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MOBILITY AND ROAD PRICING SYSTEM – THE CASE OF PORTO

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To mom

"And I knew exactly what to do. But in a much more real sense, I had no idea what to do."
Michael Scott (The Office)

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ABSTRACT

The purpose of this thesis is to analyse the mobility in the metropolitan area of Porto, and how it was affected by the implementation of road pricing. This thesis studies the theory of traffic congestion and also compares the situation in Porto to successful cases, such as Singapore, Stockholm and London. Later, a CBA analysis is done on the road pricing model in the metropolitan area of Porto. Congestion charging is used to optimize the level of congestion by making travelers pay for the increased congestion they are responsible for when entering a congested road. Thus, road pricing tries to balance the demand for transport use with the full costs of use, including the costs on other transport users. Road pricing also aims to raise revenue to invest in other modes of transport, such as public transportation. Singapore, Stockholm, Oslo and London have had success establishing road pricing schemes around their city centres. These cities overcame technological, practical, legal, institutional and acceptability-related barriers when implementing the schemes. Singapore was the pioneer of road pricing. Other cities followed after. Stockholm opted to do a referendum after a trial period, which had positive results. Edinburgh did a referendum before any trial and the result was negative, therefore the City did not implement the scheme. In Portugal, one of the ways to finance motorways, is through public-private partnerships (PPP). This model spreads the cost of the operations throughout time and makes it easier for the government to afford such costly investments. On the other hand, PPP become a disadvantage when the projects are developed regardless of its economical worth. The outcome of the PPP in Portugal was the SCUT ("No Cost to the User" roads). The government used to pay an annual "rent" based on the volume of traffic on the roads. The money for the payments came from the tax payers, even those who do not utilized the concession roads. The SCUT model became the ex-SCUT model after renegotiations. Now, the users of the roads pay for using the roads. The charging tolls brought economic, social and environmental losses from the decrease of utilization of the ex-SCUT. In Porto, mobility analyses showed that the drivers opt to drive longer distances in the secondary roads to pay less tolls. Therefore, the secondary roads present excessive congestion, and the primary roads are underused. The CBA analysis showed that the net present value of the road pricing scheme in Porto is negative, which means the scheme was not beneficial to society. It is needed to relocate the traffic from the secondary roads to the primary and underused roads. It is not logical or economically efficient to charge the same amount both on uncongested roads and congested roads. Therefore, it is necessary to rethink the locations and amount charged of the tolls. Moreover, changes in the road pricing model with huge investments in public transportation and other modes of transport, such as bicycles, would be greatly beneficial for the mobility of the city of Porto.

KEYWORDS: mobility, road pricing, congestion charging, cost-benefit analysis, Porto.

RESUMO

O objetivo desta dissertação é analisar a mobilidade na área metropolitana do Porto, e como ela foi afetada pela implementação de portagens. Esta tese estuda a teoria do congestionamento do tráfego e também compara a situação no Porto aos casos de sucesso, como Singapura, Estocolmo e Londres. Posteriormente, é feita uma análise custo-benefício do modelo de portagem da área metropolitana do Porto. Taxas de congestionamento são usadas para otimizar os níveis de congestionamento, fazendo os motoristas pagar pelo aumento de engarrafamento que eles são responsáveis quando entram em uma estrada congestionada. Assim, portagens tentam equilibrar a demanda pelo uso do transporte com os custos totais de uso, incluindo os custos de outros usuários do transporte. As portagens também visam aumentar a receita para investir em outros meios de transporte, como o transporte público. Singapura, Estocolmo, Oslo e Londres tiveram sucesso estabelecendo esquemas de portagens em torno de seus centros urbanos. Essas cidades superaram as barreiras tecnológicas, práticas, legais, institucionais e de aceitabilidade ao implementar os esquemas. Singapura foi a primeira a implementar portagens. Outras cidades fizeram o mesmo depois. Estocolmo optou por fazer um referendo após um período de teste, que teve resultados positivos. Edimburgo fez um referendo antes de qualquer teste e o resultado foi negativo, portanto a cidade não implementou o esquema de portagens. Em Portugal, uma das formas de financiar as autoestradas é através de parcerias público-privadas (PPP). Este modelo difunde o custo das operações ao longo do tempo e torna mais fácil para o governo pagar por investimentos tão caros. Por outro lado, a PPP se torna uma desvantagem quando os projetos são desenvolvidos independentemente de seu valor econômico. O resultado da PPP em Portugal foi o SCUT (estradas "Sem Custo Para o Utilizador"). O governo costumava pagar uma "renda anual" com base no volume de tráfego nas estradas. O dinheiro para os pagamentos vinha dos contribuintes, mesmo aqueles que não utilizavam as estradas de concessão. O modelo SCUT tornou-se o modelo ex-SCUT após renegociações. Agora, os motoristas pagam para usar as estradas. Os pedágios cobrados trouxeram perdas econômicas, sociais e ambientais, pois houve diminuição da utilização das ex-SCUT. No Porto, as análises de mobilidade mostraram que os condutores optam por percorrer distâncias mais longas nas estradas secundárias a fim de pagar menos portagens. Portanto, as estradas secundárias apresentam congestionamento excessivo e as estradas primárias estão subutilizadas. A análise custo-benefício mostrou que o valor presente líquido do esquema de portagens no Porto é negativo, o que significa que o esquema não foi benéfico para a sociedade. É necessário reposicionar o tráfego das estradas secundárias para as estradas principais e subutilizadas. Não é lógico ou economicamente eficiente cobrar a mesma quantia tanto em estradas não congestionadas quanto em estradas congestionadas. Portanto, é necessário repensar os locais e o valor cobrado dos pedágios. Além disso, as alterações no modelo de tarifação rodoviária, com enormes investimentos no transporte público e noutros meios de transporte, como as bicicletas, seriam muito benéficas para a mobilidade da cidade do Porto.

PALAVRAS-CHAVE: mobilidade, portagens, taxa de congestionamento, análise custo-benefício, Porto.

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Symbols, Acronyms and Abbreviations

AADT – Annual average daily traffic

AC – average cost

AMP – Metropolitan Area of Porto

ALS – Area Licensing Scheme

CBA – Cost-Benefit Analysis

CBD – central business district

CCZ – congestion charging zone

CEC – City of Edinburgh Council

COE – certificate of entitlement

ERP – Electronic Road Pricing

EU – Europe Union

GDP – Gross Domestic Product

INE – instituto nacional de estatística

I.P. – Infrastructures of Portugal

LCC – London Congestion Charge

MC – marginal costs

MB – marginal benefits

NPV – net present value

NYC – New York City

PPP – public-private partnerships

RZ – restricted zone

VCI – internal circulation path

VQS – vehicle quota system

1
INTRODUCTION

1.1. General Description

Slower speeds, longer trip times, and long queues are indicators of traffic congestion. Back in the 1960s, it was assumed traffic congestion was caused by a lack of road capacity, that is, a shortage of supply (Thomson, 1997). The goal was to build more roads to decrease congestion, but it was costly and would take time, and it would not stop the volume of cars from growing. Therefore, governments, planners and economists started seeking solutions to eradicate congestion.

Congestion pricing was one of the solutions found by planners and economists to ease road congestion. It is a traffic management tool used to make drivers pay for the externalities they cause, for instance loss of time, air pollution and noise. It can be a valuable instrument to generate new sources of revenue and more efficient modes of transport. Thus, road pricing can be used as a tool to achieve a more efficient use of the existing infrastructure (Ohazulike, 2014).

Road pricing establishes a tariff on sections of transportation networks, forcing people to change characteristics of their behavior, for example: time of travel, route and mode of transport. This system establishes which sections to charge, how much should be demanded, and when it should be charged.

The first city to introduce congestion pricing as a tool was Singapore with the so-called Area Licensing Scheme (ALS) in 1975. Many other cities followed, such as Stockholm, London, Bergen and Oslo. This scheme has allowed cities financing their transport infrastructure while easing their congestion.

The effective implementation of road pricing, especially in urban areas, motivates not only the economic efficiency, but other issues such as political and social acceptability of the scheme (Raux et al, 2014). Drivers see road pricing as a burden and are mostly against it, although studies (Börjesson et al., 2012; Eliasson, 2014) have shown that the congestion pricing achieves acceptance after the public realizes congestion is decreasing and other benefits appear (less pollution, noise).

Since economic efficiency continues to be essential to justify urban road pricing, cost-benefit analyses (CBA) are performed in order to determine whether this kind of policy, when implemented in a specific area, increases the welfare or not (Raux et al, 2014). This dissertation will present a CBA to determine if the road pricing system established in Porto is beneficial in economic terms.

1.2. OBJECTIVE

The purpose of this master thesis is to analyze the mobility in the metropolitan area of Porto, and how it was affected after the implementation of road pricing to ease urban congestion. This dissertation will also compare the situation in Porto to successful cases, such as Singapore, Stockholm and London. Moreover, this dissertation is going to discuss and apply Cost-Benefit Analysis (CBA) on the road pricing system in the metropolitan area of Porto.

1.3. METHODOLOGY

This master thesis started by doing a bibliographic research about congestion pricing, road pricing schemes and economic theory of congestion. It was also done a collection of information through articles about specific locations, such as Stockholm and Singapore, and their road pricing system.

Later, it was done analyses and reflections on different case studies, and a comparative study between them. The main focus though was in the city of Porto. Finally, a final reflection was done to conclude this dissertation. This stage allows the exposition of arguments to convince if the road pricing scheme in Porto is or isn't relevant to the mobility in the city, and what are the effects the scheme brings to transportation network of the city.

1.4. STRUCTURE

This master thesis starts with a short introduction, objective and methodology.

Then, Chapter 2 focus on the theory of traffic congestion. It shows the general principles, the theory behind congestion pricing and its advantages and disadvantages.

Chapter 3 focus on case studies. It displays the details of congestion pricing schemes in 5 cities: Singapore, Stockholm, Oslo, London and Edinburgh.

Chapter 4 focus on the road network system in Portugal and the way it is financed, mostly through PPP (public-private partnerships).

Chapter 5 is the case of Porto. It details the Metropolitan Area of Porto, its mobile population and mobile patterns.

Chapter 6 displays the theory of cost-benefit analyses and applies it to the case of Porto.

Finally, Chapter 7 is the conclusion, which summarizes and reflects the studies done in this dissertation.

2
TRAFFIC CONGESTION ECONOMIC THEORY

2.1. GENERAL PRINCIPLES

2.1.1. THE NOTION OF GENERALIZED COSTS

From the drivers' point of view many factors influence decisions: time it takes to make a trip, cost involved, quality of the infrastructure. For freight carriers, the financial cost of the transport is not the only concern, but also the speed, reliability and schedule of the services. Therefore, the demand for transport is not only dependent on the financial costs but instead on the overall opportunities involved. Thus, financial cost is a relatively small part of costs in transportation. This explains why so many people opt to use private cars when cheaper modes of transport are available to them.

User costs are very relevant for public transportation due to waiting times. When people arrive to the stops or stations without the intention of catching a particular bus or metro but know that the headways are so close that the wait will be very short. Therefore, increased output of bus or metro services reduces average waiting time and, thus, the users cost of traveling by bus or metro.

When forecasting transport demand, it is possible to estimate the components of overall cost: financial costs, time costs, inconvenience costs, etc. An efficient way to reduce the wide range of costs involved in transport is to apply a single index known as "generalized cost". The generalized cost of a trip is a single, customarily monetary, measure joining most of the substantial but contrasting costs of a trip, which constitute the overall opportunity costs of the trip (Button, 1993).

The main characteristic of generalized cost is that it reduces every cost item to a unique index, and it may be used the same way as money costs are in economic analysis. Generalized costs can be defined as:

$$G = g(C_1, C_2, C_3, \dots, C_n) \tag{2.1}$$

where G is generalized cost and $C_1, C_2, C_3, \dots, C_n$ are the costs of traveling (time, money, and others).

Generalized cost is a useful instrument in helping economists understand how variations in travel cost can influence travel behavior. It may also help policy makers explaining their ideas to a more general audience.

2.1.2. The External Costs of Transport

There are external costs generated by transport users and imposed on the non-traveling public. For instance, road drivers impose pollution and vibration on those living nearby major roads, they also impede the progress of pedestrians. According to Button (2010), externalities exist when the activities of one group affect the welfare of another group without any compensation being made. Though it is not relevant for the transport area, there are external benefits. For example, when wide streets act as fire barriers, apart from serving as transport arteries.

2.1.2.1 Transport and the environment

Figure 1 shows the problems and pollutants that can be the outcome of transport infrastructure in relation to the radius of impact and temporal incidence. As the graph shows, gases such as CO_2 and NO_x are the ones who impose worst effects on the population.

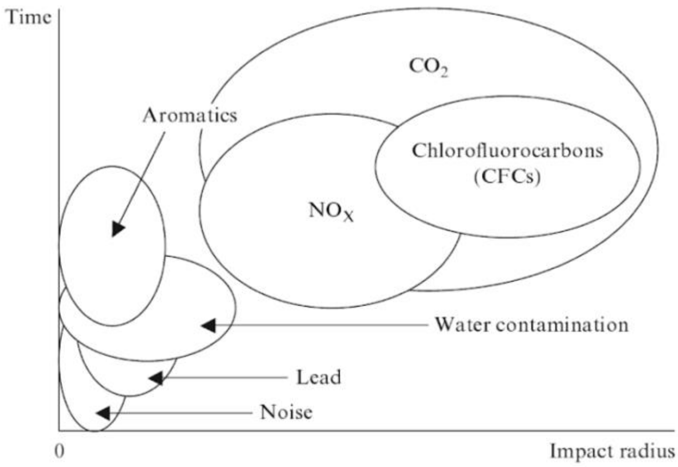


Figure 1 – Time and spatial coverage of exhaust fumes and other environmental intrusions. Source: Button, 2010.

Transport corrupts the environment in three major ways:

- Imposing environmental costs on those living, studying, working or passing-by close to big transport infrastructure, such as noise, visual and air pollution;
- Contributing to acid rain and maritime spillages, which impact long distances not only the immediate surroundings pf the transport infrastructure;
- Contributing to global warming and to the reduction of the ozone layer.

Eliminating these antagonistic effects would be great for the environment, but it would inflict costs to those who benefit from the transport infrastructure. Most frequently, improvements to the environment would reduce the net benefits experienced by transport users. For this reason, economists tend to find an optimum between the level of pollution and environmental improvement.

Figure 2 displays a graph of environmental improvements versus the money value of the costs and benefits of reducing the harmful gases emitted by vehicles. The marginal costs (MC) will probably rise abruptly when trying to reduce the fumes because filters and fuel refining can be quite expensive. The marginal benefits (MB) of less pollutant cars are going to decrease with improvements. The point in which the curves meet (E_1) is the optimal level of improvement economists try to achieve.

