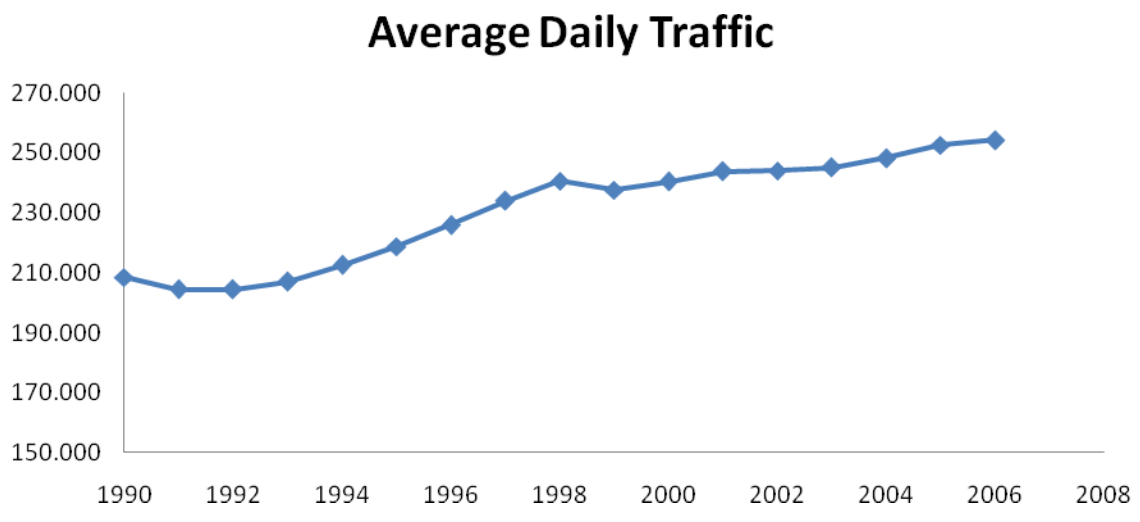

Figure 3.7 – Oslo's Scheme Traffic Tendency

In 1999, a reduction in traffic was observed but it was mainly caused by the opening of the new airport north of Oslo. (2002 Fjellinjen AS annual report)

In brief, results confirm a growth in demand, helped by higher supply from the given investments on road infrastructures.

3.2.2.2. Costs and Funds Application

Funds are managed by a company owned by the city of Oslo (60%) and the county of Akershus (40%). (Fjellinjen AS, 2006 Annual Report) In the first year of operation, the initial investment of 250 million NOK (31M€) was covered by revenue of 750 million NOK (94M€). Annual toll revenues were approximately 1 billion NOK (125M€) and operating costs consumed about 10% of the gross revenue. (TRB, 2005) More recent data, available on the Fjellinjen 2006 annual report, assure this ratio of 10% with the global operating income reaching 1248 million NOK (156M€).

Financial applications, referred above as a Norwegian "tradition", report to strategic investments on transport projects within a settled period of time which is entitled Oslo Package. From these packages of projects, toll revenue is set to cover 55% of the costs while other part is covered by the Swedish Government. (NPRA, 2006)

Oslo Package is an agreement on the way in which the cordon scheme should be used to generate investment for transport in Oslo. First Oslo Package in 1990 was primarily designed to raise funds for road construction (80%, including a ring road, an east to west tunnel and a north to east tunnel) with a lesser focus on public transport (20%). However, the introduction of the Oslo Package 2 in 2002 inverted this situation with almost all revenues dedicated to public transport. The recent Oslo Package 3 postpones the removal of the urban road pricing in Oslo till 2025. It gives the same destination to the funds as the previous package, but with further investments to the whole transport system, and also covers the operation cost of the toll scheme. (*idem*)

3.2.3. Acceptability

While the opposition in the initial phase was very strong, there were threats of sabotage, most people now seem to accept the cordons as a fact of life like parking fees and parking restrictions. Opinion polls have been carried out annually since 1989 in order to monitor attitudes of the population in respect to the toll cordon. (Larsen and Ostmoe, 2001)

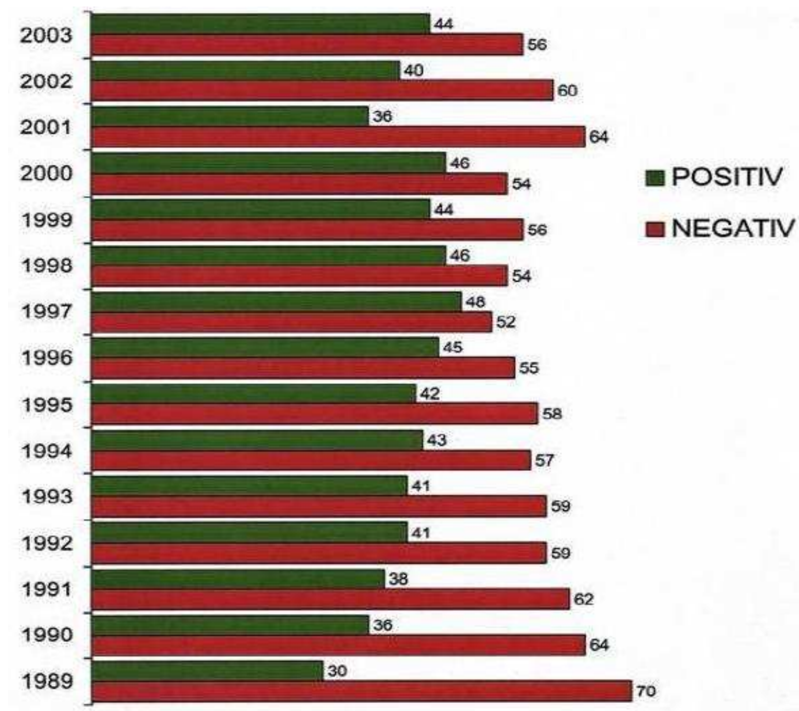

Figure 3.8 – Results from Oslo's opinion polls (Wærsted, 2005)

The acceptability assessment in this case shows that the opposition was stronger prior to the scheme application as there were 70% of negative attitudes but that figure dropped to 64% immediately after.

Eight years later, 54% were against road pricing. Nevertheless, between the years 2000 and 2001, the opposition grew stronger. This reality was indeed caused by the Oslo Package 2, since the funds were not to be spent in capacity expansion or new road projects but in public transports added with a fear that the toll ring would not be removed in 2007 which was the original decision. (Wærsted, 2005)

3.3. LONDON

3.3.1. SCHEME PRESENTATION

In 1964, the first document regarding urban toll is introduced as a possible demand management tool, as described in the previous chapter, the Smeed's Report. It concluded that the contemporary methods to tax vehicles (which changed little since) did not retain people to make trips which imposed high costs on others. This report was used in 1967 by the British Ministry of Transport in the study, 'Better Towns with Less Traffic'.

In the eighties, London Planning Advisory Committee (LPAC) concluded that the management of congestion was central to transport policy in London and that the only improvement of public transport was not sufficient. There was a need for direct measurements to retain road traffic and to obtain a better balance between supply and demand.

The succession of studies occurred until Road Charging Options for London (ROCOL) in 1998, forming a serious base for the proposed central London congestion charging scheme implemented in 2003.

This policy took almost forty years to be applied for a variety of reasons such as problems of legal applicability, pressure from the road lobby and fear of adverse impacts caused by toll. In July 2000, the mayor began the process of public consultation with an article called 'Hearing London's Views' which was sent to almost 400 key stakeholders such as the London boroughs, London MP's, MEP's, business groups, transport operators, motoring organisations and minority groups. The results of this exercise indicated that there were six times more defenders of the concept of urban toll in central London than those opposed to the initiative. Once the process of public consultation is finished, the mayor took the decision to apply tolls in 2002 starting on 17th February 2003.

The charge aims to reduce traffic congestion and improve journey times by encouraging people to choose other forms of transport if possible. As set out in the Mayor's Transport Strategy Congestion charging contributes directly to the achievement of four of the Mayor's transport priorities:

- Reduce congestion;
- Make radical improvements to bus services;
- Improve journey time reliability for car users;
- Make the distribution of goods and services more efficient.

Furthermore, by reducing traffic levels it has also contributed to reducing vehicle emissions. It also generates net revenues to support the Mayor's Transport Strategy more generally. (TfL, 2007a)

London Congestion Charging Scheme (LCCS) is an area-licensing scheme that originally covered 22 km2 in Central London. Since its western extension in 2007 the congestion charging zone (CCZ) figures an area of about 42km2. Although it captures the areas of government, law, business, finance and entertainment within its boundaries, it only covers 2.7% of Greater London. Therefore, this urban centre has few residents in relation to Greater London.

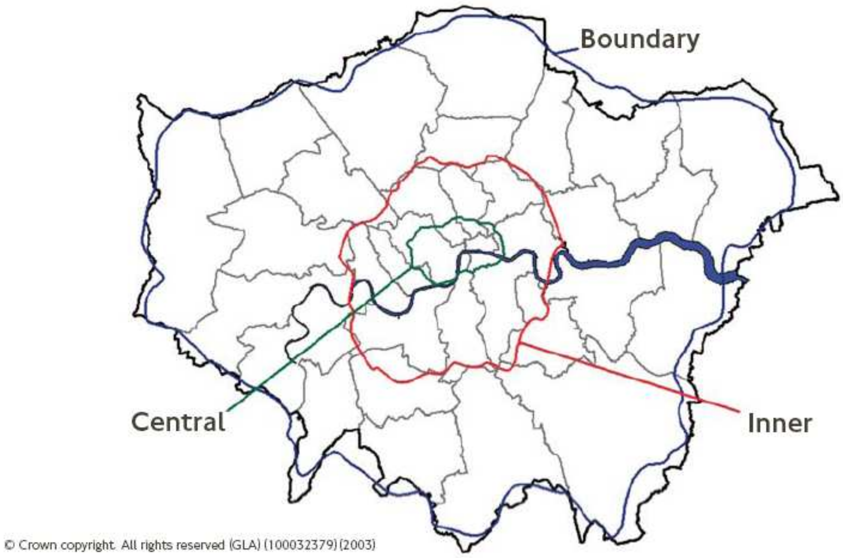

Figure 3.9 – Greater London, Inner London and Central London (TfL, 2007b)

Demographic data estimates for Greater London a population of about 7.5 million and for the city of London 7.8 thousand. In the present case study, this important region can be subdivided in, biggest to smallest, Outer London, Inner London and the CCZ. This last one, inside the city of London, had its original borders on Pentonville Road, City Road, Old Street, Commercial Street, Mansell Street, Tower Bridge Road, New Kent Road, Elephant and Castle, Vauxhall Bridge Road, Park Lane, Edgware Road, Marylebone Road and Euston Road. In February 2007, extension was prompted to capture more of the congested areas of London, including Kensington, Chelsea, and Westminster.

The tax was £5 for circulating inside the mentioned zone and it was restricted to workdays from 7am to 6.30 pm. Since the 4th of July 2005, the amount is 8£ and the charging period fell by 30 minutes to finish at 6 pm. This price structure was maintained even with the western extension in 19th February 2007. Figure 3.10 schematically represents the original CCZ and the extension.