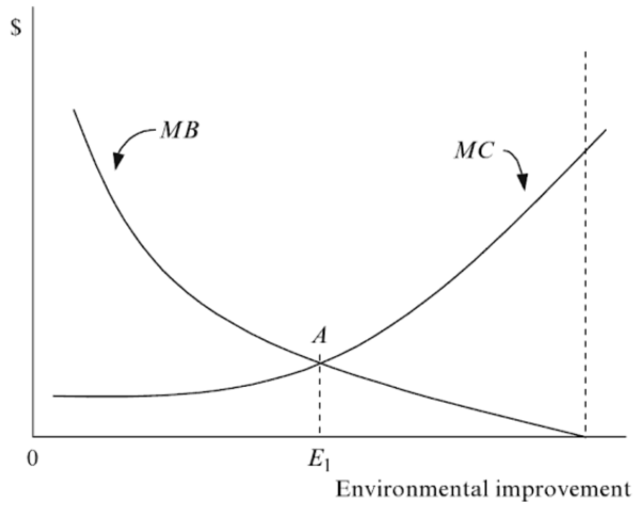


Figure 2 – Optimal environmental improvement. Source: adapted from Button, 2010.

Therefore, the excessive pollution caused by vehicles is a consequence of an excess above the optimal level of pollution show in the graph above.

2.2. TRAFFIC CONGESTION

The demand for transport varies over time. There are daily (rush hour) and seasonal (holidays) peaks. In addition, transport infrastructure has a limited capacity and one cannot change the capacity of the infrastructure to accommodate the daily or seasonal fluctuations. Congestion externalities appear and time is wasted when consumers of one facility start to obstruct other users because the capacity of the facility is restricted.

Road traffic presents some of the worst congestion difficulties. The economic costs of road congestion can be measured using the concept of the speed-flow relationship (Button, 2010). When traffic flows during a period of time at diverse speeds in a straight one-way street, the curve shown in Figure 3 shows the relationship between speed and flow.

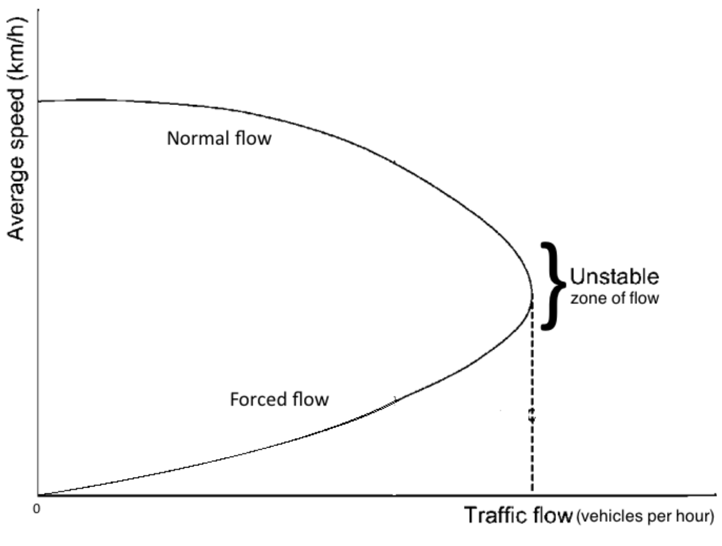


Figure 3 – Speed-flow relationship. Source: adapted from Button, 2004.

The flow depends on the number of the cars entering the road and the speed of the traffic. When the volume of vehicle is low, higher speeds are achievable. In contrast, when the volume of vehicles increases, the speeds decrease. While more cars enter the road, the speed of the traffic will decrease, but flow will increase up to a point because the additional cars counterbalance the reduction in average speed. This is known as the normal flow. The road reaches its capacity when increasing the volume of cars stops to offset the decreased speed. When the drivers keep entering the road after the capacity is reached, it causes further drops in speed. This is known as forced flow.

Figure 4 shows three graphs (A, B and C). Graph B displays the normal speed-flow relationship where the maximum flow is F_{max}. This is connected with the traffic flow-cost curves in C. Graph A shows curve D, which is the drivers' demand to join a road. In addition, diagram A displays the relation between travel cost and traffic density. The marginal cost of congestion (MC) increases whenever another car joins the road joins the road. The S curve illustrates the cost of entering the road as seen by the additional driver. That is, the cost of making the trip seen by the additional driver, neglecting the ramification of said action for the other drivers.

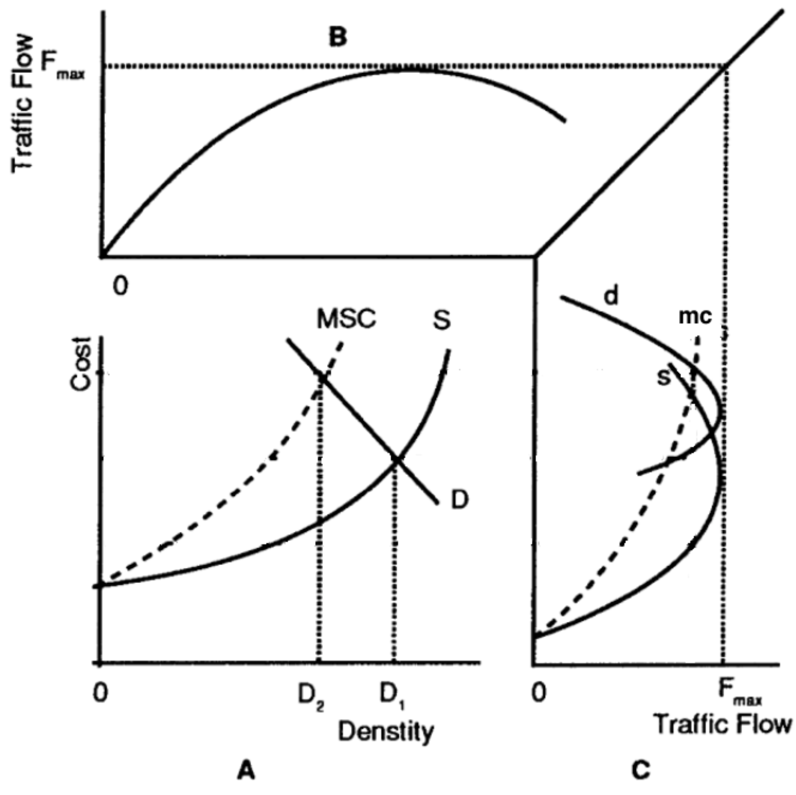


Figure 4 – Speed-flow relationship and the demand curve for road space. Source: adapted from Johansson and Mattsson (1995).

The curves shown in diagram C are derivative from the other diagrams. The average cost related to congestion is displayed by the s curve. The associated marginal curve is displayed by mc. Generalized costs stipulate the connection between traffic flows and cost. Usually, quicker trips in cities imply cheaper trips in terms of generalized costs. Therefore, the s curve portrays the average generalized cost of traveling at various levels of traffic flow. The congestion cost the extra driver imposes on the current traffic flow is shown by the mc curve. Lastly, the d curve displays the derived demand indicating the direction that the desired traffic flow adjusts as the cost of the trip alters due to the number of vehicles entering the road. In diagram A, D_1 is where the demand for road space corresponds to the average cost (S) of entering the road. This tops the optimal level D_2, which is where MSC is balanced with demand.

2.2.1. THE ECONOMIC COSTS OF CONGESTION

Most drivers are unaware of the external congestion costs they inflict on other users. Therefore, individuals using the roads consider only the costs they personally bear. Button (2010) argues that the MC curve (Figure 5) relates to the marginal cost of the new and existing travelers of an additional traveler. While the AC curve relates to the additional cost bore by the new traveler alone. The difference between the marginal cost and average cost curves at a traffic flow expresses the economic costs of congestion at that flow.

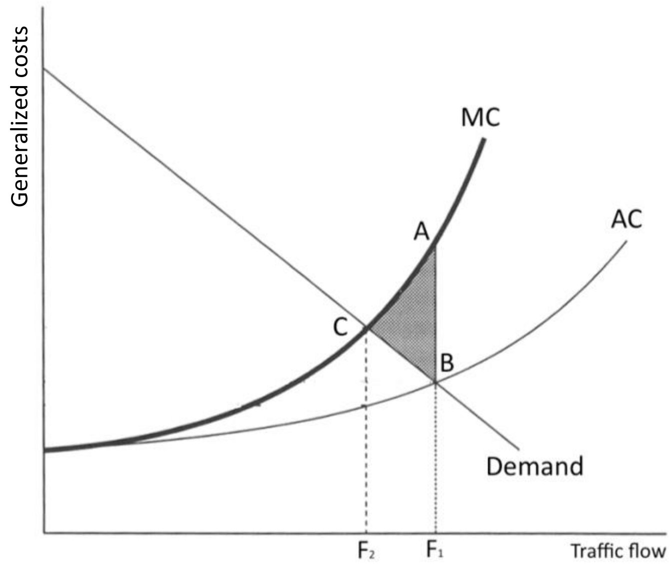


Figure 5 – Economic inefficiency of congestion. Source: adapted from Humbad, 2001.

The flow F_1 has the benefit of F_1B, but is inflicting costs of F_1A. Thus, the increased traffic above F_2, which is the optimal level, is creating costs of F_2CBF_1, but only taking advantage of ($F_2CABF_1 - ABC$), where ABC is a deadweight loss (hatched area), which is a loss of economic efficiency.

2.2.2. THE ECONOMIC VALUE OF CONGESTION

Button (1993) argues that some of the welfare loss caused by excessive congestion might be compensated by other beneficial effects of congestion which are not clear to the analyses that were shown earlier in this dissertation.

For instance, if a traveler really wants to make a trip, he or she would be prepared to wait and face the congestion. However, when a deterring charge is imposed the driver might give up taking the trip due to budget limitations. Though this argument is affected by society inequality, where the rich ones would not be as harmed as the poor part of the population.

Additionally, the costs (of reducing externalities, of organization, and of carrying the action) to eliminate an over congested road situation surpasses the benefits of removing the deadweight loss. Furthermore, when the environmental externalities of congestion disturb a small region, reducing congestion in this region might mean demand being spread to other areas. Therefore, the environmental problems would also be spread, which would not help the community.

2.3. OPTIMIZING TRAFFIC CONGESTION THROUGH ROAD PRICING

Excessive congestion contributes to both transport infrastructure and economic inefficiency, as seen in Section 2.2. Economists have thought about externality pricing not only because of environmental reasons, but also to make the drivers aware of the animosity they inflict on others. The price mechanism shall be used to optimize the level of congestion by making travelers pay for the increased congestion they are responsible for when entering a congested road. Thus, road pricing tries to balance the demand for transport use with the full costs of use, including the costs on other transport users.

A congestion charging scheme has three main duties:

- Distribute what is available;
- Demonstrate where the capacity should be adjusted;
- Contribute with the resources for financing such adjustments.

Table 1 on the next page shows the different road pricing schemes and the tasks they should each perform.

Road pricing is a user charge set by governments which guarantees that a socially optimal flows will be obtained. It is only concerned in making a better use of the infrastructure and it is not concerned about air pollution.

Figure 6 shows that the average cost is the cost sustained by an additional driver, and the marginal cost is the combination of the cost observed by the additional driver and the cost imposed on other travelers. The demand curve is the utility that travelers experience by entering the road at different generalized costs. Therefore, at F_1 travelers assume they are enjoying benefits, and not slowing down the traffic for others. The optimal flow is represented by F_2, where costs of every driver is considered. Thus, congestion pricing theory suggests that by charging $C_2 - C_1$ from the trip makers, they will be aware of the congestion cost aspects they impose on society. This results in a welfare gain of ABC.

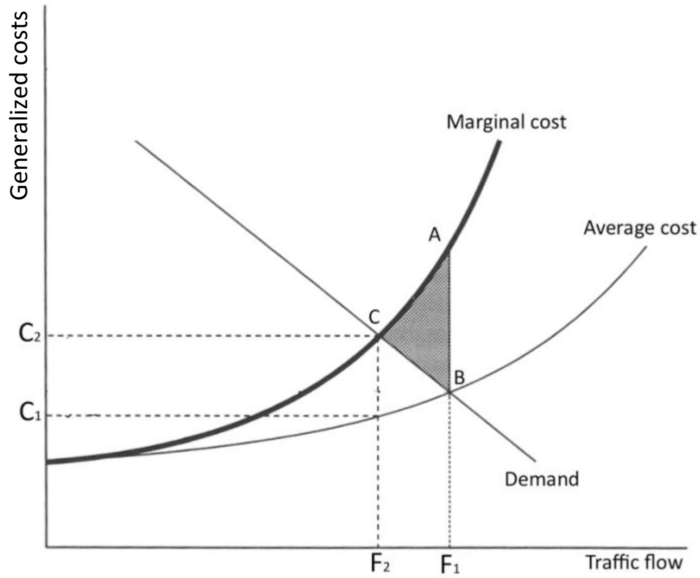


Figure 6 – Effects of road pricing. Source: adapted from Humbad, 2001.

Table 1 – Technical tasks for various forms of road charging. Source: Button, 2010.

Scheme	Entering/ exiting facilities	Presence in area	Position on road network	Distance traveled	Time congestion level	Vehicle class/ weight	Charges owed	Data communication	Data storage	Payment billing	Enforcement
Facility congestion tolls	●				●	○	●	●	●	●	●
Cordon congestion tolls		●			●	○	●	●	●	●	●
Weight-distance truck tolls	○	○	○	●	○		●	●	●	●	●
General distance tolls		●	○	●	○	○	●	●	●	●	●

● Required for the task; ○ Optimal but not required for the task.

2.3.1. Problems with Road Pricing

As shown in the previous section, it is possible to obtain economic benefits and decrease congestion by charging from road users. However, implementing such schemes has been challenging due to social and political acceptability. Niskanen and Nash (2008) argue that are three main barriers to implementing pricing policies:

- Technological and practical;
- Legal and institutional;
- Acceptability-related.

Technological barriers are being surpassed due to the advance of technology. Although it may be very expensive to legitimize its application in extensive regions. The authors (Niskanen and Nash, 2008) refer to "practical" issues such as: data quality and insufficient data on costs and benefits as well as other impacts that might be outcomes of road pricing (land use, for example); and complexity of the road network and the interaction between cities.

Legal barriers refer to the lack of power of governments to introduce pricing schemes and constraints on the schemes that would be legally allowed. For instance, road tolls are considered taxes in Sweden, which need to be resolved by the Parliament. Institutional barriers relate to the absence of planning and organization between different parts and levels of government.

The decisive issue is poor acceptability from the public, business and politicians. Public acceptability is the most important. Motorists perceive road pricing as making the worse off. The main reason for this is that the revenue collected through road pricing is seen as a tax by the users. According to Thomson (1997), road pricing penalizes vehicle owners who have low incomes for the benefit of richer motorists and non-drivers. Moreover, in per capita terms, the benefits are small and indirect, while the costs are large and direct. Also, it is a concern for the public that road pricing might be abused by governments as means of increasing revenue.

Political acceptability is relevant because the politicians are the ones who make the decisions, though they are influenced by the public and business. However, there is also the aspect that politicians are afraid to lose votes in the next election if they approve of charges. The fear they will get blamed for the large and direct costs the road users have to endure.

3
CASE STUDIES

Even considering all those barriers and difficulties, road pricing has been adopted in many cities around the world. Table 2 shows characteristics of congestion pricing schemes in many cities that use such system. This chapter will address road pricing schemes in many cities, such as Singapore, Stockholm, Oslo, London and Edinburgh.

Table 2 – Characteristics of great road pricing schemes. Source: Button, 2010.

City	Eletronic system start date	Entry charge for a small vehicle	Toll ring area (km^2)	Average daily crossings	Annual revenue (millions)
Trondheim	1991	$2.40	50.0	74900	$25.00
Oslo	1991	$2.40	64.0	248900	$196.00
Bergen	2004	$2.40	18.0	84900	$36.00
Stockholm	2006	$1.33-$2.66	29.5	550000	--
Singapore	1998	$0.33-$2.00	7.0	235000	$80.00
Rome	2001	$3.75	4.6	75000	$12.30
London	2003	$15.00	22.0	110000	$320.00
Santiago	2004	$6.42	--	250000	--

3.1. Singapore

3.1.1. Overview

Singapore was the pioneer of road pricing. They introduced a manually enforced Area Licensing Scheme (ALS) in 1975. It was a cordon-based pricing scheme. In 1998, the system was improved and got replaced by the Eletronic Road Pricing (ERP) scheme. According to Niskanen and Nash (2008), the main goal of road pricing in Singapore was to ease excessive congestion and lessen pollution issues.

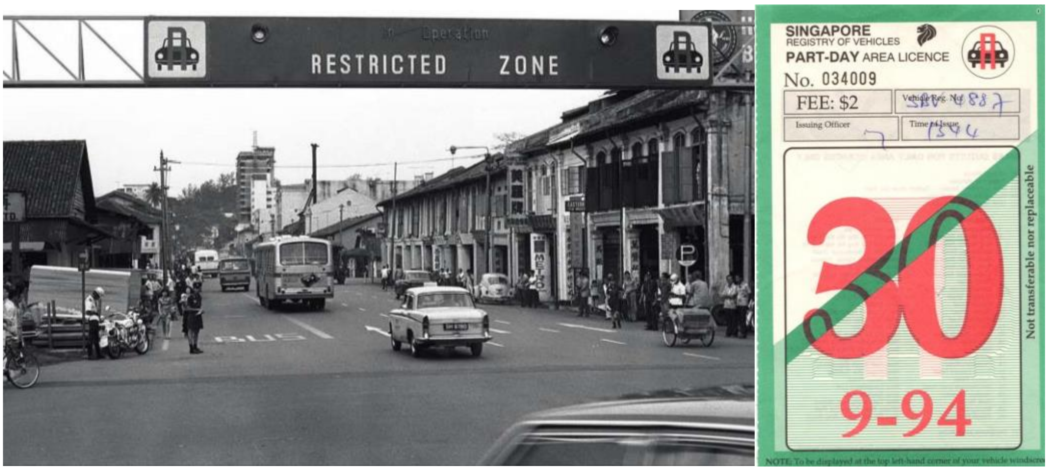
Since Singapore is a country consisting of a single city, it was easier to implement road pricing there than in other major cities who suffer the same congestion problems. There was no need to consider the interaction between traffic from different cities, and there was no barrier relating to the different levels of government (local and national).

3.1.2. Area Licensing Scheme (ALS)

This system stayed in place for 23 years. The driver would buy paper licenses before entering the controlled zone, which covered most of the central business district (CBD) and was called Restricted Zone (RZ), as seen in Figure 7.

Figure 7 – Singapore Restricted Zone. Source: Bhatt, et al. 2008.

In the beginning, the area consisted of 6 km^2, but it was further expanded to more than 7 km^2. The restricted zone was delimited by 31 control points, similar to the one in Figure 8a. The paper licenses could be purchased monthly or daily. They were colored (Figure 8b) to make it easier for the officers to check the cars (Keong, 2002). Initially, the restriction was from 07:30 to 09:30. Later, the period was expanded to the afternoon between 16:30 and 18:30.



(a) (b)

Figure 8 – Singapore Restricted Zone control point.

3.1.3. Vehicle Quota System (VQS)

This system was used to control vehicle ownership growth, since the city has a limited number of parking spots, and also to avoid that the population bought more cars. VQS was implemented in 1990 and still exists. It is necessary that potential vehicle owners pay for a license that lasts 10 years called Certificate of Entitlement (COE).

The Singapore Government would allow an increase of car ownership of 0.25% per year, but as of February of 2018 no increasing will be allowed (Provonsha and Sifuentes, 2018).

3.1.4. Electronic Road Pricing (ERP)

Technology was evolving and ALS was becoming bigger and too much for manual checking. Thus, the Electronic Road Pricing system was launched in 1998. It is operated by the Land Transport Authority of Singapore. According to Provonsha and Sifuentes (2018), the scheme is completely automatic with variable pricing created to respond to congestion in real time. Figure 9 shows the location of the ERP charge point locations.

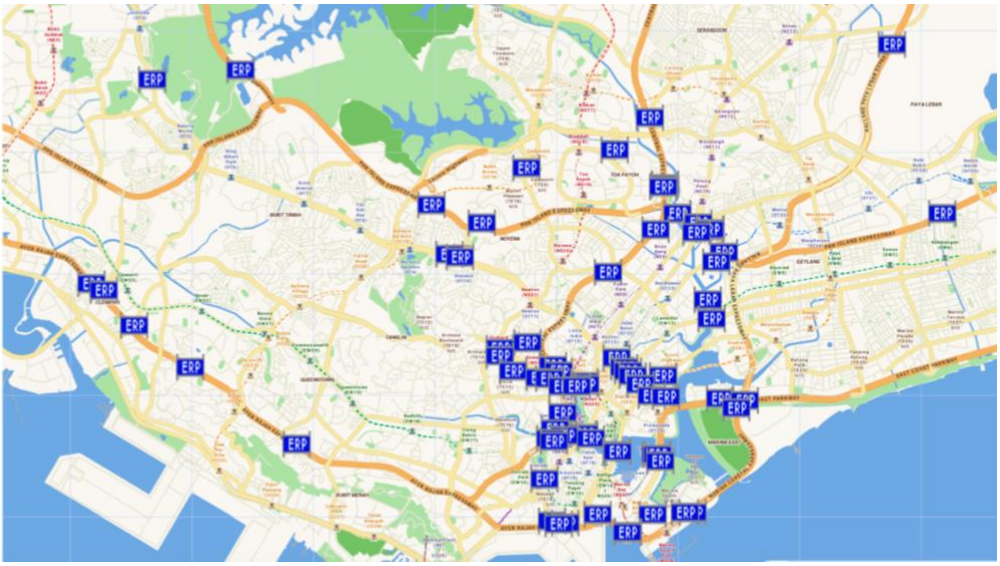


Figure 9 – ERP charging locations in March 2019.

The ERP works as shows in Figure 10. The ERP entries detect the type of vehicle and how congested the road is at the moment, then charges the variable fee from the card. The disadvantage with this system is that the users must remember to insert the card in the In-Vehicle Unit. This system started with 28 gantries, nowadays it has over 80 points.

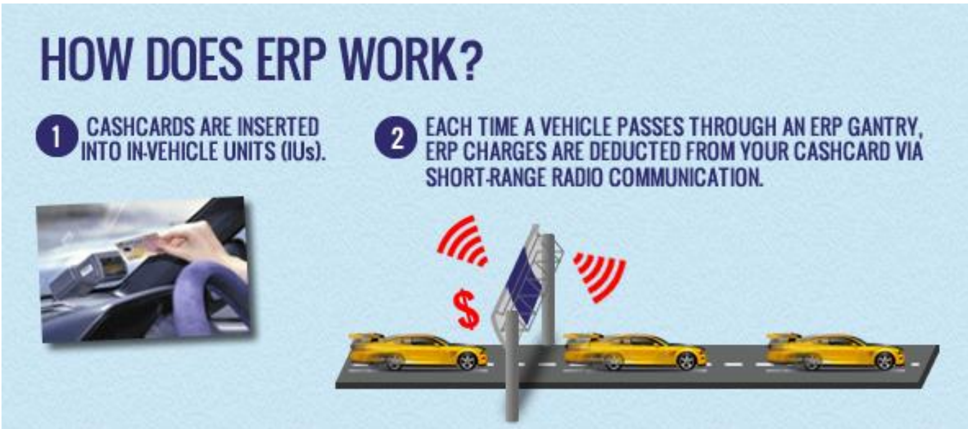


Figure 10 – How ERP works.

3.1.5. Impacts

After the introduction of ALS in 1975, there was a reduction of 44% of vehicles entering the RZ. Congestion inside the RZ was eliminated and speed increased for both cars and buses. As a result, bus and train passengers increased by 15%. Speeds on the streets that had the worst congestion went up from 15 km/h to 30 km/h (Bhatt et al., 2008). After the ERP was implemented in 1998, weekday vehicle daily traffic dropped 24% and there was a speed increase from 35 km/h to 45 km/h. It was also observed a decrease of CO and NO_x after ALS (WorldBank, 1978).

Road pricing is just one part of the strategy for congestion reduction in Singapore. Many improvements, such as less pollution, improved public health, better accessibility and connectivity, assist the congestion decline. The revenue from the ERP is aiding public transportation and making Singapore better for pedestrian, bus and train users, and cyclists. Moreover, the population supports the pricing policy as it is linked to beneficial outcomes. Thus, it is possible to conclude that ALS (now, ERP) and VQS have been successful and a great example to many cities to get inspired by.

3.2. STOCKHOLM

3.2.1. OVERVIEW

Road pricing was implemented in Stockholm in 2006 as a seven-month trial. The trial was followed by a referendum, where most of the population voted in favor of the chargers. The system has then been in place since August 2007. The scheme consists of a cordon-based road pricing. It has the objective of decreasing congestion and increasing environmental quality.

In Sweden, an infrastructure charge is different from a congestion tax. Infrastructure charges are charged to cover the construction costs of, for example, a bridge or tunnel. Thus, people who use the infrastructure are paying for it. On the other hand, congestion taxes are legitimized by the fact that people who are contributing to excessive congestion and environmental issues pay for the costs it causes to society (Transportstyrelsen, 2019). The congestion prices are considered government tax; therefore, violators are committing tax evasion.

3.2.2 THE CHARGING SYSTEM

As mentioned earlier, the Stockholm charging system is a toll cordon encompassing the city center. It decreases traffic through 26 charging points located at the main bottlenecks situated at the arterial roads leading into the city center (Börjesson et al., 2012), as seen in Figure 11. The area of the cordon is approximately 35 km^2.

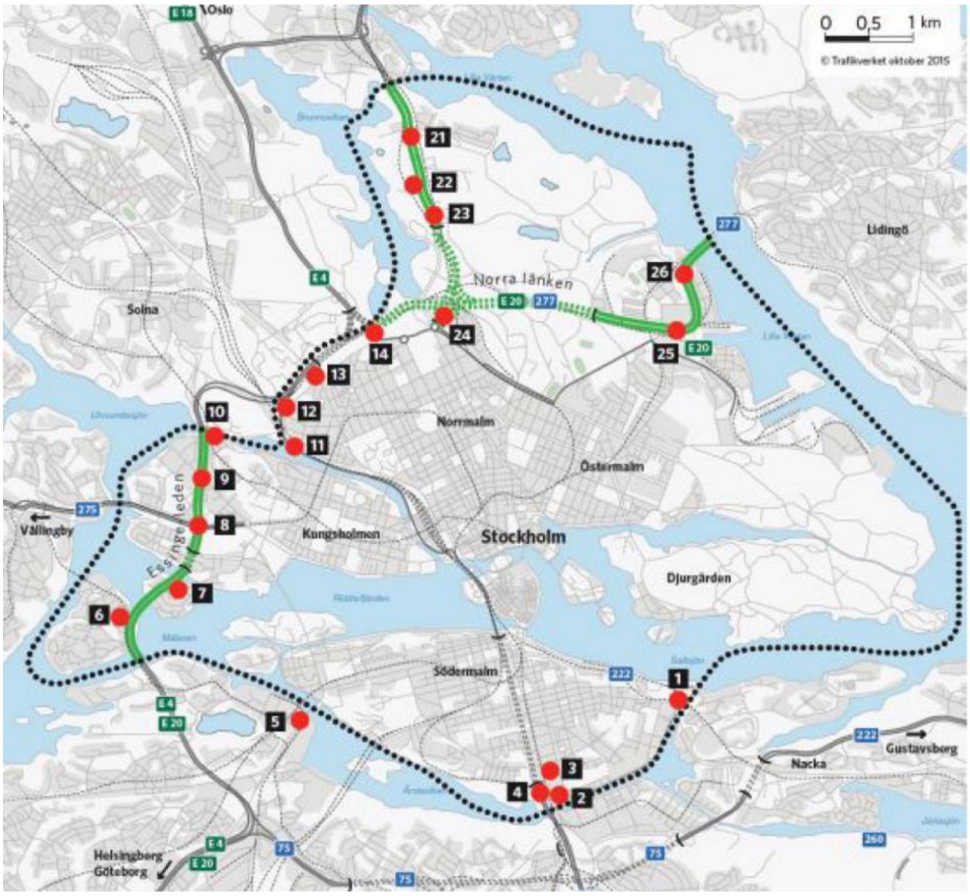


Figure 11 – Stockholm's charging cordon. Source: Börjesson and Kristoffersson (2018).

The cost varies between peak hours, 30 minutes before and after the peak, and during the rest of the day. The price suffered alterations after 2006, as seen in Table 3. The maximum a user can be charged per day is around 10 euros.

Table 3 – Charged amount in Stockholm depending on time of the day. Source: adapted from Börjesson and Kristoffersson (2018).

Time	Cordon prices (€) 2006	Cordon prices (€) 2016
06:30 – 06:59	1.0	1.5
07:00 – 07:29	1.5	2.5
07:30 – 08:29	2.0	3.5
08:30 – 08:59	1.5	2.5
09:00 – 09:29	1.0	1.5
09:30 – 14:59	1.0	1.1
15:00 – 15:29	1.0	1.5
15:30 – 15:59	1.5	2.5
16:00 – 17:29	2.0	3.5

17:30 – 17:59	1.5	2.5
18:00 – 18:29	1.0	1.5
18:30 – 06:29	0	0

According to Eliasson (2009), the investment cost for the introduction of the pricing system in Stockholm was more than 200 million euros. Table 4 shows the yearly revenue, passages and operating costs of the Stockholm pricing system.

Table 4 – Revenue, passages and operating cost of the system in Stockholm. Source: adapted from Börjesson and Kristoffersson (2018).

	Revenue (M€/year)	Passages (M/year)	Operation cost (M€/year)	Operation cost/Revenue (%)
Stockholm 2008	70.9	82.0	22.0	31
Stockholm 2013	86.5	77.5	10.2	12
Stockholm 2015	91.4	80.5	9.6	11
Stockholm 2016	140.0	93.4	10.3	7

The Transport Administration (Trafikverket) supervised the design of the scheme and the Swedish Transportation Agency (Transport Styrelsen) took care of the payments. Both agencies currently administer the pricing scheme in Stockholm.