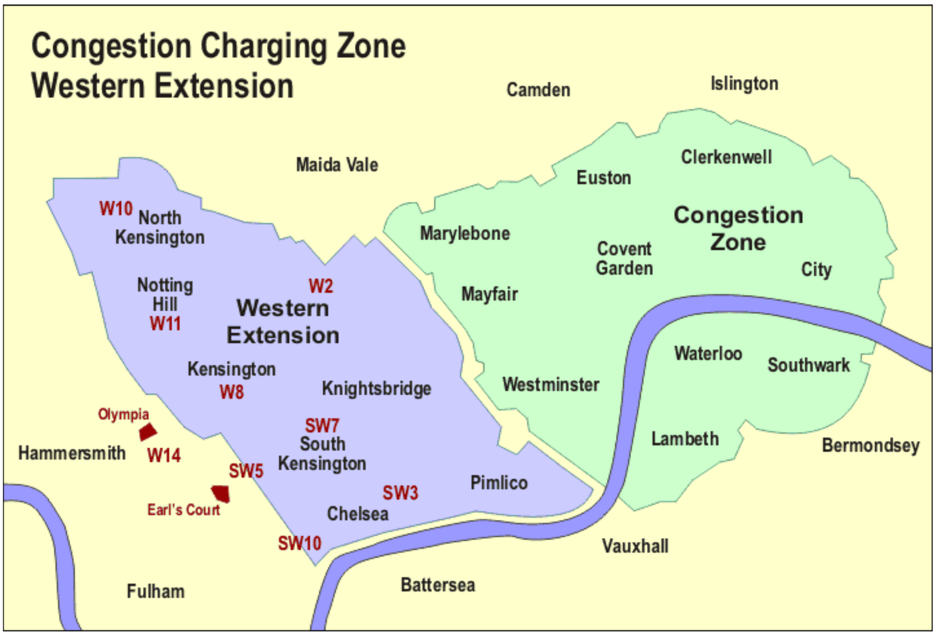

Figure 3.10 – The original London CCZ and its extension (Scarlet Couriers)

The CCZ is now divided by a road where drivers do not pay for passing through.

Characteristics of the scheme are presented in table 3.3, expressing a weak demand management policy, as tax does not oscillate with traffic flow.

Table 3.3 – London's Scheme Characteristics

	LCCS
Objective	Reduce congestion and improvements to bus service
Charging Zone	Area-licensing scheme covering the city centre, concerning 40km2
Car Tariff	Constant, £8 (10€)
Charging Period	From 7am to 6pm, only on workdays
Technology	No in-vehicle special equipment, automatic number plate recognition software
Enforcement	Automatic, with video cameras
Exemptions	(consult annex A.2)

3.3.2. Results

The appraisal on this case is based on the annual indicators provided by the monitoring reports by Transport for London (TfL). It is not be possible to work out the desired division by phases, but instead a possible reflection by years and its relation with the implementation path will be.

3.3.2.1. Traffic and Congestion

Vehicle counts, figure 3.11, show that there was an important initial reduction of 18%, for vehicles with 4 or more wheels, and later a slight drop by 3% when the tax increased to £8. The results also display that for the category "potentially chargeable", which includes cars, minicabs, vans, lorries and others, there was a fall of 27% in the first year, followed by variations of -1%,-3%, +1% respectively for the subsequent years, which confirms a drop 2006-2002 of 30%.

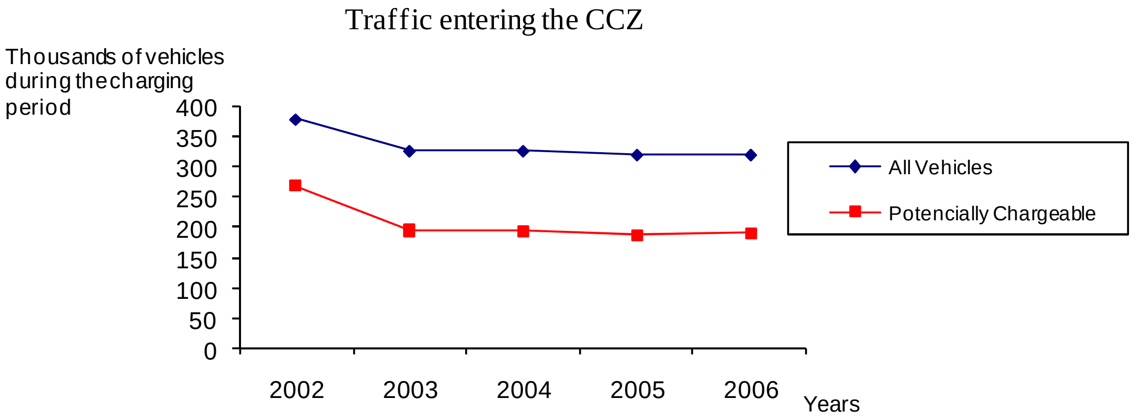

Figure 3.11 – Year-on-year traffic entering the CCZ

The first three months available data for the post-extension period is still not very conclusive. However, according to TfL, the entrance of vehicles of 4 or more wheels in the extension zone fell approximately 10%. Vehicle counts also report a minor increase in the original zone due to the raise of users with 90% reduction, residents of the extension zone.

Out of the CCZ, on the Inner Ring Road traffic levels were not affected and for the radial traffic approaching the charging zone indicators reveal a slight decrease.

Traffic patterns prove a decrease in demand as a consequence of the price-mechanism. On the other hand, as shown below, congestion indicators are not so enthusiastic.

In what concerns the average speed inside the CCZ, the decreasing tendency observed till the minimum value of 14 kph in 2002, suffered a substantial increase of 3 kph with the introduction of this policy. Nevertheless, the decreasing tendency was maintained. According to TfL "that reflected both increased levels of street works (which, in later analysis, have been found to be particularly significant in 2006), and progressive adjustments to the effective vehicular capacity of the road network in pursuit of other priorities by the various agencies involved in managing London's traffic over recent decades." [TfL, 2007a, pp.36]

Transport for London defines congestion as the extra time spent relatively to night trips or free-flow values. The base time of 1.9 min/km is considered as the free-flow travel time, in accordance with TfL. From there travel time per kilometre caused by the congestion is equivalent to average time less basic time. Data shows that in 2002 the average time of course, exclusively due to congestion, was 2.3

minutes per kilometre, value which dropped to 1.6 in 2003 followed by an increase to 1.7, 1.8 and 2.1 in 2004, 2005 and 2006 respectively. The price-mechanism effect is confirmed, including the above described problems.

Figure 3.12 – Year-on-year average extra travel time within the CCZ

3.3.2.2. Costs and Funds Application

London is clearly the case where financial results were worst. In the first year, operational costs raised up to 75% of the gross revenue. This malfunction seems to have been corrected throughout recent years. Table 3.4 proves it and confirms a drop of 42% for the same relation of costs.

Table 3.4 – London Financial Results (M£) (TfL Annual Reports)

	2003	2004	2005	2006
Gross Revenue	186.7	218.1	254.1	213
Operational Costs	141.4	121.7	147.8	90
Net Revenue	45.3	96.4	106.3	123

By law, the net revenues from this scheme must be spent on measures to further the Mayor's Transport Strategy. Originally, the revenues from the scheme were only available to TfL for the first ten years of the operation of the scheme. However, TfL has been advised by Government that a longer period of hypothecation, till 2017, would apply following the introduction of the western extension. (TfL, 2007a)

As an example of the application of congestion charging scheme revenues, the priorities and the amount spent on them for the financial year 2006/2007 follow.

£ 101 million for bus network operations (contributions to major enhancements of London's bus garages, stations, stops and shelters; bus priority and real-time customer information systems; and bus operations and support activities), £ 14 million for roads and bridges (contributions for invest in programmes to improve the quality of street conditions, including reconstructing and resurfacing carriageways and footways and upgrading and strengthening structures), £ 5 million for road safety (contributions for measures to reduce road casualties, both on TfL roads and borough roads) £ 3 million for walking and cycling (contributions for a programme of improvements for pedestrians, both on TfL roads and on borough roads; includes contributions for borough local transport improvements). (*idem*)

3.3.3. Acceptability

Data provided by Transports for London based on social impacts surveys (2002, 2003) is not as up to date as the previously approached indicators. However, statistical results reinforce the common raise in public acceptability in a post-implementation period.

"Now that respondents have experienced the scheme, an increased proportion feels they have gained than expected this to be the case. Overall, significant numbers have found their experience is not as expected, both on themselves and their household. The majority who have changed their view say that the charging scheme has actually made no difference to them." [TfL, 2004b, pp. 4]

Table 3.5 shows the results from the question "Do you think you have (will) personally gained/gain or lost/lose as a result of the Congestion Charging Scheme?"

Table 3.5 – London Public Acceptability (TfL, 2004b)

	Opinion	2002	2003
CCZ	Gained	18%	25%
	Made no difference to me	31%	43%
	Positive and Negative	6%	6%
	Lost	37%	25%
Inner London	Gained	14%	23%
	Made no difference to me	40%	45%
	Positive and Negative	9%	5%
	Lost	27%	26%
Outer London and beyond the M25	Gained	25%	24%
	Made no difference to me	27%	44%
	Positive and Negative	8%	2%
	Lost	37%	28%

These surveys also reveal the positive and the negative arguments among the inquired. In relation to positive effects, in order of preference, less traffic/congestion, better public transport, less pollution/improved air quality, made travelling/journey easier/more reliable and quieter/less noise pollution. On the other hand, negative effects are businesses have suffered, penalising residents, less parking spaces and expensive charges/cost of the scheme, noting that this last one had 19% of the choices in 2002 and curiously after the implementation of the LCCS that value fell to 3%.

3.4. STOCKHOLM

3.4.1. SCHEME PRESENTATION

This European capital is located on Sweden's east coast, where Lake Mälaren meets the Baltic Sea. Surrounded by water, this implies that all vehicles borrow bridges necessarily. Some of them, like the Central Bridge or Essingeleden Bridge frequently face congestion problems at rush-hours. An illustrative example is that the volume of traffic in 2005 on these two principal arteries often largely exceeded the capacity for which they were initially built. Moreover, Stockholm’s geographic condition makes it difficult, for technical, economical, and environmental reasons, to relieve the pressure on these central roads by building beltways.

The city of Stockholm has 770 000 inhabitants. The metropolitan area has a population of 2 million people and 3 million live within a daily commuting distance. The population of Stockholm grows at approximately 20.000 inhabitants per year, which brings more and more traffic for streets and roads of the city. This also means more difficult access to the city and reduced mobility. Additionally, this causes environmental problems like noise and undesired vehicle emissions.