The system is fully automatic. The vehicles are identified at the control points (Figure 12) through a picture of their plate taken by a camera. The speed of the traffic is not affected since the drivers do not need to stop or slow down. The driver is then sent an invoice for the total tax he/she must pay for that month.

Figure 12 – Control point in Stockholm. Source: Transportstyrelsen.se (2019).

As seen in the picture above, the display shows the current amount of the tax. The technology consists of (Figure 13):

1. Laser detectors (B) that sense when a vehicle is approaching the control point and trigger the cameras (A and D);
2. Camera D takes picture of the front of the vehicle;
3. Camera A takes picture of rear of the vehicle.

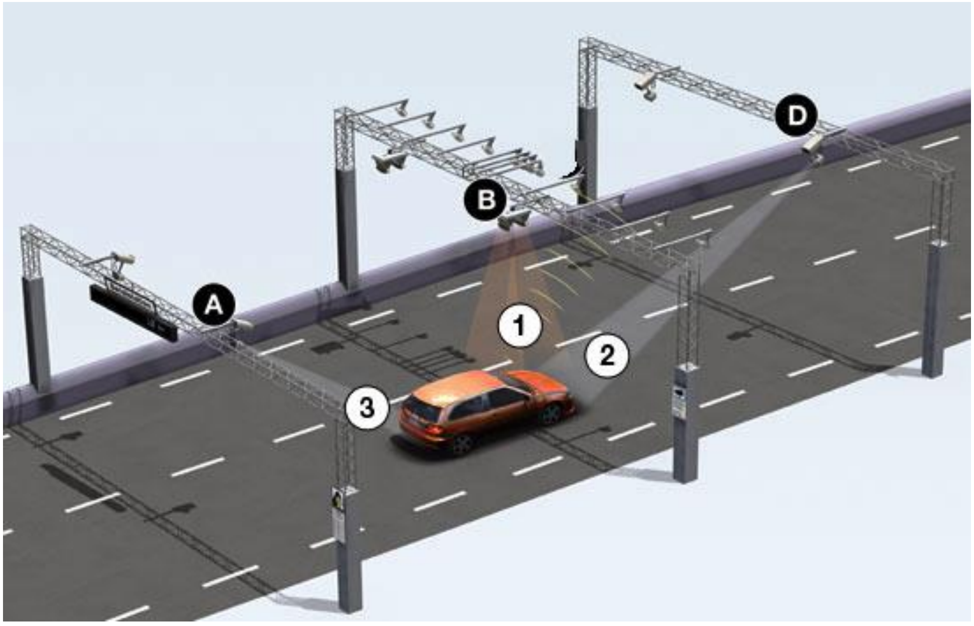


Figure 13 – Technology at control points in Stockholm. Source: adapted from Transportstyrelsen.se (2019).

3.2.3. Impacts

During the trial in 2006, the polls showed roughly 80% of opposition to the congestion charges. However, the reduction in traffic in the cordon was around 22% compared to 2005 data. It resulted in reduction of congestion around 30-50% (Provonsha and Sifuentes 2018). Therefore, speeds were increased and the number of passengers in public transportation increased by more than 5%.

Because of the success of the scheme, public acceptance increased, and the population voted in favor of the charges on the referendum. Moreover, the Parliament’s environmental goals were met when there was a reduction of almost 14% in CO_2 emissions and almost 7% in NO_x.

The introduction of road pricing in Stockholm was successful. It provided many mobility benefits, such as less congestion and higher speeds, and better environment. Although, Börjesson et al. (2008) wonders if the effects are going to disappear over time, when the travelers get used to pay the tax. So far, there is no evidence that the effects are wearing off. In addition, the example of Stockholm has various implications that might be useful for other cities considering the implementation of congestion pricing.

3.3. Oslo

3.3.1. Overview

The scheme in Oslo started as a road user charging (known as “Oslo Package 1”) which was implemented in 1990. It was not considered a congestion charging scheme because there was no objective of reducing congestion or pollution from vehicles (Raux et al, 2014). The main goal of the scheme was to raise funding for new road infrastructures. When charges were increased and public transport infrastructure became more important, the package was called “Oslo Package 2”. In 2008, “Oslo Package 3” was launched.

Almost all of the toll schemes in Norway are supplemented by allowances from the National government. These schemes are usually based on local actions, but they need to be approved by the Norwegian parliament. It is the Norwegian Public Roads Administration that is responsible for the planning, construction and maintenance of the toll systems in addition to collection the toll (Ramjerdi et al, 2004).

3.3.2. Oslo Packages 1 and 2

As mentioned before, Oslo Package 1 was implemented in 1990 to finance transport infrastructure, such as tunnels under the city center. This system was adopted because there was a lack of funds for road investments (Bekken and Norheim, 2007). Both packages were viewed negatively by the majority of the population (Figure 14), but it still got political approval.

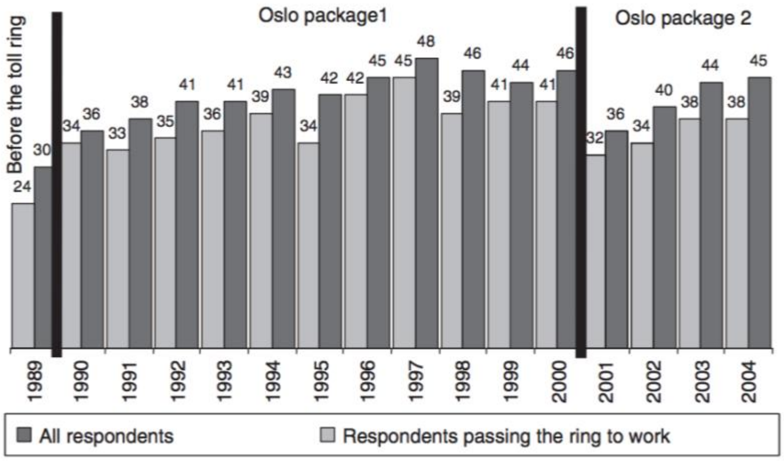


Figure 14 – Positive attitude towards Oslo Packages 1 and 2. Source: Bekken and Norheim, 2007.

As seen in Figure 14, acceptance of the Packages grows over time. The decrease observed in 2001 was probably due to the increase of the toll rates. After a few years, the acceptability was back to the 45% as before Package 2 was implemented. The main reasons population is in favor of the tolls are the investment in public transportation and roads.

Oslo Package 2 was a supplement of the first package. It was based on vehicle traffic increasing quickly and lack of funds for public transportation. The Parliament approved the second package in 2001. The toll was increased approximately €0.25 per trip, and public transportation fare increase by nearly €0.10. This package counted with 19 toll plazas, as seen in Figure 15. According to Bekken and Norheim (2007), the main investment was in railway, but there was also a new metro ring and many terminals/stations.

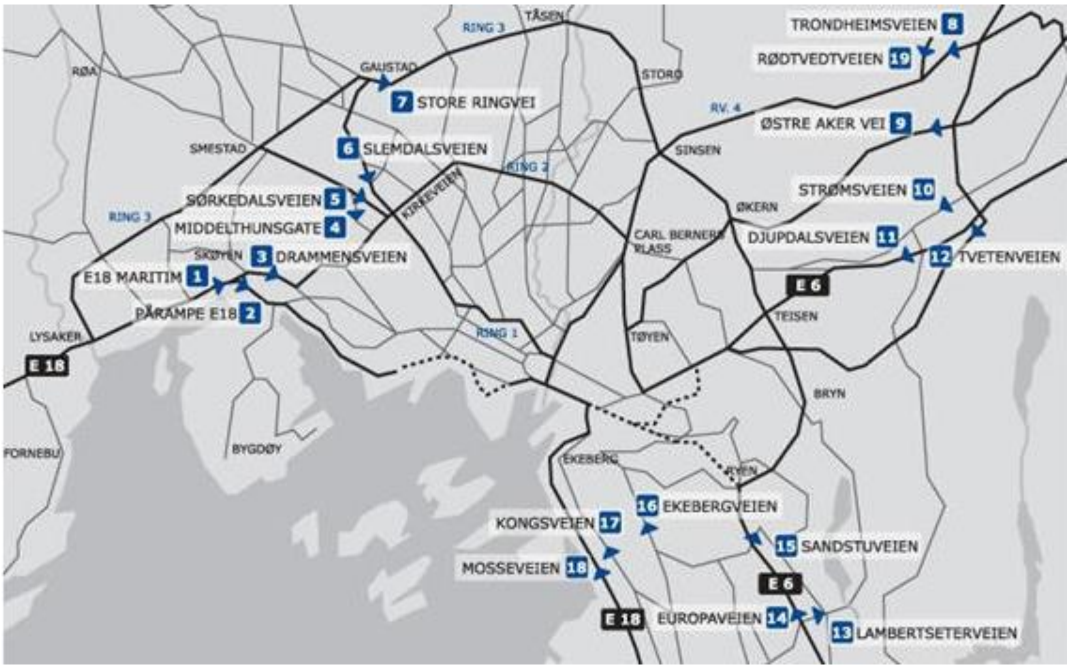


Figure 15 – Location of toll plazas for Oslo Package 2. Source: Curacao Project.

With the end of the toll ring coming closer in 2007, a new package was implemented.

3.3.3. Oslo Package 3

Oslo Package 3 was established in 2008. The tolls were increased, and all the toll plazas became fully automated. Also, electric cars are exempted from paying the toll. The objectives of this package are (Bysveen, 2014; Statens vegvesen, 2013):

- Reduce congestion and the need of driving a vehicle;
- Increase accessibility for all road user groups;
- Prioritize public transportation, commercial traffic, pedestrians and bicycles;
- Decrease noise, air pollution and emission of gases such as CO and NO_x;
- Fewer killed or injured;
- Improve quality of life in the city and in the suburbs.

As seen from the objectives of Package 3, it is possible to conclude that the Oslo toll ring became a congestion charge scheme since the main objective switched from investing in road infrastructure to reducing traffic congestion in the city.

From June 2019, toll collection will start from 73 toll stations (Figure 16). The improved system, with more stations, will make more people pay for the tolls introduced with Oslo Package 3. Also, the charging will be more equitably distributed than it is today, according to Statens vegvesen.

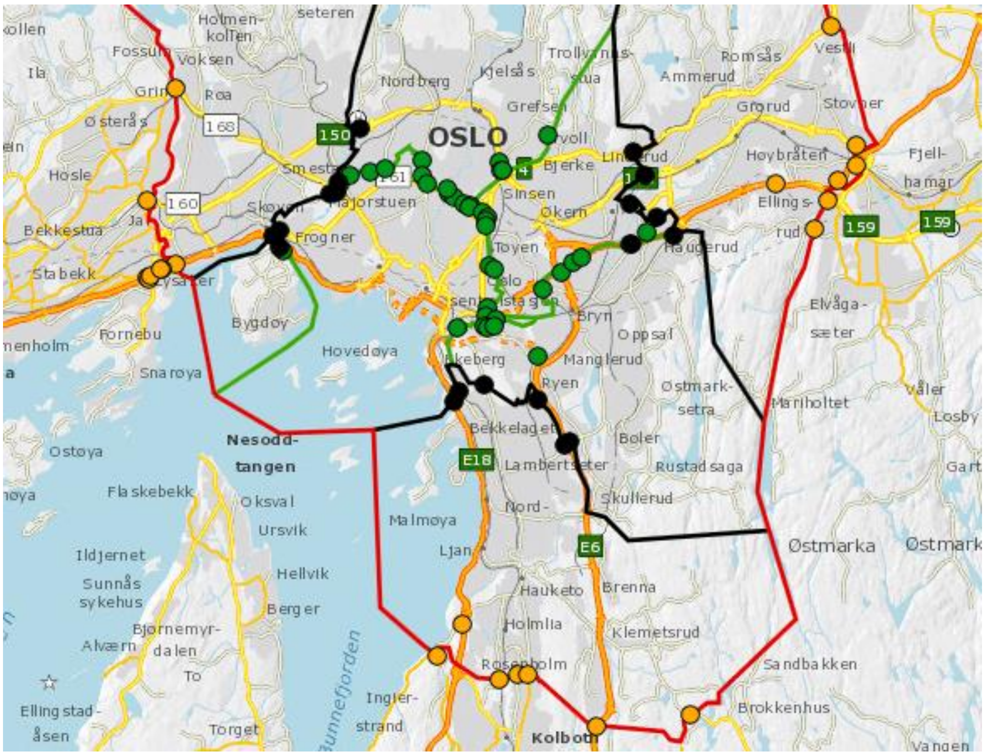


Figure 16 – Location of toll stations for Oslo Package 3. Source: Statens vegvesen.

In Oslo, the user only pays for one pass if they pass more than one station within the hour. Table 5 below shows the rates the users pay depending on the type of vehicle and the time they cross the toll points.

Table 5 – Rates in Oslo from July 2018. Source: Fjellinjen.

	Gasoline or hybrid vehicles	Diesel	Electric vehicles
Crossing outside rush hour	45 NOK (€4.70)	50 NOK (€5.20)	No cost
Crossing at rush hour (6:30-9:00 and 15:00-17:00)	55 NOK (€5.70)	60 NOK (€6.22)	No cost

A way of getting a 10% discount in the rates above is having an AutoPASS (Figure 17) attached to the vehicle. When the vehicle passes a toll station, the AutoPASS automatically registers it. Therefore, there is no need for stopping or slowing down. There are two ways of paying the tolls when the vehicle has an AutoPASS: either the user pays a particular amount in advance or the driver pays invoices, which are sent in arrears.

Figure 17 – AutoPass attached to vehicle.

3.3.4. Impacts

According to Bysveen (2014), the road traffic in Oslo increased 6% between 2000 and 2012, which is a small grow compared to the 22% increase in population. On the other hand, the number of passengers using public transportation increased 38% in the same period. This upsurge in passengers using public transportation is seen as a huge success of the investments that were made by Packages 2 and 3.

The Oslo Packages were implemented without a previous referendum. However, surveys were carried out since the first year of the tolls' operation in 1990. It was found that the Packages gained approval throughout time. In 1990, 70% of the population was against the Packages, but only 47% were against in 2012 (Bysveen, 2014).

The substantial improvements in public transportation, such as metro, train, bus and trams, in addition to investments in accessibility to bicycles and pedestrians, have made the population keen to the idea of paying tolls. It seems that the more investments there are in other mode of transport, the more the population stays behind congestion charges. Therefore, this is a lesson to be learned and should be appealing to other cities trying to implement road pricing.

3.4. London

3.4.1. Overview

The London Congestion Charge (LCC) was implemented in February 2003. It was part of a program called the Mayor's Transport Strategy, which combined expansion of bus services, traffic calming measures and bus priority proposals (Lehe, 2019). The main objectives of the LCC were (Peirson and Vickerman, 2008):

- Reduce congestion inside and around the cordon;
- Improve travel time reliability;
- Improve bus services;
- Invest In the "Underground" (metro);
- Distribute goods are service better, more sustainably and efficiently;

- Generate revenues to improve transport in London.

In 2004, the mayor of London asked the population if the charging zone should be expanded to the west. Rejecting the negative response, the mayor chose to expand it. The western charging started in February 2007. When a new mayor assumed position in 2008, there was another referendum, which showed that the population still rejected the expansion. The western charging zone was removed in January 2011. Figure 18 displays the changes in the congestion charging zone (CCZ).

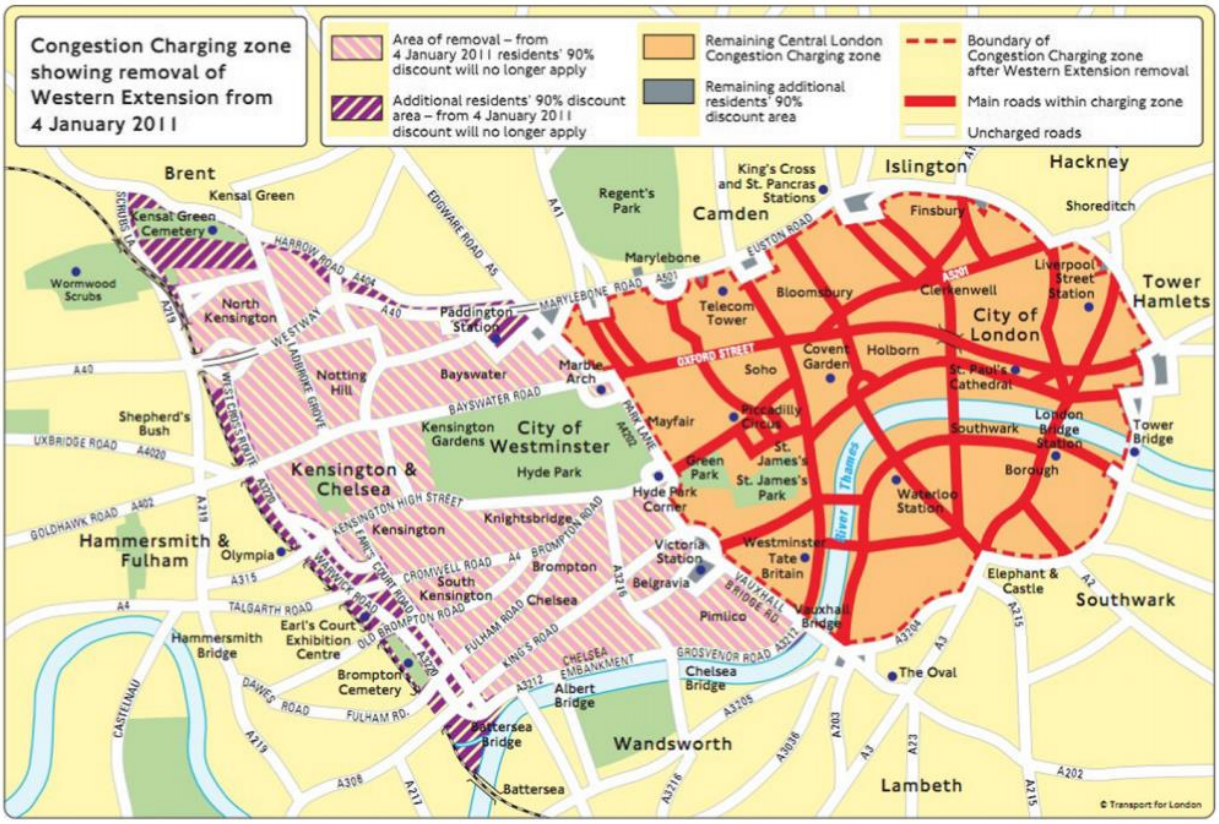


Figure 18 – Congestion charging zone in London. Source: Lehe, 2019.

3.4.2. London Congestion Charge (LCC)

The LCC works as a daily license scheme, that is, one charge/payment allows the user to drive unlimited within the 22 km^2 of the CCZ (orange and red in Figure 18) from 7:00 to 18:00. The charge also covers the parking within the zone. Therefore, there is a need for reinforcement with patrolling cars.

There are many ways of getting discounts or exempted from the charge. London residents have 90% discount. Motorcycles, buses, vehicles with more than 9 seats, cabs, vehicles used by disabled people, and vehicles with low carbon emissions are exempt from the charge. The LCC started by charging £5 in 2003, but increased the charge to £8 in July 2005, to £10 in January 2011and to £11.50 in June 2014.

Figure 19 shows the number of accesses to the CCZ by vehicle type. Minicabs are ordinary cars that can be requested through an app, such as Uber and Cabify. It is noticeable that there was a considerable drop in the use of cars after the implementation of the congestion charge. The number of taxis increased, probably because taxis are exempt of the charge. There was also an increase in the number of bicycles and motorcycles.

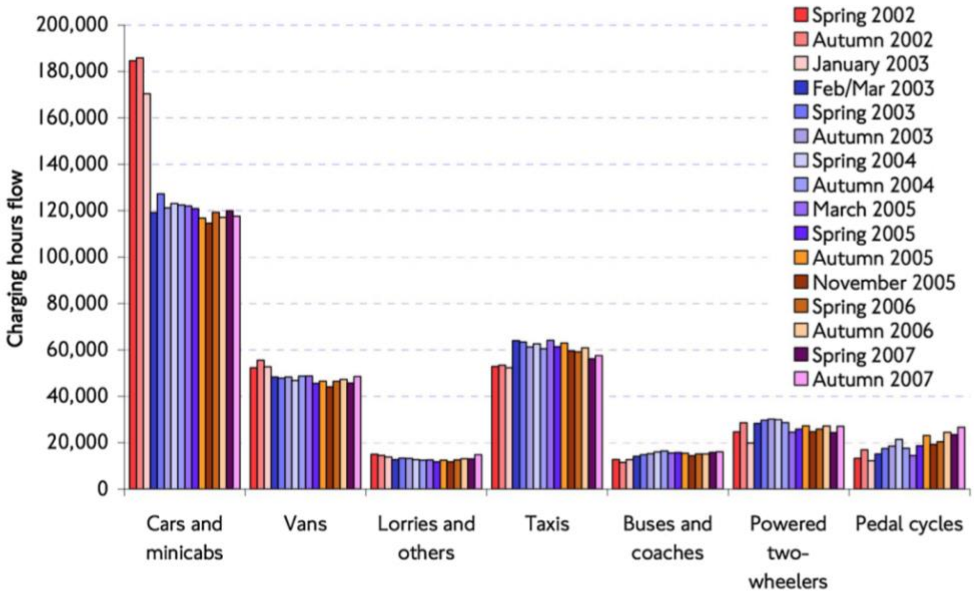


Figure 19 – Number of entries to CCZ. Source: Lehe, 2019.

According to Lehe (2019), the London Congestion Charge has cost more and created less revenue than expected. It was predicted that the assembling costs would be between £30 and £50 million, but it was actually nearly £162 million. This cost was linked to changes in traffic, projects for cyclists and pedestrians, and road improvements. Table 6 shows summarizes the finances of the LCC. Moreover, London transportation strategy requires by law that all revenue collected must be invested into the transport infrastructure of the city (Provonsha and Sifuentes, 2018).

Table 6 – London Congestion Charge finances. Starred years display the Western Extension was working. Source:adapted from Lehe, 2019.

Year	Price (£)	Revenue (M£)	Cost (M£)	Profit (M£)
03/04	5	171	93	78
04/05	5	192	90	102
05/06	5/8	210	88	122
06/07	8	213	90	123
07/08*	8	268	131	137
08/09*	8	326	177	149
09/10*	8	313	154	159
10/11*	8/10	287	113	174
11/12	10	227	90	137
12/13	10	222	90	132
13/14	10	235	85	149
14/15	11.50	257	85	173

15/16	11.50	258	90	168
16/17	11.50	250	86	164

3.4.3. Impacts

There was a reduction of 30% in traffic congestion, compared to levels before the LCC was implemented. Average speed increased by 30% in 2004. Traffic entering the CCZ decreased by 18% and traffic circulation the charging zone decreased 15%. Bus service increased and travel time reliability as well. It was estimated that 50% of the car trips no longer made were shifted to public transportation (Provonsha and Sifuentes, 2018).

The City of London was capable of maintaining these mobility benefits despite the growth of the population. The traffic has been reduced almost 10% from 2000 to 2015, even though the population of London grew by 20%. Moreover, CO_2 emissions decreased by 16% and NO_x emissions declined by almost 14%, improving the quality of the air in the city.

Even though London is a city with a population of 8.8 million people (in 2016), the LCC showed that it is possible to be successful when introducing a charging scheme in such a complex environment. Some measures for such success were as follows: on the same date that the scheme was implemented, there were 300 new buses introduced. There were new bus routes and increased frequency of previous existing ones. Around 8,500 park-and-ride spots were incorporated. Also, it was stablished bicycle lanes, which increased the safety of the cyclist. Therefore, it was possible for London to reduce congestion, decrease air pollution and achieve the objectives of the LCC.

3.5. Edinburgh

3.5.1. Overview

The Edinburgh case is a little different from the others since it was not actually put in practice. A congestion charging scheme was proposed for the city since forecasts showed that traffic will increase between 20% between 2001 and 2021, and time spent stuck in traffic will double (Santos, 2004).

The scheme proposed by the City of Edinburgh Council (CEC) consisted of a double cordon system (Figure 20). The smaller cordon was around the city center and would operate during week days from 07:00 to 18:30. The larger cordon was set around the entire city; it would operate only during the morning rush hour from 07:00 to 10:00. A fee of £2 would be charged from the users passing the cordons and entering the city. The objective of a double cordon was to achieve twice the reduction in traffic congestion in five years (Peirson and Vickerman, 2008). Residents of Edinburgh would be exempted from the charge.

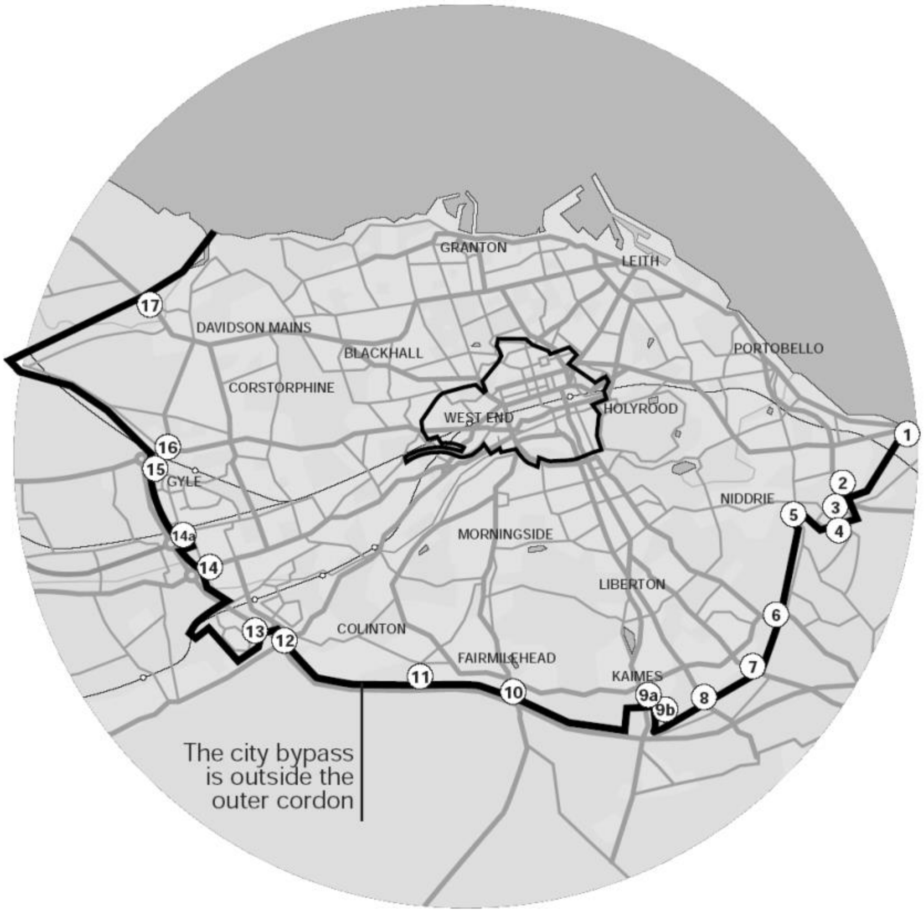


Figure 20 – Location of proposed inner and outer charging cordons (in black) and charging stations (numbers). Source: Allen et al, 2006.

The Edinburgh scheme does not charge the drivers moving within the cordon or the ones exiting the cordons. Therefore, it was mainly focused on changing the behavior of the commuters.

3.5.2. Expected Results

Table 7 shows the expected results if the congestion charging scheme had been implemented.

Table 7 – Expected traffic impacts for Edinburgh. Source: adapted from Santos (2004).

	Congestion (%)	Traffic across cordons (%)		Travel to city center (%)	Travel by public transport (%)
		Outer	Inner		
2006	-7	-31	-9	2	2
2016	-36	-34	-15	5	35
2026	-32	-25	-10	6	41

As seen in the table above, the impacts would be very significative. Thus, Edinburgh City has been discussing trying to implement the congestion charges again as a solution to the air pollution in the city (Swanson, 2017).

It was expected to raise £706 million at 2002 prices over the 20 years of the scheme. Improvements in public transportation that were predicted to be funded by the revenue from the charging scheme were (Allen et al, 2006):

- Nearly £200 million for supplementary bus services;
- £154 million for a tram line towards the southeast of Edinburgh;
- £111 million for road maintenance;
- £147 million for rail improvements;
- £17 million for transport accessibility;
- £24 million aimed to road safety.

3.5.3. Acceptability

Despite the fact that the was going to be allocated for local transport projects, as shown in the list above, Edinburgh citizens strongly rejected the charge in the referendum made by the CEC. Nearly 75% of the residents of Edinburgh who voted were against the congestion charging scheme (Laird et. al, 2007), even though Edinburgh residents were exempted of the charges.

Moreover, three of the four towns around Edinburgh also rejected the proposal, though the residents of said towns could not vote in the referendum. The neighboring local authorities were against the charges because they believed it was unfair to its residents since a major part of them would have to cross the cordons to go to work in Edinburgh. The fact the residents of Edinburgh were free from the charges also encouraged the rejection of the adjacent local authorities.

The City of Edinburgh was the one responsible of charging and distributing the revenue. Laird et al (2007) argued that even though CEC proposed to share the revenue with Edinburgh neighbors, there was no legal obligation. Therefore, the neighboring local authorities did not have legal grounds to secure funding from the revenues and that cause some insecurity from their part.