The average traffic speed on main roads to and from the downtown area during rush-hours is more than 60% below the limit, which is considered as severe congestion (Transek, 2004, as cited in Armelius, 2006). The average rush-hour speed of city buses between the suburbs and downtown is 20–40% below the average speed during evenings (SL, 2005, as cited in Armelius, 2006). On one of the main routes, the average rush-hour speed of the city buses is just 12 kph, i.e. slower than a bicycle. (Armelius, 2006)

According to these indicators, it was inevitable to think of an urban road pricing mechanism. Several systems have been proposed such as the Dennis Agreement, similar to the Oslo case, were the charge was applied to inbound vehicles over a toll ring and as a format of package that financed both a part of the infrastructure and as a means of controlling traffic. Traffic reduction calculated for the inner city reached a bit more than 20%.

Other proposals came from the Swedish Society for Nature Conservation (SSNC) based on 5-10 zones divided by toll rings with a price to pay for passages between zones. In 1999, the Swedish Institute for Transport and Communications Analysis (SIKA) presented a report where was suggested that, for the city of Stockholm, a road pricing that fully correspond to the external costs, would nearly eliminate all congestion.

In 2001 the Swedish Environmental Protection Agency (EPA), (who commissioned Transek AB for construction and calculations), also proposed a road pricing system. The computations showed that a charge of a bit more than € 0.2/km in the inner city and half of that outside the city and in the closest municipalities during peak hour would eliminate most bottlenecks in Stockholm. The traffic in the inner city during peak hours would be reduced by 21%, and the number of vehicle kilometres in the county reduced by 3%. Trips through the inner city during peak hours would be considerably faster, with a gain in travel time of about 10 minutes for a trip that formerly took 30 minutes. The average travel time effects would, on the contrary, be small, less than 2 minutes per trip on an average. This is explained by the fact that only a small part of the total trips pass the bottlenecks. (SNRA, 2002)

In an attempt to reduce the growing congestion and to improve the environment, a full scale process was carried out. A particular process to introduce congestion charging in Stockholm consisted of two parts: an extension in public transports from 22nd August 2005 to 31st December 2006 and a congestion pricing scheme trial from 3rd January to 31st July 2006. Park & Ride facilities were provided in order to promote habits of intermodality.

The main objective of this test was to gain public acceptability without a big-bang implementation path. In order to produce the desired scheme, functional objectives were proposed, particularly to tackle traffic on the inner city by 10% - 15% during peak hour, to improve urban transports in Stockholm and to reduce pollution.

The town of Stockholm was in charge of coordinating the project with other municipalities as well as providing general information concerning the process and the reasons for which it was set up. It was also in charge of surveys and evaluations. Stockholm Transport was responsible for the expansion in public transport for a trial period, constructing car parks and the assembly of the installations and information related to the process. Swedish Road Administration had to build and exploit the congestion charging scheme, in particular via the collection of funds and public information in this respect.

The charging zone has about 47km^2 and circles 280 000 inhabitants. The eighteen control points of the toll are illustrated in figure 3.13.

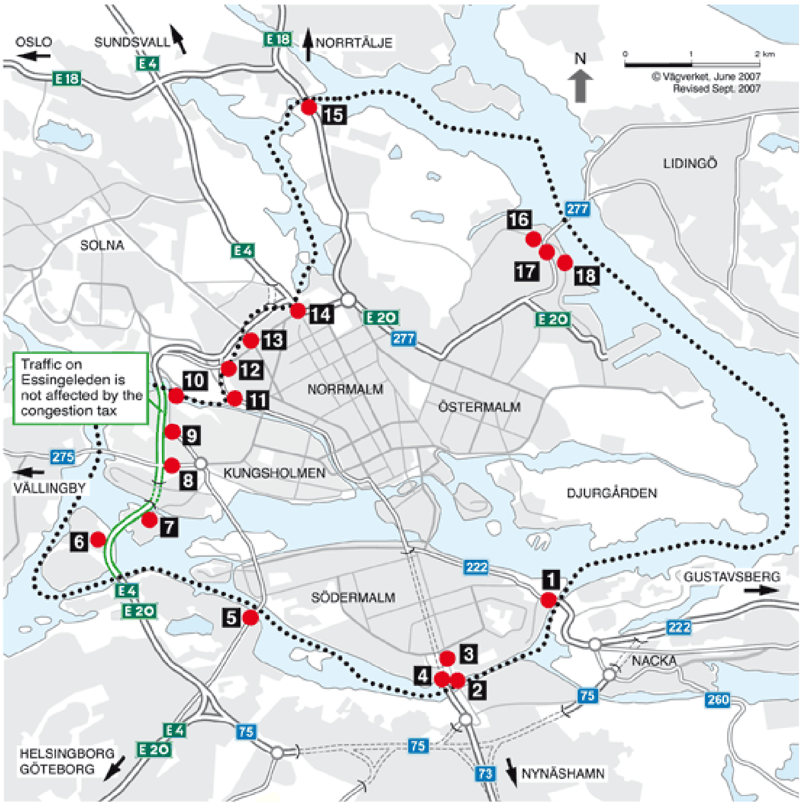

Figure 3.13 – Stockholm's cordon scheme (Swedish Road Administration)

After the seven month trial period and a reflection on the results, the system has been running permanently since 1st August 2007. Vehicles crossing the border of the congestion charging area have their generalised travel cost increased by a tax that varies according to the period of day. This interesting point means that some demand management policy is beyond Stockholm's scheme. Characteristics are presented in table 3.6.

Table 3.6 – Stockholm's Scheme Characteristics

	Stockholm congestion tax
Objective	Reduce congestion, improvements to bus service and environmental benefits
Charging Zone	18 control points, about 47km^2 (36% of the city's residents live inside)
Car Tariff	Variable, from SEK 10 (€ 1) to SEK 20 (€ 2)
Charging Period	From 6.30 am to 6.30 pm (Workdays only). No operating during the month of July or on public holiday eve
Technology	No in-vehicle special equipment, automatic number plate recognition software
Enforcement	Automatic, with video cameras (Optical Character Recognition (OCR) software)
Exemptions	Emergency vehicles Buses with a total weight of at least 14 tonnes Diplomatic cars Taxis Motorcycles Vehicles registered abroad Military vehicles Vehicles that are designed to operate completely or partially on electricity or gas other than LPG, or on a fuel blend consisting predominantly of alcohol (Approximately 30% of vehicles were exempt from the charge)

This case's price structure reveals itself to be adjusted to a demand management policy than the cases of Oslo or London. Price discrimination has three levels, each for each period of time, segmented in peak periods (7.30-8.30 am, 4-5.30 pm) SEK 20 (€ 2), semi-peak periods (7-7.30 am, 8.30-9 am, 3.30-4 pm, 5.30-6 pm) SEK 15 (€ 1.5) and medium-volume periods (6.30-7 am, 9 am-3.30 pm, 6-6.30 pm) SEK 10 (€ 1). Figure 3.14 composes these charging periods.

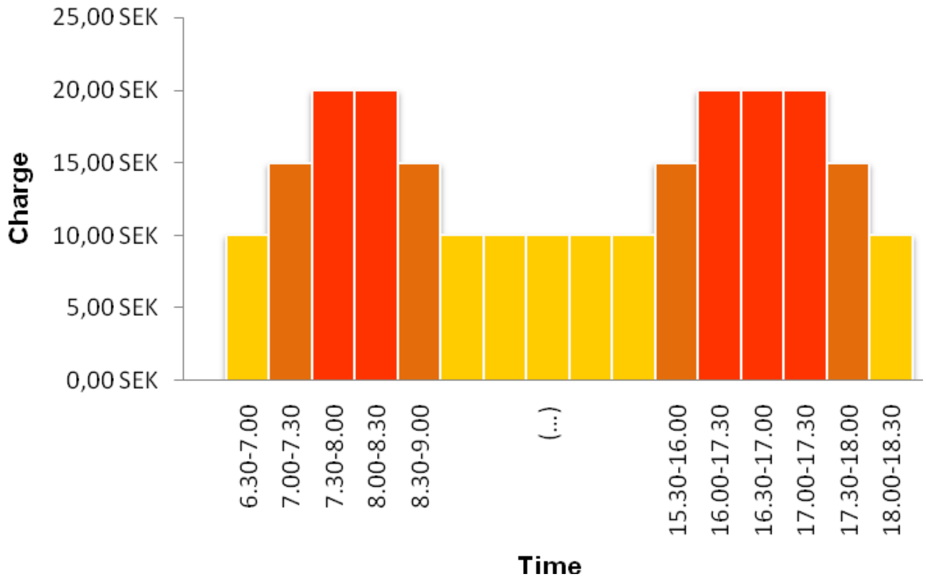

Figure 3.14 – Stockholm's price structure

3.4.2. Results

3.4.2.1. Traffic and Congestion

The trial experience acquired for the management of the current permanent application has been enriching. Results from comparative, before and after trial, traffic counts are displayed in figure 3.15 where the decline in the number of vehicles passing the cordon toll is clear. This drop exceeded the established objectives given, which is estimated at 22% for the all congestion charging period (6.30-18.30). The reduction during the morning peak period was a bit inferior, 16%, while the reduction during the afternoon/evening peak period was 24%. Another statement to these results reflects the variation of the price elasticity of demand as the reduction in traffic was higher in the middle of the day than during the normal commuting peaks. Concerns about trip motivation can support this evidence. Working trips are regularly taken at peak hours and so, those drives with more rigid timetables are less attracted to abort trips or to change the transport mode.

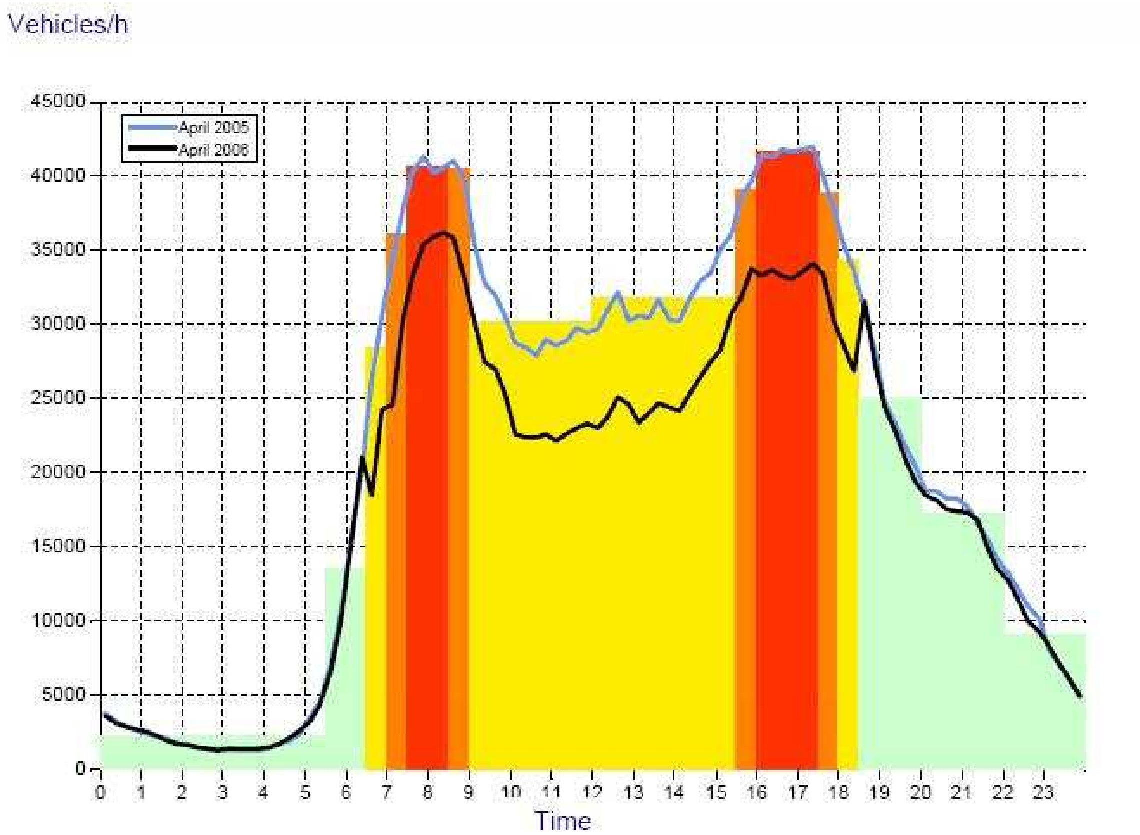

Figure 3.15 – Stockholm's traffic impact [CSTO, 2006, pp. 10]

The reductions in journey times in and around the inner city were somewhat significant. These reductions have been particularly great on the arterial roads to and from the inner city. Queuing times on these roads have fallen by one third for inbound traffic during the morning peak period and have fallen by one half for outbound traffic during both afternoon and evening peaks. (CSTO, 2006)

In general, the trial has achieved its objective of improving the fluidity of the traffic on the city's busiest roads. Road use in the inner city, measured in vehicle kilometres travelled, has fallen by approximately 14%. As a result, it is reasonable to assume that traffic-related emissions in the inner city have also fallen. Moreover, traffic has also been reduced in the outer city, although the reduction here was marginal. (*idem*)

3.4.2.2. Costs and Funds Application

The budget for the entire Stockholm Trial was SEK 3.8 billion. This amount included the three above referred trial phases. After deductions for residual values the cost of the Stockholm Trial was approximately SEK 2.7 billion. With congestion tax revenue at approximately SEK 763 millions p.a. and operating costs of SEK 220 million p.a., it would have taken over 3.5 years for net income to cover the investment cost. (Transek AB, 2006)

3.4.3. Acceptability

"At the start of the trial many Stockholm residents reacted with outrage. A majority of residents opposed the tax and even organised demonstrations to vent their disapproval." [Cfit, 2006]

However, this situation changed. During the trial, people gradually began to accept the policy and adjusted their travel behaviours. Surveys reflect that the percentage of citizens who believed that it was a rather/very bad decision to conduct a congestion tax trial fell from 55% in autumn 2005 to 41% in May 2006.

A referendum evolving the city of Stockholm and some peripheral municipalities was held on September 2006. Results for the inner city affirmed the majority support for this policy but were not solid. 53% voted 'yes' to the introduction of a permanent scheme and 47% voted 'no'. Voting percentage was 76.4%. Outside the city, in favour voters were lower with 48%.

“This leads to some confusion in how to interpret the results with the residents within Stockholm more in favour of the system than those in the surrounding municipalities.” [idem]

3.5. SYNTHESIS

In conclusion, table 3.7 summarises the main elements of the four studied schemes.

Table 3.7 – Case Studies’ Comparative Table

	Singapore	Oslo	London	Stockholm
Year of Implementation	1973 (ALS) 1998 (ERP)	1990	2003	2006 (Trial) 2007
Metropolitan Population (millions)	4.6	0.84	7.5	1.9
Metropolitan Area (km^2)	704	454	1577	6519 (1)
Congestion Charging Zone Area (km^2)	7 + peripheral gantries	40	42	47
Scheme Objective	Reduce Congestion	Financing Transport Infrastructures	Reduce Congestion	Reduce Congestion
Scheme Type	Cordon + peripheral gantries	Cordon	Zone	Cordon
Price Structure	Variable (as function of time, gantry location and vehicle type)	Constant (heavy vehicles pay the double)	Constant	Variable (as function of time)
Charging Period	Variable (as function of the gantry location)	24hours, 7days a week	From 7am to 6pm (workdays only)	From 6.30am to 6.30pm (workdays only)
Operating costs as a percentage of the gross revenue	15%	10%	30%	22%
Funds Application	Programmes for the benefit of all Singaporeans	Road and Public Transport Infrastructures	Priority to Bus Service Improvement	Road and Public Transport Infrastructures

(1) – Water spaces, so characteristic of the region, are included

This section focuses comparative terms such as similarities, differences and singular remarks concerning the four case studies.

The present Singaporean scheme is by far the closest to the economic theory of congestion. Price discrimination is high as toll rates vary by location of the gantries, by crossing time and by vehicle type. In Stockholm, time relation to demand management is used for a single cordon and in London there is not a real peak pricing policy as seen by the time constant toll value. Oslo is a particular case in this feature because calculations on the tax value were made in order to maximize income.

Each price-mechanism proves to be efficient in traffic volume reduction; this shows that demand is not price inelastic. Segments of drivers correct their travel behaviours and a new equilibrium is formed. Adjustments to the toll price as a result of these modifications were practiced along the years in Singapore and continue to be reviewed every three months. This remark enhances the importance of the assessment model on the pre-implementation study phase so as to the monitoring phase to facilitate an active intervention.

Another common characteristic is the raise in public acceptability in a post-implementation period. People seem to be oblivious of the advantages inside the policy, an important part maintain there negative view while some realise the benefits and change there opinion after a first period of adaptation.

Some schemes made the option of charging heavy vehicles double. This has a valid technical argument called vehicle equivalence factor in traffic engineering terminology where heavy vehicles create congestion on that proportion when compared to light vehicles.

The three phase Stockholm trial is an interesting case to compare two policies on reducing car dependency in today’s towns, a supply raise on public transports and a demand management to individual transport.

4

MODELLING CONSIDERATIONS

From a general description of transport models to the practical methodology used to evaluate the implementation of a road pricing scheme on the city of Porto, this chapter focuses on aspects related to modelling flows on road networks and how models can support the decision making.

4.1. General Description of the Transport Model

4.1.1. Transport Models

Models appeared in 1960s, but it was only later with the evolution of computers that they did become efficient and therefore credible. Another reason for their current success is the easiness today to access data, valid and in quantity, capable of being analysed.

There are several advantages to use models because they allow one to analyse with automatic tools the current situation and foresee, with the introduction of scenarios, the impact that certain measures can introduce on the system.

The classic four-stage model is behind the current macroscopic models. That conventional transport model included trip generation, trip distribution, modal choice and route choice.

General description of these concepts:

- Trip Generation: determines the number of trips from each zone;
- Trip Distribution: determines how the trips are allocated to other zones. The result is an Origin-Destination (OD) matrix;
- Modal Choice or Split: determines how OD flows are split between modes. This function depends on the availability of each mode, their respective costs, and preferences;
- Route Choice: determines how OD flows by each mode are distributed over the transport network(s). The Wardrop’s first principle is crucial for this stage considering that users want to minimize their travel time or, in a generalised cost approach, the travel cost (as exposed in 2.2.3). If the traffic exceeds the capacity of specific transport segments (which is often the case), congestion occurs and affects utility on each link. This in turn, through a feedback process, may influence trip generation and distribution.

“In the 1980s and 1990s further modelling developments emerged in response to the critics: dynamic methods and activity-based methods. Dynamic methods were developed in response to the ‘static’ nature of most preceding approaches.” [Kane and Behrens, 2002, pp. 3]

"Activity-based methods emerged in the late 1970s and early 1980s in response to the limited behavioural theory underpinning the conventional aggregate four-stage models. In activity-based approaches the observation of the trip is replaced by a detailed consideration of the activity which leads to the trip." [*idem*]

Nowadays, there are different categories of models at different scales (macroscopic, mesoscopic and microscopic). The model used for the city of Porto on this dissertation belongs to the group of macroscopic models. Emme 3 is a route choice model based on OD matrixes observed (data collected from surveys and traffic counts), suitable for urban transportation and modal choice studies.

4.1.2. THE MODEL OF PORTO

This section is based on a report on modelling the Porto Metropolitan Area provided by TRENMO on request.

The model used on this dissertation was developed with the aim of studying the intermodal transport system on the Porto Metropolitan Area, so that it would be possible to perceive its evolution and conflict so as to evaluate the efficiency on the transport network.

Developed with planning software and transport modelling 'Emme 3', the level of interactivity with the user not only allows a continuous supervision and adaptation to the real circumstances but also a simulation of future situations by the construction of different scenarios.

The statistic information was acquired almost in its totality to the 'Instituto Nacional de Estatística' (INE), Portuguese National Statistics Institute. Because statistic zones are different than the Emme 3 model recommended zones, mostly in dimension, there was a conversion which culminated on the constitution of 1334 zones (figure 4.1).

Figure 4.1 – Zones in the model [TRENMO, 2008, pp. 49]

This zoning presents a pressed mesh in the municipality of Porto, by increasing the dimension of the zones with the distance from the metropolitan centre.

Following the delimitation of the zones, the coordinates of the corresponding centroids were calculated. Afterwards, some corrections were made in order to avoid overlapping with the road network, given that these centroids represent the generation and attraction to their respective zones.

The next step on the construction of the model was the introduction of the transport network, which is composed by links and nodes (figure 4.2). Centroids are represented as nodes, although their connection to the network is made by a specific link called connector. This forms the link between the OD demand matrix and the transport network.

Figure 4.2 – Part of the Porto's Model Network

Once the road network was introduced and tested, the public transport service of the STCP and the private operators were loaded. This codification was performed by sequential information of the road network arcs (defined by the origin and destination nods) where the bus lines passed, as well as the bus stops.

The codification of the underground and train services completed the network.

After the settlement of the basic conditions, it is possible to run the model (allocate users by their choices). In short, there is an auto assignment for car users and a transit assignment for public transport users. The creation of a modal choice model to improve the simple auto and transit assignments is also feasible.

The algorithm implemented in Emme 3 to decide the problem of the equilibrium in auto assignment is the linear approach considered initially by Bruynooghe, Gibert and Sakarovitch (1968) and later developed by others.

In the centre of this algorithm is the user route choice as described above (4.1.1) on the four-stage modal, satisfying the Wardrop's first principle (see chapter 2 of this dissertation).

As a consequence of this approach, traffic flow appears on links that were calculated in a way that all the paths chosen for a pair OD have equal travel times or costs (this last case by applying a generalised cost approach).

The system is iterative, due to congestion the time on each link depends on traffic flow. This relationship is given by a volume-delay function (vdf) (conceptual equation 4.1). In each iteration flows are allocated on links and travel times are recalculated so that model users can reorganise their route choices. The solution to the equilibrium problem passes to minimise the area under the volume-delay curves. Thus, after some iterations the equilibrium is reached.