In addition, one of the reasons Rye et. al. (2005) highlights for the rejection of the Edinburgh scheme was its complexity. The public did not understand how it was supposed to work with the double cordons. A complicated scheme leaves room for disagreements and objections. Another reason for the rejection was that the charging scheme would start in 2006, but the first tram line would not start working until 2011.

There are many lessons to be learned from Edinburgh scheme. First, a bigger and better informational campaign would have helped the residents of Edinburgh and surrounding cities understand the double cordon scheme more easily. Another suggestion would be not making a referendum or undertaking the referendum after the congestion scheme is already working. For Laird et al (2007), the main lesson is the need to be clear about the use of the revenues, making sure it is efficient and fair for everyone involved. Also, it is important that the public transportation improvements are implemented before or at the same time as the congestion charging scheme.

3.6. Chapter Considerations

Singapore was the city that started urban congestion pricing. The city did not face many barriers when implementing the scheme, namely the barrier between the different levels of government was inexistent since Singapore is a city-state. The scheme achieved its goals of reducing congestion and pollution and set an excellent example to other cities around the world.

Congestion charging in Stockholm started with a trial followed by a referendum. The system has been in place since 2007 and it has been a success, reducing congestion and pollution. In addition, Eliasson (2009) found that the scheme in Stockholm yields a positive net present value, which means the scheme is beneficial to society.

In Oslo, the road pricing scheme has had different phases. Only in 2008 it truly became a congestion charging scheme, with the objective of reducing congestion. One of the differences between the charging system in Stockholm and the system in Oslo is that in Stockholm the user pays as they go in and out of the city, so they pay twice. Meanwhile, in Oslo, they only pay as they enter the city. Another difference is that there was no referendum. The most radical difference was the increase of passengers on public transportation after huge investments. Another great example for other cities.

London was another huge success. Congestion and pollution decreased, and speeds increased within the city. There were extensive investments on bicycle lanes and public transportation, which made the population shift from cars to other mode of transport. The huge investments in other modes of transport was one of the main reasons for the success of the scheme in London.

Even though a congestion charging scheme was not implemented in Edinburgh, the city sets an example for other cities trying to implement the scheme. Edinburgh taught that sometimes it is better not to do a referendum, such as Oslo. Or the referendum should be done afterwards like it was done in Stockholm. Moreover, the City of Edinburgh should have learned from the huge investments that London did on public transportation.

This chapter showed that implementing a congestion charging scheme is very difficult and it involves complex city environments. Although, many cities have done it successfully with huge benefits to society, such as less pollution and better air quality.

4
THE PORTUGUESE ROAD NETWORK

4.1. FINANCING OF THE ROAD NETWORK IN PORTUGAL

In Portugal, one of the ways to finance big structures, such as motorways, is through public-private partnerships (PPP). This model spreads the cost of the operations throughout time and makes it easier for the government to afford such costly investments.

4.1.1. PUBLIC-PRIVATE PARTNERSHIPS (PPP)

World Bank (2017) defines PPP as "a long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility and remuneration is linked to performance".

When building motorways, the most common model of PPP is concession of roads. That is, a contract is made between the Government and a private company where responsibilities are assigned to each part. Usually, the private company is responsible for the project, construction, financing and operation of the road (Cruz, 2018). Figure 21 displays the usual contract model of PPP in Portugal.

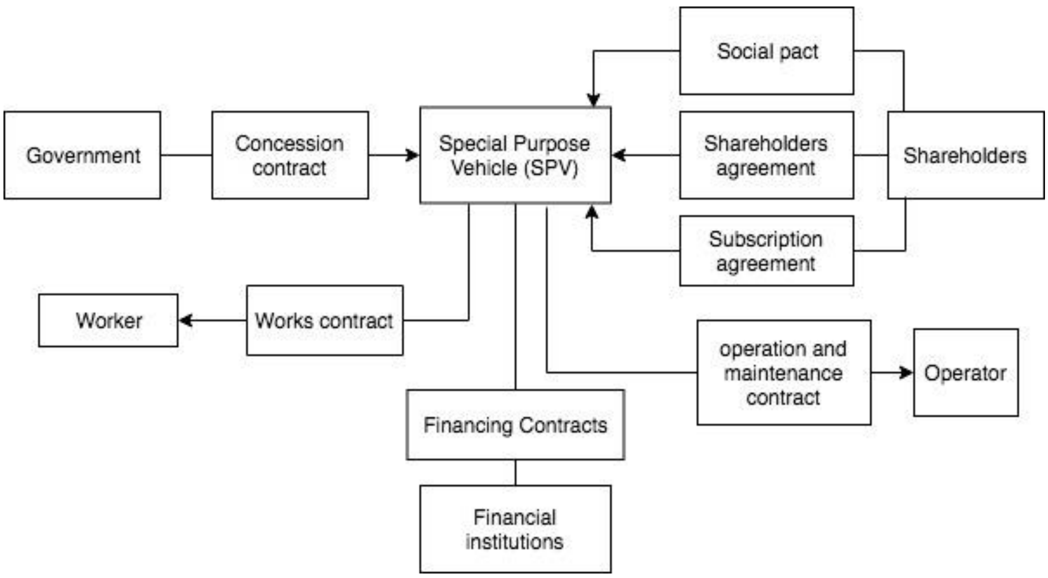


Figure 21 – PPP model usually used in Portugal. Source: adapted from Cruz (2018).

Even though the construction and operation of the road is responsibility of the private company, the Government must ensure the road infrastructure is working well. It is responsibility of the State to ensure that the service offered by the private institutions is reaching the expectations of the contract. Therefore, this model requires that the Government is continuously monitoring the service provided and quality of the infrastructure.

There are many reasons for the State to opt for a PPP, such as management flexibility and a better integration of the different phases of the project (concession, construction and operation). These factors might guarantee that the costs of the infrastructure are lower in the long run. Moreover, the Government transfers some risks to the private company, such as missing deadlines and other costs.

As mentioned earlier, PPP allows that the costs of the project are spread throughout time. Moreover, while the project is under construction, the government does not make any payments to the private companies. The payments only start when the structure opens to public utilization (Figure 22).

When the payments are based used, it means that the government pays based on the traffic flow on the roads. Payments based on availability means the private company must guarantee a level of service according to the contract to be paid by the government; the payment of this method is independent of the volume of traffic on the infrastructure.

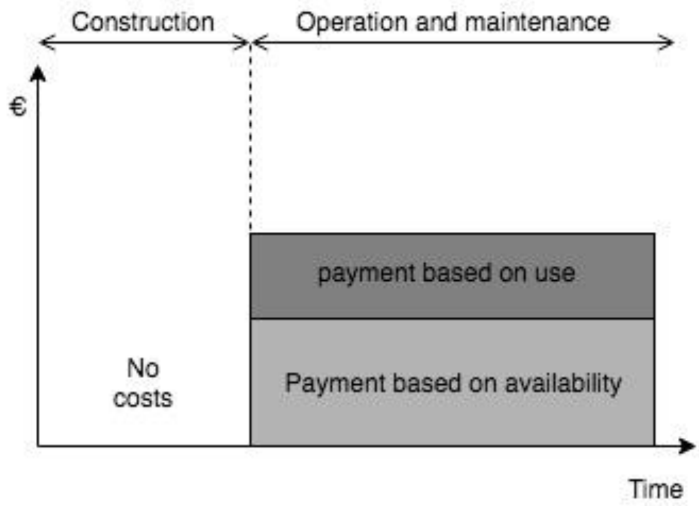


Figure 22 – Cash flow of PPP model. Source: adapted from Cruz (2018).

4.1.1.1. Advantages of PPP

One of the main advantages of PPP is the integration of the phases of the project (concession, construction, operation and maintenance), which allows the optimization of solutions and risk reduction. Therefore, there is a reduction of costs and errors, which also decreases the time for the construction of the project.

The integration of the phases allows the launch of bigger public tenders, attracting bigger companies, which results in greater competition. As a result, the Government can focus more on the service provided and less on the technicities of the project. The State is then more focused on planning and regulating.

In addition, the major advantage of PPP is that the government raises private investment towards the construction of public infrastructure. Therefore, reducing the impact in the public budget while growing the road network infrastructure of the country.

4.1.1.2. Disadvantages of PPP

On one hand, raising private investment towards public infrastructure is an advantage. On the other hand, it can become a disadvantage when the projects are developed regardless of its economical worth. As mentioned earlier, when the project is developed through a PPP, there is immediate impact on the public budget, therefore it is easier to get projects approved without doing a thorough cost-benefit analysis.

Another disadvantage is that it is necessary to define the lifetime of the project (30, 40 or 50 years) with cost and revenues estimation. The long time of the project and its complexity makes it difficult to make such estimations without errors. Therefore, new negotiations need to be made between the government and the private companies. Usually, they result in large cost and loss of quality of service.

4.1.1.3. Renegotiations

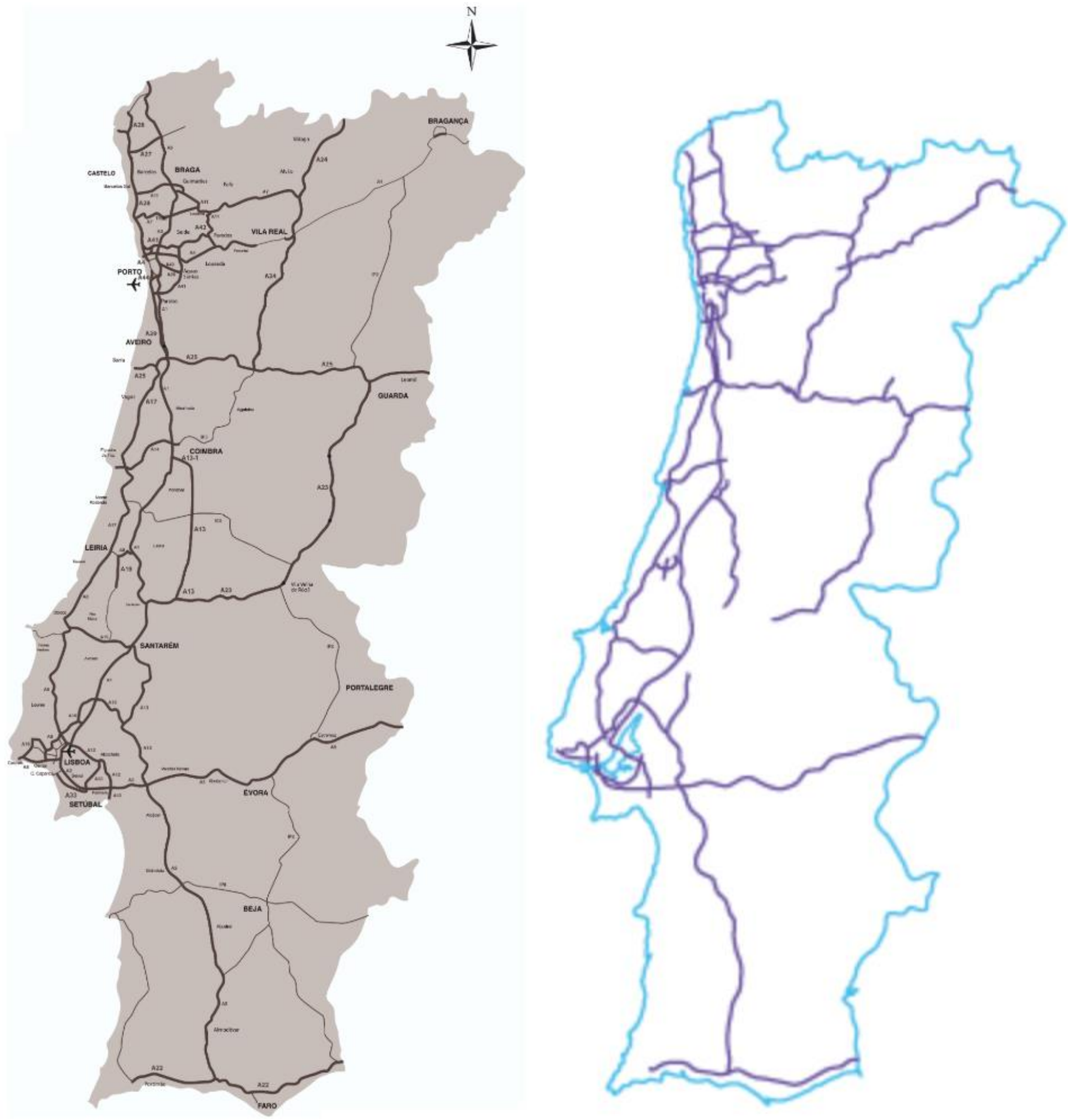
The renegotiations happen because, usually, the contracts are incomplete since it is impossible to predict everything that is going to happen during the lifetime of the project (more than 30 years). The renegotiations are not always negative for the public, it is possible that both parts are benefited from these.

Renegotiations are very common in Portugal. Between 1995 and 2010 there were 87 renegotiations in the country. According to Cruz (2018), every contract for the motorways sector was renegotiated. This sector has an average number of renegotiations per contract of 2.1, and an average of 2.4 years elapsed until the first renegotiation.

The main cause for the renegotiation of motorway projects is to change the shape of the project, such as the location of nodes and roads. For more than half of the projects (45 out of 87) the renegotiation resulted on the increase of rates and more payments from the State (31 out of 87).

4.2. National Road System

In 2017, the national road network (Figure 23a) consisted of 17,708 km, which 15,109 km are concessions (Figure 23b) and 2,948.8 km are highways. Between 1990 and 2010, Portugal was one of the EU countries that grew its road network the most thanks to PPP, which helped leveraging money to cover the costs of the expansion.



(a) (b)

Figure 23 – (a) Portuguese road network (b) Concession roads. Source: Infraestruturas de Portugal and APCAP.

4.2.1. SCUT MODEL

SCUT means in Portuguese “Sem Custo para o Utilizador”, which translates to “No Cost to the User”. The idea of the SCUT for the Portuguese road network was designed in the 1990s. This model was the outcome of public-private partnerships. It worked by concessions receiving revenues from the so-called “shadow tolls”. Shadow toll is a specific case of PPP where there is no direct collection of road tolls from the driver. That is, for the driver there is no cost associated with the use of the road since that there is no real toll. Rather, the government pays an annual “rent” based on the volume of traffic on the roads (Santos and Santos, 2012). The money for the payments comes from the tax payers, even those who do not utilize the concession roads.

The SCUT model had the aimed to improve the accessibility and mobility of certain areas to ensure productivity gains and economic development. One of the points presented to build these new SCUT roads was to divert traffic from the older, deteriorated roads to the newer and safer ones.

According to Pereira et al (2017), the SCUT represented a cost worth of 2.65% of the Portuguese GDP in 1999, the year the construction of the SCUT started. The system consisted of seven highways, and it was about 987 km long. It accounted for 46% of the Portuguese national road network in 2008, when the constructions were finished. Unfortunately, the results were not as good as expected. The financial charges were too heavy for the government, that did not collect enough revenue to deal with the payments. Therefore, the model had to be extinguished.