Volume-delay functions can express the utility of using a link. In Emme3, they represent the time to pass a link, so a negative utility and increasing function.

$$vdf = length \frac{60}{\max speed} \times \left(1 + A \times \left(\frac{flow}{capacity} \right)^{B} \right) \qquad (4.1)$$

A and B are link specific constants and have to be calibrated. This equation represents a simple congestion function that contains the free flow time (length divided by the maximum speed allowed on the link and multiplied by 60 to have a result in minutes) and the second member where time depends on the flow and link capacity.

The transit assignment and the modal choice model have their own fundaments, not relevant for the present dissertation (therefore, they will not be explained).

Data stored in matrixes is divided by time periods organised with similar demand characteristics. In the model of Porto there are four periods in a day: two peaks (morning peak from 7am to 9am and evening peak from 5pm to 8 pm); an intermediate period (from 9am to 5pm and from 8pm to 9pm) and the night (from 9pm to 1am).

It is possible to create different scenarios for each period, essential for testing road pricing as explained in section 4.2.

However, the model has its limitations. The demand is fixed at each period and intervals of time are too long to design an urban road pricing scheme well. Indeed, this is a macroscopic model so an extensive analysis is not permitted.

Furthermore, modal choice and route choice are the only alternatives for users. For a better road pricing assessment model, it would be desirable not only to model shorter periods of the day and to compute departure time choice, park & ride options, car sharing, but also other changes in travel behaviour.

Another restraining point to the model is that the generalised cost approach is made at a constant value of time, evidencing a non-segmentation of the demand by revenue.

4.2. PRACTICAL WAY OF MODELLING URBAN ROAD CONGESTION PRICING

The methodology used for implementing a road pricing system on the Porto's transport model has a very practical sense.

For each peak period, on the base scenario, name given to the scenario representative of the current situation, an attribute was included to evaluate congestion on each link, called congestion rate (equation 4.2). This attribute tries to show the congested links when looking at the entire network. The benefit of using this approach is to identify congested city zones faster.

$$Congestion \quad Rate \quad (\%) = \frac{Extra \quad Time}{Total \quad Time} \times 100 \qquad (4.2)$$

Congestion rate was defined by the proportion of extra time due to congestion in the total time spent on a link. This was derived from the volume-delay function, separating the free-flow time member from the extra time one.

In urban areas, the critical problems are not on the links, exception to singular bottlenecks, but on the nodes. However, an increase on demand for a node only causes congestion if the model uses a volume-delay function for nodes, which is not the case of this model.

Once a zone or different degrees of congested zones are defined road pricing is possible to be introduced in the model. It starts by adding a reference to the value of toll τ_a on each link. For the case of multiple zones the value of τ_a is equal for links within a given zone and takes the zero value for non tolled links.

The generalised cost approach is fundamental for the auto assignment. Therefore, and as explained in chapter 2, the generalised cost (equation 2.1) accommodates on the link fixed cost member, value τ_a.

The theory of road congestion pricing developed for single links suggests time and location varying charges equal to the marginal congestion cost at the efficient level of traffic (equation 4.3).

$$\tau_a = VOT \times t'_a(x_a) \times x_a \qquad (4.3)$$

Where x_a is the flow on link a and t_a is the time spent on the link as a function of the flow, also known as volume-delay function.

Indeed, on networks there are different ways to manage this. One is described in chapter 2 as a simple model of analysis. Another and closer to a sensitivity analysis consists in trying to achieve the main goals of the ERP in Singapore (average speed ranging between 20 and 30 kph on arterial roads and between 45 and 65 kph on expressways).

In the absence of a defined zone and in the perspective of an optimal approach, the objective is to reallocate the flows on the links passing those from the natural equilibrium to a social optimum equilibrium, achieving the Wardrop's second principle or, if possible to model, the Wardrop's third principle suggested by D.J. Holden (1989) which includes congestion impacts on the different transport modes. Note that this reallocation of the flow, as the name indicates, is a valid approach to deal with route choice. However, and as said above, route choice is not the only option for drivers, so the value of the toll may not be a simple result of the evaluation of the spatial effects.

This complexity plus social and technological constrains to the implementation of the system, such as exemptions/discounts for residents or the place of high gantries, inhibit the search for the optimal toll and justify the use of simulation.

In this perspective, Akiyama et al (2004) describe a useful framework to achieve second-best pricing policies related to the maximization of the social surplus on cordon or multi-cordon toll schemes.

The general simulation procedure with an Emme 3 model continues with the creation of different scenarios. They may represent different zones charged or multiple zones at different levels of pricing. The evaluation of the new assigned networks can be based on their respective congested links by observing their respective congestion rates.

Other characteristics may enter the evaluation of each scenario, such as car usage, modal share, average time per trip, average cost per trip, toll revenue, equity, total vehicle kilometre travelled, average distance per auto trip, user benefits, external cost reduction, welfare gain, etc..

With this variety of scenarios the one to be selected as “the scheme” has to be well justified because each city has its own problems and priorities.

5

THE CASE OF PORTO

General data analysis and results from the Porto's transport model are reviewed in this chapter. A reflection to a possible introduction of road congestion charging for the city of Porto is also developed.

5.1. GENERAL DESCRIPTION

5.1.1. THE GREATER METROPOLITAN AREA OF PORTO

The Greater Metropolitan Area of Porto (GMAP) constitutes an area of 1.575 km^2 with a population of 1.570.800 inhabitants, where about half of the wealth created in the Northern Region of Portugal is centred. There are approximately 487 000 working posts presently. (AMP website)

This area is the agglomeration of fourteen municipalities: Espinho, Gondomar, Maia, Matosinhos, Porto, Póvoa de Varzim, Valongo, Vila do Conde and Vila Nova de Gaia, plus recently joined Arouca, Santa Maria da Feira, S. João da Madeira, Trofa and Santo Tirso.

The traffic flow dynamic is influenced by the spatial distribution of land use. The municipalities of Porto, Maia and Matosinhos are the heart of working posts while other municipalities are mainly residential. For the morning peak and because rush-hours are conditioned by home to work trips, this land function difference causes convergent flows to the working areas and hence some arterial roads became congested.

5.1.2. TRANSPORT NETWORK IN GMAP

In what concerns the road and rail networks, Porto and its Metropolitan Region have been facing great development in the past forty years.

In the 60s and 70s, main railways and roads revealed the radial demand matrix and the passage over Douro River was made by two road bridges (Arrábida and Luís I) and a railway bridge (Maria Pia). (Cardoso and Silva, 1997)

Technical characteristics and the capacity of the road network were not appropriate for the auto demand at the time. With various road intersections, these infrastructures had been transforming into true urban streets. However, it was possible to identify some axles of high capacity that, still today, are part of the basic net (auto-estrada do Norte, Via Rápida, Via Norte and Circunvalação). (*idem*)

Opposing this trend a ring road, named Via de Cintura Interna (VCI or IC23), was built and expected to solve the congestion problems.

Antão de Almeida Garrett, with his “Plano Geral de Urbanização de Cidade do Porto” (1947), was the first to propose a road around the city centres of Porto and Vila Nova de Gaia. Curiously, this document appears sixteen years before the revolutionary Buchanan Report.

Even if it has been a valid idea to remove cars from the inner cities (Porto and Gaia zones inside VCI) the first kilometres were built only in June 1963 between Coimbrões and Francos with the construction of the Arrábida Bridge, finally being concluded in January 2007 with the tunnel crossing the Républica Avenue at João de Deus (Gaia). (Azeredo and Azeredo, 2002 and IOL Diário online)

Today the GMAP contains other peripheral non-radial highways such as A41 and A4 at north, and the extension of the A29 to IP1 in the south. On the National Road Plan (PNR 2000), another ring road, exterior to VCI, named IC24 is also projected, but yet to be constructed.

This development clearly expresses the philosophy of an engineer, to increase flow capacity, leading to a higher car dependency in the region. Indeed, in spite of solving congestion problems, they are only postponing it. If in a first period an improvement on driving conditions is verified, a new induced demand is also verified. This effect brought later an increase on the average travel time on the GMAP and obviously less free space to build new road facilities or capacity expansion.

Figure 5.1 shows the major roads in GMAP.

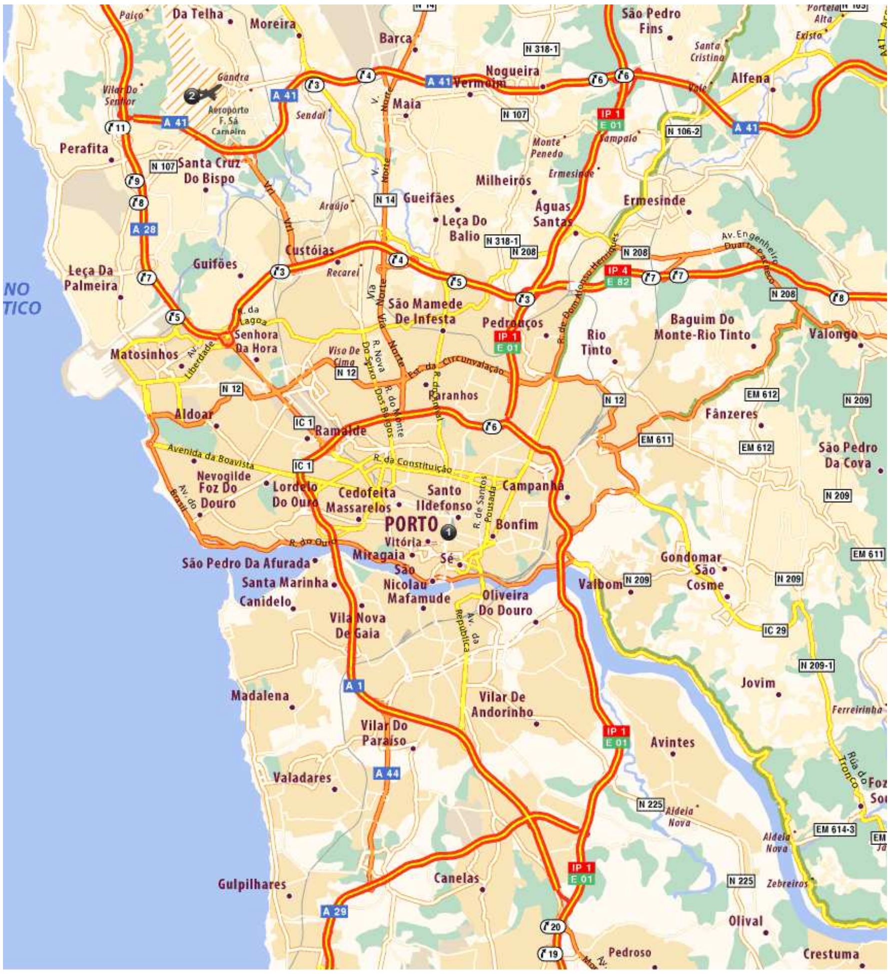

Figure 5.1 – Road Network in GMAP (via Michelin)

In what concerns bus service, it can roughly be said that the Sociedade de Transporte Colectivos do Porto, S.A (STCP), entirely public funded, has the inner city monopoly while the outer city services are assured by about twenty private transport companies.

The railway service is provided by Caminhos de Ferro Portugueses (CP), with a set of suburban and regional trains, but never reaching a significant modal share. (Cardoso, N. and Silva, P., 1997)

Since the beginning of the twentieth century, the main infrastructure projects were the new Campanhã train station and the S. João Bridge substituting the old Maria Pia Bridge.

More recently a revolutionary project to all GMAP was launched. The underground/tramway network, named Metro do Porto is operating since January 2003 and covers the main branches in terms of transport demand and yet allows the articulation of the main public transport interfaces.

5.1.3. Travel Patterns in GMAP (Related to the Subject)

The Portuguese National Statistics Institute (INE) launched a survey on travel patterns called ‘Inquérito à Mobilidade da População Residente – 2000’ (INE, 2000). This document was made in the northern region of Portugal and concluded that the individual transportation represented 50% of the trips with origin and/or destination in Porto, or 61% if only analysed trips using motorized vehicles. This value, which means about 580 thousand trips per day, expresses the importance of this mode.

Furthermore, the vehicle occupancy in individual transport seems to be weak as more than 70% of the cars only have the driver inside. In this perspective, car sharing is one of the behaviours that users could have when a road pricing scheme enters in operation. However, modelling this behaviour is not in the program of this dissertation.

Continuing with travel pattern analysis from the survey, the main trip motivation is home to work trips on workdays and leisure on weekends. On workdays, the daily variance of the trips taken is considered to have three peaks. The conventional morning, midday and evening peaks. Not that due to the loss in the habit of having lunch at home, for the GMAP the midday peak does not have a real significance, as expressed in the survey.

Another relevant and more up-to-date report in analysing individual transport travel patterns in the city of Porto is commissioned by the Municipality of Porto, called ‘Mobilidade na Cidade do Porto: Análise das deslocações em transporte individual’ (2007). It uses data from a new survey and estimates a new OD matrix for the morning peak in GMAP, related to an average day in 2005.

The analysis of that OD matrix reflects that the Municipality of Porto is a significant attraction zone for morning trips (from 7h30 to 9h30). On workdays, for the 130.000 estimated trips, the proportion of movement within the city as origin and destination outside the city centre is up to 32,7% (42.523 trips), clearly higher than the exits from the city of about 9,7% (12.621). It also reveals that the proportions of internal and passing through movements are respectively, 29,2% (37.991) and 28,4 % (36.884), as described in the following figures. (Gomes et al, 2007)

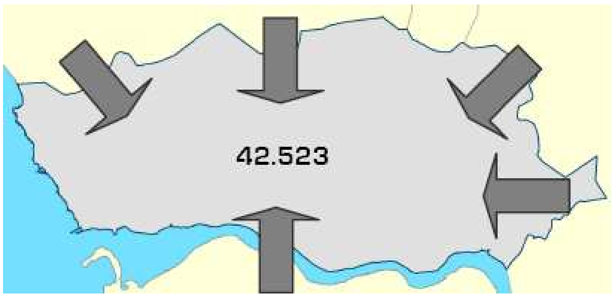

Figure 5.2 – Morning entries (Gomes et al, 2007)

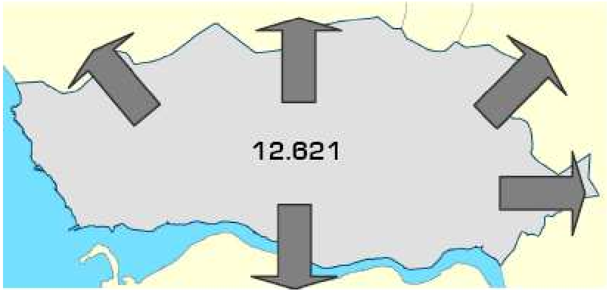

Figure 5.3 – Morning exits (Gomes et al, 2007)

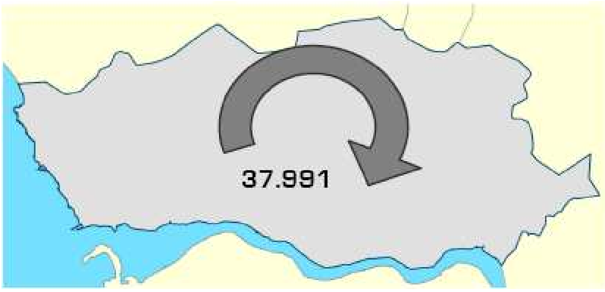

Figure 5.4 – Morning exclusively internal movements (Gomes et al, 2007)

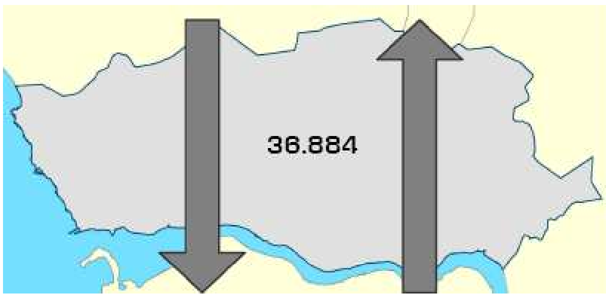

Figure 5.5 – Morning passing through movements (Gomes et al, 2007)

The above stated 'effect of attraction zone' is well shown in these four figures and is basically related to the great economic centre that this zone forms. This data analysis just confirms the previous conclusions of the 'Inquérito à Mobilidade da População Residente – 2000' (INE, 2000).

The inclusion of major public institutions, such as universities and hospitals, in this area, equally contributes to this situation.

Passing through movements are obliged to drive on the VCI. There are six main entries connecting this ring road to the outer city (AIP Avenue, Via Norte, A3/A4, IC29, Arrábida Bridge and Freixo Bridge). Figure 5.6 shows the inbound and outbound flow on these links for the entire morning peak, two hours.

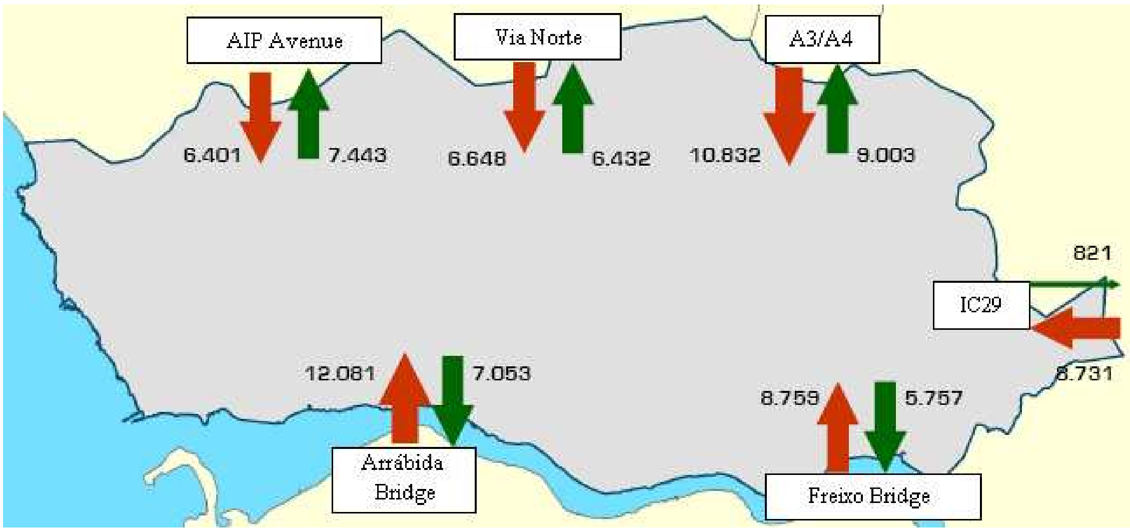

Figure 5.6 – Morning flows on six major entry links (Gomes et al, 2007)

In conclusion, the ‘Mobilidade na Cidade do Porto: Análise das deslocações em transporte individual’ (2007) report states that:

- “The Inner city of Porto, whose road network has a total length of 328 km, receives more than 57.000 motor vehicles between 7h30 and 9h30, related to entrance and interior flows. This represents 147 vehicles per kilometre, while the outer zone (between VCI and the municipality limit) receives 23.000 vehicles for a road network of about 347 km of length, which means 67 vehicles per kilometre;
- These values show the pressure that cars have in the inner city leading to an average speed lower than in the outer zone;
- On the other hand, this volume attraction zone needs an extra parking area, destined for the central zone on 63ha, in this case it would be possible to offer park facilities to satisfy all demand. It is also mentioned that according to a study of car parking characterization in the city of the Porto (CMP/FEUP, 2005), the offer in a zone whose limits are similar to the inner city of the report is 57.865 places, corresponding to an area close to the estimated (63,6 hectares). Taking in account the fact that a considerable portion of places in the public way is occupied before the morning period, this value reflects difficulties to find a free space to park the car.” [Gomes et al, 2007, pp. 13-14]

This report also affirms that there are smaller and specific zones with a high rate of movements. It is the case of the historical centre (‘Baixa do Porto’), the zone close to the Boavista Roundabout and the Boavista Avenue and the University campus in Asprela. (*idem*)

5.2. CONGESTION PRICING IN PORTO

A minority report about the base scenario elaborated by the multimodal transport model will be presented next.

This base scenario was evaluated by using the methodology described in chapter 4, section 4.2 of this dissertation. In order to analyse congestion, two levels of congestion rate were defined, 50% and 80%. For example, if we consider the volume-delay function of the VCI (figure 5.7), the 50% congestion rate level is equivalent to 45kph, which is an acceptable value for speed, while the 80% level has a flow speed of 18kph, meaning hypercongestion.

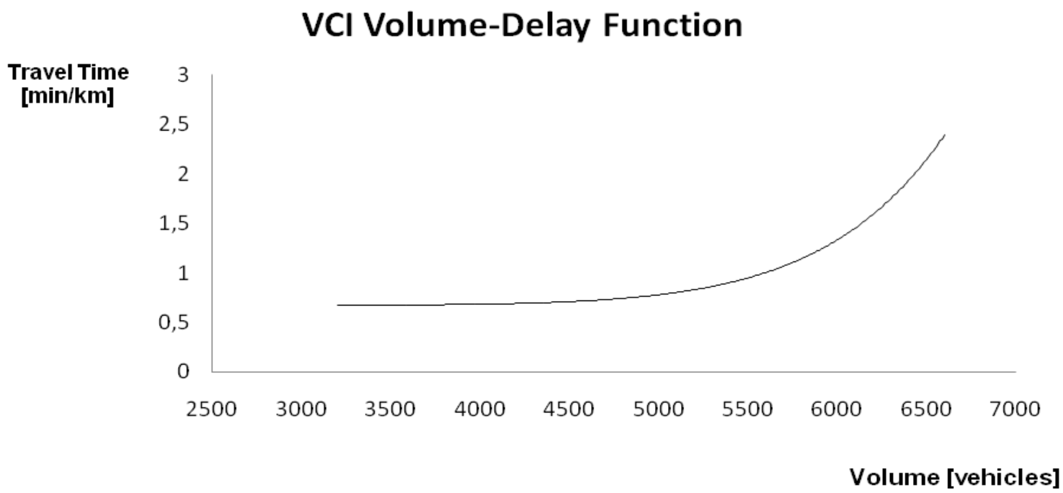

Figure 5.7 – VCI Volume-Delay Function

For obvious reasons, the morning (from 7am to 9am) and evening (from 5pm to 8pm) peaks were the only periods to be analysed. Note that at the time the model was tested, the average oil price was 1.29€/l, somewhat below the present price.