4.2.2. The New Model (Ex-SCUT Model)

There was a renegotiation of the concession contracts to insert tolls on the SCUT (now, ex-SCUT). Santos and Santos (2012) argued that congestion was never an issue. The tolls were established to raise public revenues. The first tolls were introduced in 2010, and more followed by the end of 2011.

During the renegotiations, the concession companies took advantage of it to change other aspects of the contracts. For example, the renegotiation changed the way the risk was shared between the State and the private companies. There was no more traffic risk to the companies, since the model was substituted for a payment based on availability. The traffic risk and the cost generated was financed by the Infrastructure of Portugal (I.P.).

After the renegotiation, the revenue of the concession companies increased slightly (from 3,579 M€ to 3,667 M€). Although, I.P. had a net benefit of 1,420M€, this cannot be seen as improvement in social well-being since the introduction of tolls reduces the user surplus.

Great Lisbon and Great Porto areas had no financial charging before the renegotiations. It changed when the payment based on availability was introduced, where a charge of 1,508 M€ was put in the contract. It is very difficult to obtain revenues to cover this value, which means the Government was then affording a huge cost that did not exist before the new negotiations. For the same areas, I.P. got a benefit of 363 M€ through the charging tolls. The charging tolls brought economic, social and environmental losses from the decrease of utilization of the ex-SCUT.

5
THE CASE OF PORTO

5.1. The Metropolitan Area of Porto

Figure 24 shows the Metropolitan Area of Porto (AMP), which consists of 17 municipalities – Arouca, Espinho, Gondomar, Maia, Matosinhos, Oliveira de Azeméis, Paredes, Porto, Póvoa de Varzim, Santa Maria da Feira, Santo Tirso, São João da Madeira, Trofa, Vale de Cambra, Valongo, Vila do Conde e Vila Nova de Gaia – with a population around 1.7 million inhabitants, which corresponds to 17% of the Portuguese population, in nearly 2040 km^2.

Figure 24 – Metropolitan Area of Porto. Source: INE, I.P. (2018).

In 2016, the population density of the AMP was around 842 inhabitants/km^2 while the national was 112 inhabitants/km^2, which is seven times lower. Table 8 displays the demographic data of the AMP. It is noticeable that there are huge discrepancies in the population density through the region.

Table 8 – Estimative of resident population in 2016. Source: adapted from INE, I.P. (2018)

	Area (km^2)	Population density (inhab/km^2)	Population
Portugal	92,225.6	111.8	10,309,573
AMP	2,041.3	842.1	1,719,021
Arouca	329.1	64.4	21,211
Espinho	21.0	1,403.6	29,560
Gondomar	131.9	1,257.0	165,743
Maia	82.9	1,638.9	136,011
Matosinhos	62.4	2,777.0	173,339
Oliveira de Azeméis	161.1	412.8	66,496
Paredes	156.8	550.3	86,263
Porto	41.4	5,169.5	214,119
Póvoa de Varzim	82.2	758.4	62,344
Santa Maria da Feira	215.9	643.3	138,867
Santo Tirso	136.6	505.5	68,983
São João da Madeira	7.9	2,702.8	21,460
Trofa	72.0	530.5	38,210
Vale de Cambra	147.3	147.1	21,676
Valongo	75.1	1,270.1	95,411
Vila do Conde	149.0	532.3	79,327
Vila Nova de Gaia	168.5	1,708.8	300,001

5.1.1. Mobile Population

According to INE, I.P. (2018), around 79% of the population between 6 and 84 years old of the AMP is mobile, that is, it is estimated that 1.3 million people, resident in the AMP, performed at least one trip per day. The municipalities of Porto, Matosinhos and Valongo were the ones that have the largest mobile population, corresponding to more than 80%. On the other hand, Oliveira de Azeméis, Santo Tirso and Póvoa de Varzim were the municipalities that presented the smallest mobile population, as seen in Figure 25.

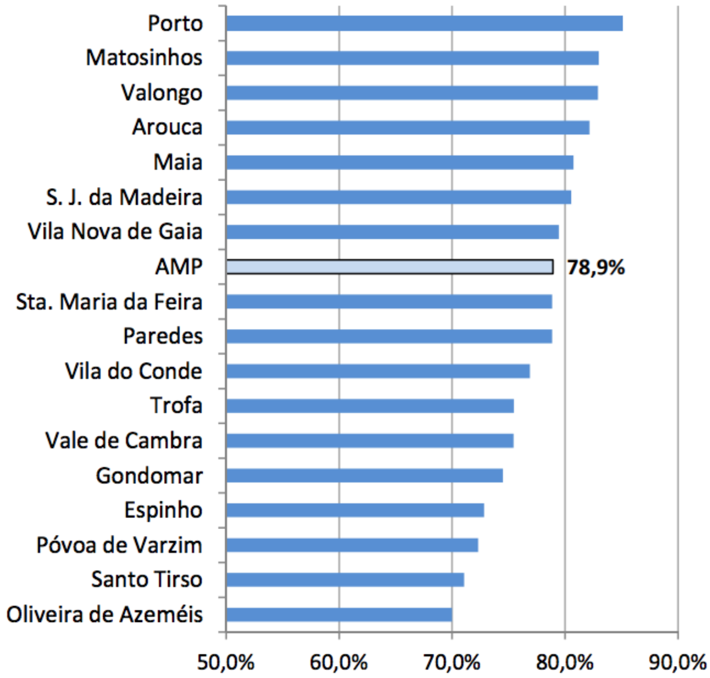


Figure 25 – Mobile population per municipality of the AMP. Source: INE, I.P. (2018).

Many factors affect the mobility of the population, such as level of education and income. The population who did not finish high school are the ones who travel the least. Meanwhile, the ones who have finished university are the ones who travel the most. Moreover, the level of income clearly affects the mobility of the population. As Figure 26 shows, the population with the smaller income, travels the least.

Figure 26 – Mobile population by monthly average net income. Source: INE, I.P. (2018).

5.1.2. Mobility Expenses

The data shown in this section was obtained from INE, I.P. (2018).

5.1.2.1. Fuel

Drivers from the Metropolitan Area of Porto spend, in average, 60 to 150 euros per month with fuel. Porto is the municipality with the largest percentage of residents that do not spend money with fuel

(28%). This is probably due to the public transportation alternative, such as metro lines. Students and professionals are the ones who spend the most with fuel.

5.1.2.2. Parking

Parking is a common expense for almost 32% of the residents of AMP. The population of Porto is the one who spend the most with parking. 6.4% of Porto's residents spend more than €50/month with parking, which is a very elevated cost.

Following Porto with the largest expenses with parking are the municipalities of Póvoa de Varzim (31.6%), Matosinhos (27.8%) and Vila do Conde (27.3%). Again, students and workers are the ones who spend the most with parking.

5.1.2.3. Public transport

Residents from Porto, Vila Nova de Gaia, Matosinhos and Gondomar are the ones who spend the most with public transportation. Probably because these municipalities are covered by the metro lines. Students are the ones who spend the most with public transport.

5.1.2.4. Road tolls

41.5% of AMP residents with vehicles spend money on road tolls. The drivers that spend the most with road tolls are located in Póvoa de Varzim, Valongo, Vila do Conde and Santo Tirso. Although, most of the population of AMP does not have a large cost with road tolls, averaging less than €10 per month.

Workers are the parcel of the population who spend the most, around €30 per month on road tolls.

5.2. Mobility Analysis

5.2.1. Modal Split

The growth of the population of the AMP has been creating pressure on individual and collective transports. The City of Porto has been having population losses, from 300 000 inhabitants in 1991 to 233 000 inhabitants in 2011; now, the city with the largest population in the AMP is Vila Nova de Gaia, with 301 000 inhabitants.

Most of the movements in the AMP are produced using individual cars, primarily as the driver (more than 50% of the cases), but also as the passenger (almost 17% of the cases). Walking and cycling come as the second most use of transportation of the region.

Cars are the main mode of transportation used in the municipalities of Oliveira de Azeméis (84%) and Santa Maria da Feira (82%), presumably for lacking a good public transportation system. On the other hand, Porto (48%) and Espinho (57%) were the municipalities that cars are used the least for movements. It is also where cycling and walking have the highest percentage of usage.

5.2.2. Mobility Patterns

Figure 27 and Figure 28 show the travel patterns to and from Porto, respectively. Vila Nova de Gaia is the city that has more people traveling to Porto. On the other hand, most of the trips starting in Porto have Matosinhos as destination.

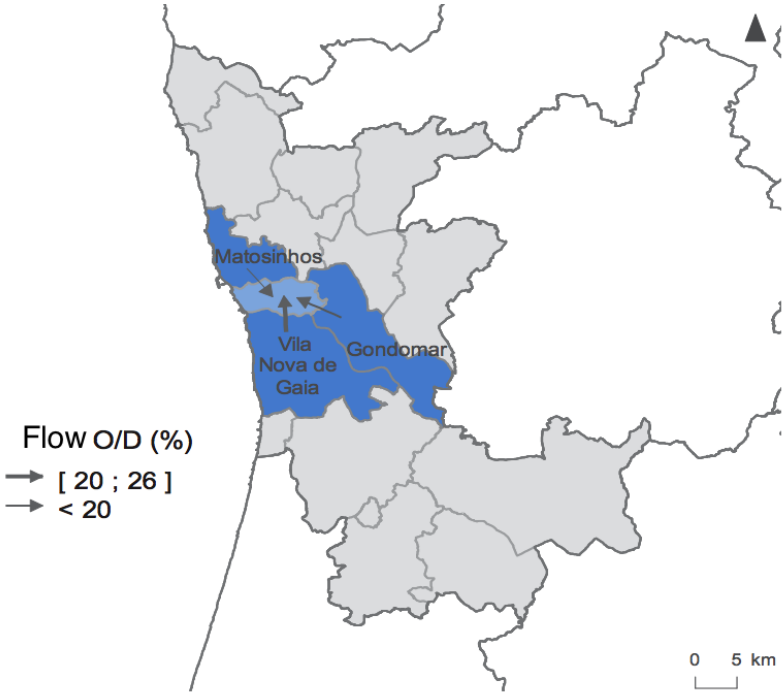


Figure 27 – Three main cities of travel origin to Porto. Source: INE, I.P. (2018).

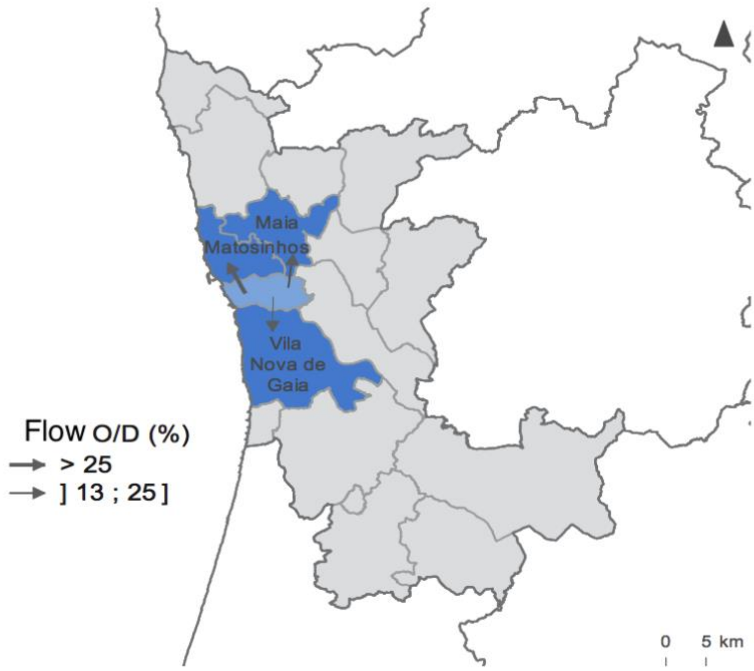


Figure 28 – Three main cities of travel destination from Porto. Source: INE, I.P. (2018).

The way the charging is done in Porto and its surrounding area affects the travel patterns of the drivers. For example, none of the charged roads present an Annual Average Daily Traffic (AADT) higher than 60 000 vehicles. In other words, the drivers opt to take the roads that are not charged, creating excessive congestion on few roads while the charged ones are underused.

Figure 29 analyzes the movements from Grijó in Vila Nova de Gaia to Lavra in Matosinhos. That is, from the South to the North coast of the AMP. If the driver chooses to go through the Arrábida Bridge, there will be a cost of 0.60€ and a distance of 31.4 km. If the driver opts for the Freixo Bridge, the cost is of 1.25€ and the distance is 35.9 km. If the driver decides for the longest path of 59.4 km utilizing the A41 motorway, the cost is 4.80€. The obvious choice is the first one: Arrábida Bridge, which presents the highest AADT and congestion.

Figure 29 – Movements from Grijó to Lavra. Source: Cruz (2018).

Figure 30 displays the movements from Grijó to Braga. The motorway options are the same of the previous example: A28, A20 and A41 with respective prices of 0.60€, 0.60€ and 3.80€, and respective distances of 35 km, 29.7 km and 47.3 km. This time, the obvious choice is Freixo Bridge, which is heavily utilized.

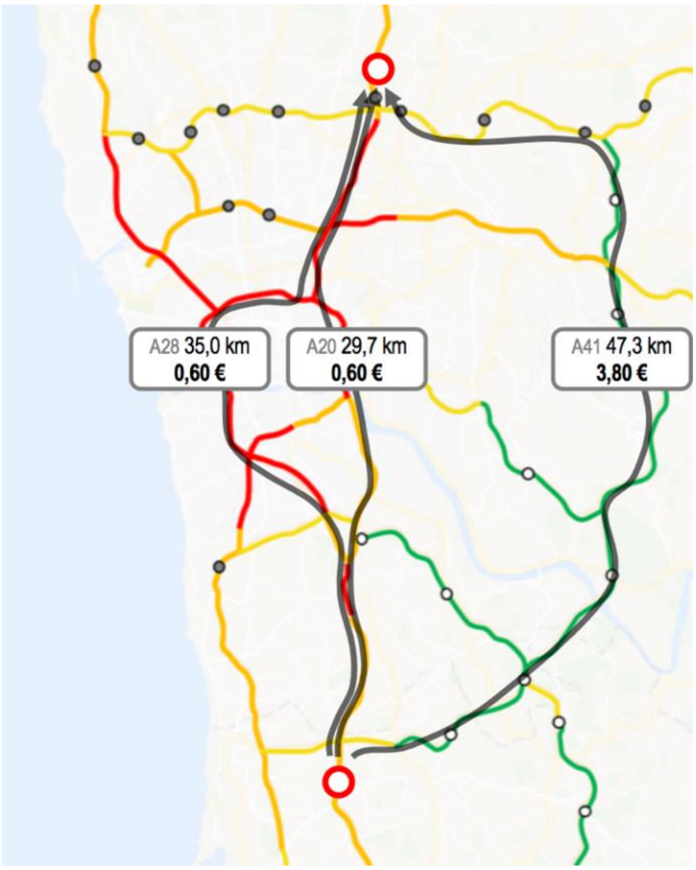


Figure 30 – Movements from Grijó to Braga. Source: Cruz (2018).