The following figures 5.8, 5.9, 5.10, 5.11, show the spatial distribution of the congested links on the referred periods and by congestion levels.

Figure 5.8 – Morning Peak, red links at congestion rate more than 50%

Figure 5.9 – Morning Peak, red links at congestion rate more than 80% (severe congestion)

Figure 5.10 – Evening Peak, red links at congestion rate more than 50%

Figure 5.11 – Evening Peak, red links at congestion rate more than 80% (severe congestion)

The model shows that the amount of links with severe congestion is negligible to be the cause for the implementation of a congestion charging scheme.

Those peak periods have a fixed demand equivalent to an average hour. In reality congestion problems only exist in short periods of time (of about 30 minutes) and on some located bottlenecks (for instance Arrábida Bridge or AIP Avenue) or specific zones (Boavista Roundabout, University campus of Asprela or Campo Alegre).

Exceptions to this are rainy days, road accidents, public transport strikes, riots, not to mention other singular events.

In this *status quo* the collection of toll revenue would hardly create profits to cover the investment and the operational costs. Furthermore, if any net revenue exists, its application on the desired development of the public transport service wouldn't have enough visibility to provide a public acceptance of the policy.

Traffic congestion in the city of Porto was growing at a high rate and was producing economic and environmental problems. Quoting the report on the underground impacts 'O crescimento nesta década (1990-2000) terá sido o maior de sempre, já que se assistiu a uma duplicação dos utilizadores de automóvel a nível metropolitano' the growth in this decade (1990-2000) was the greatest ever, since the metropolitan area attended a duplication of automobile users. [Metro do Porto, 2008b, pp. 24]

On the absence of bus lanes, car traffic also causes congestion to buses. This discourages people to use this public transport mode leading to a reduction of operation efficiency, generating an increase on car usage; a "snow ball" effect.

However, the congestion problem in recent years has been clogged. This decrease in congestion occurred on the one hand by the proliferation of the underground/tramway network and on the other hand by the boom in oil prices (which severely raised the generalised cost of the car mode).

Comparing the reality before and after the implementation of the Porto's underground network, this way of transport attracted passengers from other modes, namely car and bus. From the underground users, 23, 6% used car and 45, 9% used STCP buses before. (Metro do Porto, 2008a, pp. 43)

This means a real tackle in congestion. A reduction in 11.130 automobiles was achieved since the launching of the underground service. Notice that this reduction concerns all GMAP. The car vehicle occupancy showed a slight increase from 1, 48 to 1, 58 occupants which shows that the number of users who drive alone or with few passengers saw the underground as an opportunity to lower their travel costs. (Metro do Porto, 2008c, pp. 104)

The other great impact on auto demand is the well-known increase in oil prices (figure 5.12) because of the USA intervention on Iraq. This calculates a price on the distance travelled that certainly surpasses the congestion charge applicable to the city of Porto in the previous congested years.

Even if the cut off on peak demand is achieved, this does not have the same result of a congestion charging scheme because it does neither intends to be a demand management policy nor tries to charge drivers for their congestion external cost. Moreover, the individual equilibrium persists.

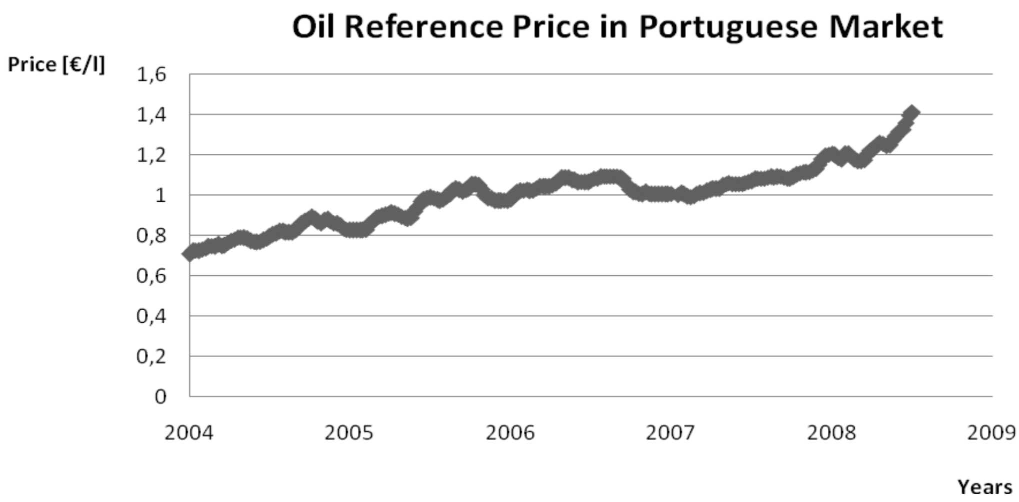

Figure 5.12 – Oil Price Tendency in Portuguese Market 2004-2008 (DGEG, 2008)

In conclusion, at the present moment the option to introduce a road congestion charging scheme in Porto has to be excluded.

6

CONCLUSIONS

This dissertation started with the economic analysis of the road congestion problem enclosing some developed theories in this scientific field.

These theories permitted a later reflection in the case of Porto.

Four congestion charging schemes were also studied, comparing their methods, results and public acceptability. They present some similarities, differences and singular remarks.

First of all, the present Singaporean scheme is by far the closest to the economic theory of congestion. Price discrimination is high as toll rates vary by the location of gantries, crossing time and vehicle type. In Stockholm time relation to demand management is used for a single cordon and in London there is no peak pricing policy as seen by the constant value of the toll. Oslo is a particular case in this feature for the reason that calculations on the tax value are made in order to maximise income.

Each price-mechanism proved to be efficient in controlling traffic volume tendency to rise, which shows that demand is not price inelastic. Segments of drivers correct their travel behaviours so a new equilibrium is formed. Adjustments to the toll price as a result of these modifications were practiced throughout the years in Singapore and continue to be reviewed every three months. This remark enhances the importance of the assessment model on the pre-implementation study phase so as to the monitoring phase to facilitate an active intervention.

Another common characteristic is the increase in public acceptability in a post-implementation period. People seem to be oblivious of the advantages inside the policy, an important part to maintain their negative view while some realise the benefits and change there opinion after a first period of adaptation.

A relevant point interiorised during the research for this dissertation is that the application of a road pricing scheme may always be attached to an improvement in public transport service.

Some schemes made the option of charging heavy vehicles double. This has a valid technical argument called vehicle equivalence factor in traffic engineering terminology where heavy vehicles create congestion on that proportion when compared to light vehicles.

Another interesting policy is the Three Phases Stockholm Trial where two measures for the reduction of car dependency in nowadays towns can be compared: a supply raise on public transport and a demand management to individual transport.

The analysis of these cases provided an overview in why and how they came about, and a reflection on the economic theories concerning the city of Porto.

In relation to the multimodal transport model used for the Metropolitan Area of Porto, the actual situation of congestion on the road network was examined and the model showed that the amount of links with severe congestion is negligible to be the cause for the implementation of a congestion charging scheme.

In reality congestion problems only exist in short periods of time (of about 30 minutes) and on some located bottlenecks (for instance Arrábida Bridge or AIP Avenue) or specific zones (Boavista Roundabout, University campus of Asprela or Campo Alegre).

Exceptions to this are rainy days, road accidents, public transport strikes, riots, not to mention other singular events.

So, in this *status quo* the collection of toll revenue would hardly create profits to cover the investment and the operational costs. Furthermore, if any net revenue exists, its application on the desired development of public transport service wouldn't have enough visibility to provide a public acceptance of the policy.

Traffic congestion in the city of Porto was growing at a high rate and was producing economic and environmental problems. Considering this problem, public investment was directed to the expansion of the road network and, recently, to accomplish one of the great dreams of the people of Porto, the underground network. This transport facility has been efficient and unique in the battle against road congestion problems, leading to better and more comfortable mobility, especially in the city centre.

On the other hand the continuous growing of oil prices cannot be ignored. This fact encourages people to use public transport and is also favourable for public transport investment, since Portugal is still one of the most oil dependent countries in EU. Even in London, this phenomenon made the new Mayor question the continuity of the 2003 implemented congestion charging scheme.

The demand transfer from individual to collective transports is the main step to solving road congestion problems. The case of Porto particularly expresses this idea. If, on the one hand that transfer was made due to a better offer in public transport (higher capacity and better quality of service), car usage was particularly controlled by the raise of fuel costs on the other hand.

In conclusion, the sum of these two effects, as well as the data analysed, exclude the introduction of a congestion charging scheme for the city of Porto.

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ANNEXES

A1 – ERP RATES IN SINGAPORE, APRIL 2008 (LTA)

(on the last two pages)

A2 – LONDON DISCOUNTS AND EXEMPTIONS [G. SANTOS, 2005, PP. 515]

Discount/status	Category
Fully exempt	Motorcycles, mopeds and bicycles Emergency vehicles Public service vehicles with nine or more seats licensed as buses Vehicles used by disabled persons that are exempt from vehicle excise duty Licensed London taxis and mini-cabs
100% discount with free registration	Certain military vehicles Local government service vehicles (e.g. refuse trucks, street maintenance) Vehicles with nine or more seats not licensed as buses (e.g. community minibuses)
100% discount with a one-off £10 registration	Vehicles driven for or by individuals or institutions that are Blue Badge holders
100% discount with £10 registration per year	Alternative fuel vehicles: requires emission savings 40% above Euro IV standards Roadside assistance and recovery vehicles (e.g. motoring organizations such as the Automobile Association)
90% discount with £10 registration per year	Vehicles registered to residents of the central zone

ERP RATE TABLE FOR PASSENGER CARS, TAXIS AND LIGHT GOODS VEHICLES (With Effect From 4 Feb 08 to 4 May 08)

	Arterial Roads				Expressways													Orchard Cordon and Rest of CBD								
	Weekdays																						Saturdays			
Monday to Friday	Bendemeer Road southbound after Woodsville Interchange	Kallang Road westbound after Kallang River	Thomson Road southbound after Toa Payoh Rise	Dunearn Road eastbound after Dunkirk Avenue	AYE between Portsdown Road and Alexandra Road	BKE between Dairy Farm Road and PIE	CTE after Braddell Road, Serangoon Road and Balestier slip Road	CTE between Ang Mo Kio Ave 1 and Braddell Road	ECP after Tanjong Rhu Flyover	ECP from Ophir Road	KPE slip road into westbound ECP	PIE after Kallang Bahru exit	PIE eastbound after Adam Road and Mount Pleasant slip road into the eastbound PIE	PIE slip road into CTE	CTE Northbound between Jalan Bahagia and PIE	**CTE Northbound between PIE and Braddell Rd**	ECP Eastbound before exit to Rochor Road, entrance from Ophir Road	Restricted Zone (Nicoll Highway)	Rest of CBD (19 Gantries)	Orchard (9 Gantries)	YMCA Gantry and Fort Canning Tunnel Gantry	Handy Road Gantry	Rest of CBD (20 Gantries)	Orchard (9 Gantries)	YMCA Gantry and Fort Canning Tunnel Gantry	Handy Road Gantry
7.00am - 7.05am	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.50	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00				$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
7.05am - 7.25am	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00				$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
7.25am - 7.30am	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00				$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
7.30am - 7.35am	$0.50	$0.00	$0.50	$0.00	$0.00	$0.50	$0.80	$1.80	$0.80	$0.00	$0.80	$0.50	$0.50	$1.80				$0.50	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
7.35am - 7.55am	$0.50	$0.00	$0.50	$0.00	$0.00	$1.00	$1.50	$2.50	$1.50	$0.00	$1.50	$0.50	$0.50	$3.50				$0.50	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
7.55am - 8.00am	$0.50	$0.00	$0.50	$0.00	$0.00	$1.00	$1.50	$2.50	$1.50	$0.00	$1.50	$0.50	$0.50	$3.50				$0.50	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
8.00am - 8.05am	$0.50	$0.00	$1.00	$0.50	$0.50	$1.50	$2.00	$2.50	$2.00	$0.50	$2.00	$1.00	$1.00	$3.50				$1.50	$1.00	$0.00	$0.00	$1.00	$0.00	$0.00	$0.00	$0.00
8.05am - 8.25am	$0.50	$0.00	$1.50	$0.50	$0.50	$1.50	$2.00	$2.50	$2.50	$0.50	$2.50	$1.00	$1.00	$3.50				$2.50	$2.00	$0.00	$0.00	$2.00	$0.00	$0.00	$0.00	$0.00
8.25am - 8.30am	$0.50	$0.00	$1.50	$0.50	$0.50	$1.50	$2.00	$2.50	$2.50	$0.50	$2.50	$1.00	$1.00	$3.50				$2.50	$2.00	$0.00	$0.00	$2.00	$0.00	$0.00	$0.00	$0.00
8.30am - 8.35am	$1.00	$0.50	$2.00	$1.00	$1.00	$1.00	$3.00	$2.50	$2.50	$0.50	$2.50	$1.50	$1.50	$4.30				$2.50	$2.50	$0.00	$0.00	$2.50	$0.00	$0.00	$0.00	$0.00
8.35am - 8.55am	$1.50	$0.50	$2.00	$1.00	$1.50	$1.00	$4.00	$2.50	$2.50	$0.50	$2.50	$1.50	$1.50	$5.00				$2.50	$2.50	$0.00	$0.00	$2.50	$0.00	$0.00	$0.00	$0.00
8.55am - 9.00am	$1.00	$0.50	$1.30	$0.50	$1.00	$0.50	$2.50	$1.50	$1.80	$0.50	$1.80	$1.00	$0.80	$3.00				$2.50	$2.50	$0.00	$0.00	$2.50	$0.00	$0.00	$0.00	$0.00
9.00am - 9.05am	$0.50	$0.50	$0.50	$0.00	$0.50	$0.00	$1.00	$0.50	$1.00	$0.00	$1.00	$0.50	$0.00	$1.00				$2.00	$2.00	$0.00	$0.00	$2.00	$0.00	$0.00	$0.00	$0.00
9.05am - 9.25am	$0.50	$0.50	$0.50	$0.00	$0.50	$0.00	$1.00	$0.50	$1.00	$0.00	$1.00	$0.50	$0.00	$1.00				$2.00	$2.00	$0.00	$0.00	$2.00	$0.00	$0.00	$0.00	$0.00
9.25am - 9.30am	$0.50	$0.50	$0.50	$0.00	$0.50	$0.00	$0.50	$0.50	$0.50	$0.00	$0.50	$0.50	$0.00	$0.50				$1.50	$1.50	$0.00	$0.00	$1.50	$0.00	$0.00	$0.00	$0.00
9.30am - 9.35am								$0.50										$1.00	$1.00	$0.00	$0.00	$1.00	$0.00	$0.00	$0.00	$0.00
9.35am - 9.55am								$0.50										$1.00	$1.00	$0.00	$0.00	$1.00	$0.00	$0.00	$0.00	$0.00
9.55am - 10.00am								$0.50										$0.50	$0.50	$0.00	$0.00	$0.50	$0.00	$0.00	$0.00	$0.00
10.00am - 10.05am								$0.50										$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
10.05am - 10.25am								$0.50										$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
10.25am - 10.30am								$0.50										$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
10.30am - 10.35am								$0.50										$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
10.35am - 10.55am								$0.50										$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
10.55am - 11.00am								$0.50										$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
11.00am - 11.05am																		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
11.05am - 11.25am																		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
11.25am - 11.30am																		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
11.30am - 11.35am																		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
11.35am - 11.55am																		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
11.55am - 12.00pm																		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
12.00pm -12.05pm																		$0.50	$0.50	$0.50	$0.50	$0.50	$0.00	$0.50	$0.50	$0.50
12.05pm - 12.25pm																		$0.50	$0.50	$0.50	$0.50	$0.50	$0.00	$0.50	$0.50	$0.50
12.25pm - 12.30pm																		$0.50	$0.50	$0.50	$0.50	$0.50	$0.00	$0.50	$0.50	$0.50
12.30pm - 12.35pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
12.35pm - 12.55pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
12.55pm - 1.00pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
1.00pm - 1.05pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
1.05pm - 1.25pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
1.25pm - 1.30pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
1.30pm - 1.35pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
1.35pm - 1.55pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
1.55pm - 2.00pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
2.00pm - 2.05pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
2.05pm - 2.25pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
2.25pm - 2.30pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
2.30pm - 2.35pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
2.35pm - 2.55pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
2.55pm - 3.00pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
3.00pm - 3.05pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
3.05pm - 3.25pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
3.25pm - 3.30pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
3.30pm - 3.35pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
3.35pm - 3.55pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
3.55pm - 4.00pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
4.00pm - 4.05pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
4.05pm - 4.25pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
4.25pm - 4.30pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
4.30pm - 4.35pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
4.35pm - 4.55pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
4.55pm - 5.00pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
5.00pm - 5.05pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
5.05pm - 5.25pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
5.25pm - 5.30pm																		$1.00	$1.00	$0.50	$0.50	$1.00	$0.00	$0.50	$0.50	$0.50
5.30pm - 5.35pm															$0.50			$1.50	$1.50	$1.00	$0.50	$0.50	$0.00	$1.00	$1.00	$0.50
5.35pm - 5.55pm															$0.50			$1.50	$1.50	$1.50	$0.50	$0.50	$0.00	$1.00	$1.00	$0.50

ERP RATE TABLE FOR PASSENGER CARS, TAXIS AND LIGHT GOODS VEHICLES (With Effect From 4 Feb 08 to 4 May 08)

	Arterial Roads				Expressways													Orchard Cordon and Rest of CBD								
	Weekdays																						Saturdays			
Monday to Friday	Bendemeer Road southbound after Woodsville Interchange	Kallang Road westbound after Kallang River	Thomson Road southbound after Toa Payoh Rise	Dunearn Road eastbound after Dunkirk Avenue	AYE between Portsdown Road and Alexandra Road	BKE between Dairy Farm Road and PIE	CTE after Braddell Road, Serangoon Road and Balestier slip Road	CTE between Ang Mo Kio Ave 1 and Braddell Road	ECP after Tanjong Rhu Flyover	ECP from Ophir Road	KPE slip road into westbound ECP	PIE after Kallang Bahru exit	PIE eastbound after Adam Road and Mount Pleasant slip road into the eastbound PIE	PIE slip road into CTE	CTE Northbound between Jalan Bahagia and PIE	**CTE Northbound between PIE and Braddell Rd**	ECP Eastbound before exit to Rochor Road, entrance from Ophir Road	Restricted Zone (Nicoll Highway)	Rest of CBD (19 Gantries)	Orchard (9 Gantries)	YMCA Gantry and Fort Canning Tunnel Gantry	Handy Road Gantry	Rest of CBD (20 Gantries)	Orchard (9 Gantries)	YMCA Gantry and Fort Canning Tunnel Gantry	Handy Road Gantry
5.55pm - 6.00pm															**$0.50**			**$1.50**	**$1.50**	**$1.50**	**$0.50**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
6.00pm - 6.05pm															**$1.00**	**$0.50**	**$0.50**	**$2.00**	**$2.00**	**$2.00**	**$0.50**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
6.05pm - 6.25pm															**$1.00**	**$0.50**	**$0.50**	**$2.00**	**$2.00**	**$2.00**	**$0.50**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
6.25pm - 6.30pm															**$1.00**	**$0.50**	**$0.50**	**$1.50**	**$1.50**	**$1.50**	**$0.50**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
6.30pm - 6.35pm															**$1.00**	**$1.00**	**$1.00**	**$1.00**	**$1.00**	**$1.00**	**$0.50**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
6.35pm - 6.55pm															**$1.00**	**$1.50**	**$1.00**	**$1.00**	**$1.00**	**$1.00**	**$0.50**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
6.55pm - 7.00pm															**$1.00**	**$1.50**	**$1.00**	**$0.50**	**$0.50**	**$1.00**	**$0.50**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
7.00pm - 7.05pm															**$1.00**	**$1.50**	**$1.00**	**$0.00**	**$0.00**	**$1.00**	**$1.00**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
7.05pm - 7.25pm															**$1.00**	**$1.50**	**$1.00**	**$0.00**	**$0.00**	**$1.00**	**$1.00**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
7.25pm - 7.30pm															**$1.00**	**$1.00**	**$1.00**	**$0.00**	**$0.00**	**$1.00**	**$1.00**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
7.30pm - 7.35pm															**$1.00**	**$0.50**	**$0.50**	**$0.00**	**$0.00**	**$1.00**	**$1.00**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
7.35pm - 7.55pm															**$1.00**	**$0.50**	**$0.50**	**$0.00**	**$0.00**	**$1.00**	**$1.00**	**$0.50**	**$0.00**	**$1.00**	**$1.00**	**$0.50**
7.55pm - 8.00pm															**$1.00**	**$0.50**	**$0.50**	**$0.00**	**$0.00**	**$0.50**	**$0.50**	**$0.50**	**$0.00**	**$0.50**	**$0.50**	**$0.50**
8.00pm - 8.05pm															**$1.00**											
8.05pm - 8.25pm															**$1.00**											
8.25pm - 8.30pm															**$1.00**											
8.30pm - 8.35pm															**$1.00**											
8.35pm - 8.55pm															**$1.00**											
8.55pm - 9.00pm															**$1.00**											
9.00pm - 9.05pm															**$1.00**											
9.05pm - 9.25pm															**$1.00**											
9.25pm - 9.30pm															**$1.00**											
9.30pm - 9.35pm															**$1.00**											
9.35pm - 9.55pm															**$1.00**											
9.55pm - 10.00pm															**$1.00**											
10.00pm - 10.05pm															**$0.50**											
10.05pm - 10.25pm															**$0.50**											
10.25pm - 10.30pm															**$0.50**											

Note: Graduated Rate