The movements from the North coast to the West of the AMP are displayed in Figure 31, with trips from Leça da Palmeira in Matosinhos to Ermesinde in Valongo. If the driver chooses to go through the A41, there will be a cost of 1€ and a distance of 19.8 km. If the driver opts for the A4, the cost is of 0.65€ and the distance is 12.7 km. If the driver decides to take the longest path of 20.2 km through the Internal Circulation Path (VCI), there is no cost.

As mentioned before, the roads with no charging are the most congested ones. The drivers opt to take the VCI since there are no tolls, but their choice inflicts the biggest marginal cost of all the options and the most externalities (noise, air pollution, loss of time). The A4 presents the shortest distance, least externalities and less congestion than the VCI, but since there is a charge of 0.65€, the users still opt for the VCI.

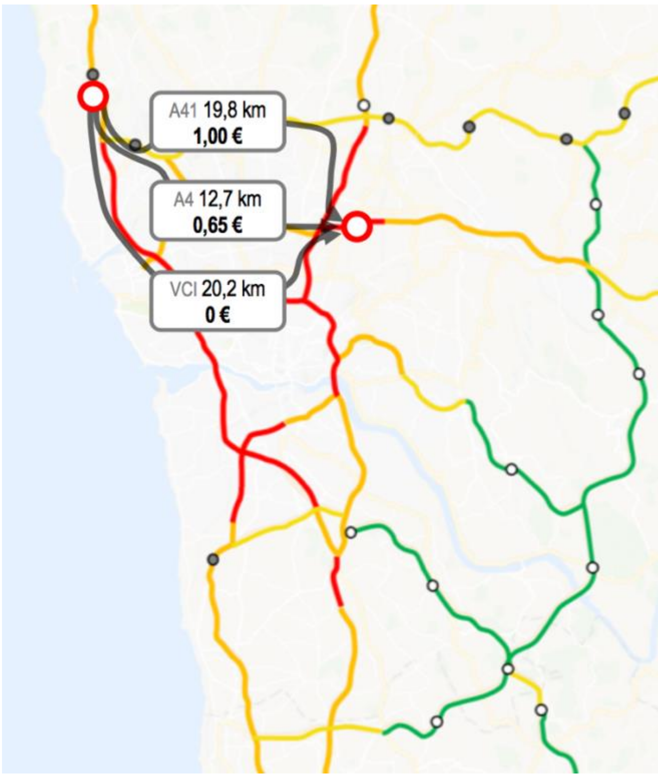


Figure 31 – Movements from Leça da Palmeira do Ermesinde. Source: Cruz (2018).

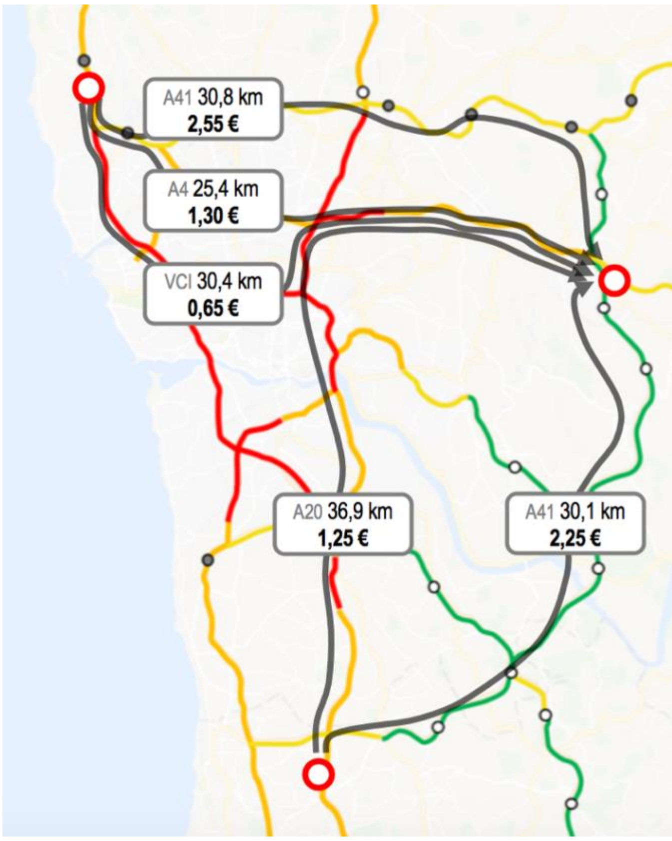


Figure 32 – Movements from Matosinhos and Espinho to the East of the AMP. Source: Cruz (2018).

Figure 32 shows both the movements from the North coast (Matosinhos) and from the South coast (Espinho) to the AMP interior. Again, it is noticeable that the drivers opt for the cheapest path through the VCI or A20 (Freixo Bridge), even though those are the roads with the worst congestion. It is evident that the drivers do not take into account the costs that they are imposing on other drivers by using an already congested road.

6
COST-BENEFIT ANALYSIS

Cost-benefit analysis is a form of appraisal. That is, considering the impacts, both positive and negative, of a project to inform the decision makers. CBA is a general method for comparing benefits and costs of prospective projects (Small and Verhoef, 2007). It is focused on the economic effects that different projects might bring to a community. Although it should not be used as a complete decision instrument, it includes many elements (externalities) that are considered non-economical, such as noise, air pollution and loss of time. Table 9 summarizes the main cost and benefits in road projects.

Table 9 – Cost and benefits in road projects. Source: adapted from Cruz (2018)

	Costs	Benefits
Direct	Planning costs (project, planning, traffic studies, etc)	Tariff revenue (tolls)
	Construction investments	Ancillary revenues (toll plazas, service stations)
	Expropriations	
	Operation and maintenance costs	
Indirect	Environmental costs	Time
		Casualties
		CO_2 emissions

The main characteristics of cost-benefit analysis, according to Mackie and Nellthorp (2009), are:

- CBA considers all relevant costs and benefits from a social perspective;
- The evaluation process starts on the maximum amount of money that the user is willing to pay for the trip. This is also called willingness to pay;
- All the cost and benefits are expressed in monetary terms, either market prices (more commonly used for PPP) or factor costs;
- Compiles the cost and benefits during the life of the project.

Figure 33 displays the CBA process in a transport utilization, such as road infrastructure improvement or road pricing. The major elements of the figure are: user benefit estimation, investment costs, cost and revenue of operator, impacts on government (e.g. taxation), externalities. Comparing the user benefits and the effects the revenues will cause with the investment, operation, maintenance and other costs.

CBA makes important contributions to the decision process of a project. However, the quality of the input data, such as forecasts, is very important to the success of the analysis.

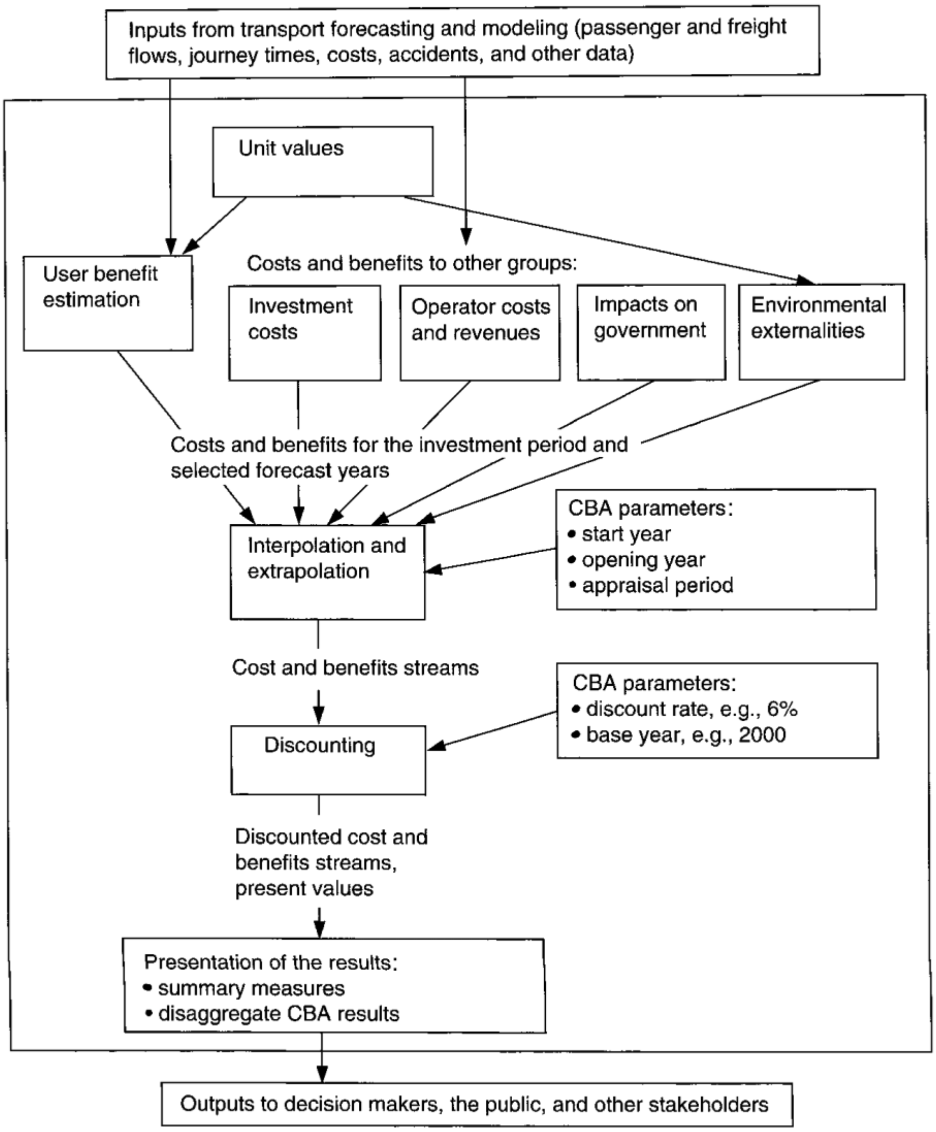


Figure 33 – CBA process. Source: adapted from Mackie and Nellthorp (2009).

To carry out a cost-benefit analysis, the main steps to be taken are (Mackie and Nellthorp, 2009):

- Inputs: modeling and forecasting inputs in terms of trip, cost and time; estimation of the investment costs, changes in infrastructure and operation costs; and estimation of the number of accidents and casualties, and environmental impacts;
- Cost and benefit estimation: usually, the rule of a half is used. This rule can be applied to transport schemes that interact with other components of the transport system where the demand curves are approximately linear (Button, 2009);

- Interpolation and extrapolation: this step calls for growth rates for quantities and unit values to attain cost and benefit streams over the entire evaluation period;
- Discounting: future cost and benefits are updated accordingly with public sector conventions on discount rates;
- Summary measures: gives an overall measure of the project's performance in cost-benefit terms.

The essential summary measure of the net social benefits is the net present value (NPV):

$$NPV = \sum_{t=0}^{t=n} \frac{B_t - C_t - K_t}{1+r} \tag{6.1}$$

where,

B_t are the benefits in the year t;
C_t are the recurring costs in the year t;
K_t are the investment costs in the year t;
r is the social discount rate;
n is number of years in the assessment period.

Usually, the projects with a positive NPV are accepted, since it is assumed that society will be improved with the project when $NPV > 0$.

6.1. CBA OF THE CASE OF PORTO

As seen in Chapter 4, the concession companies slightly increased their profit while removing the risk of traffic. Beyond the financial aspects of the change from SCUT to tolled roads, a CBA is needed to define the change created value for society. That is, if the benefits (direct and indirect) of the change overcome the costs.

The following impacts were considered for the CBA:

- Time: the introduction of tolls moved the traffic to secondary roads, with a smaller capacity, creating more congestion;
- User costs: using a vehicle might be more or less costly depending on what road the driver takes;
- Environmental externalities: the diverted traffic to the other roads increase the level of CO_2 and NO_x emissions;
- Casualties: the occurrence of casualties in secondary roads is more common than in main roads, which are now being charged.

Other consequences are seen when road charges are introduced, such as impacts in the local economy and the creation or loss of jobs. This analysis fails to check the costs of the maintenance of the secondary roads, which had their traffic increased after the change. Table 10 shows some of the costs and benefits associated with the change of the road tolls in and around Porto.

The net profit for I.P. is positive since there is a new revenue source, the road tolls. On the other hand, the user costs are negative since the tolls are an extra cost for the road user. Moreover, the alteration of route and longer distances also have a negative impact on the user costs.

The environmental externalities express the CO_2 emissions by the vehicles. The impact is negative because the traffic is diverted from the ex-SCUT to the secondary roads, which are more congested. The slower speeds increase the time that the cars are stopped which increase the CO_2 emissions.

The diversion of traffic to the secondary roads also has a negative impact on the casualties. According to Pereira et al (2017), the introduction of the tolls in the SCUT roads have increased the number of accidents. He estimated that the light injuries only represent a loss of 31.2 M€ per year.

Time represents the most negative impact. Since the secondary roads have less capacity and the traffic becomes slower as the roads get more congested. When summing up the positive and negative impacts, the result, or the Net Present Value, is negative. Therefore, the introduction of the tolls did not bring improvement to society.

Table 10 – Cost and benefits of the Metropolitan Region of Porto. Source: adapted from Cruz (2018).

	Costs/Benefits
Net profit for I.P.	184 M€
User costs	-31 M€
Environmental externalities	-8 M€
Casualties	-114 M€
Time	-485 M€
NPV	**-454 M€**

To get a value for the user costs, it was used an average cost of 0.36 €/vehicle.km traveled. The value for the environmental externalities were obtained by admitting an overall cost of CO_2 of 20 €. The casualties value were obtained by escalating in 3.5% the values given by Pereira et al (2007). The time value was estimated by a study made by Ernst & Young in 2012.

7
CONCLUSIONS

Congestion charging is spreading throughout the world. It started in Singapore in the 70s and then it spread over many cities in Europe in the following decades. Now, cities in the United States are starting to consider the implementation of congestion charging. For example, New York City was the first city in the US to approve road pricing (Durkin and Aratani, 2019). Inspired by the cities mentioned earlier, NYC saw congestion charging as a solution to raise money to modernize its subway network and decrease excessive congestion within Manhattan.

The cities studied in this dissertation (Singapore, Stockholm, Oslo, London and Edinburgh) have had success in the implementation of road pricing, with the exemption of Edinburgh where the charge was not implemented. In the case of Edinburgh, the scheme was confusing and improvements in the public transportation system of the city were not planned to be implemented at the same time that the charge would begin to take effect. Therefore, the population rejected the scheme in a referendum.

Even though the schemes in Singapore, Stockholm, Oslo and London were carried out in different ways, they all have in common the fact that there were huge investments in public transportation and bicycle lanes. It is possible to conclude that when congestion pricing is implemented along with big investments in other modes of transport, there is a great chance that the scheme will be successful and accepted by the population. Another common point is that the acceptability elevated in the four cities after the implementation of the scheme, due to less congestion and pollution, higher speeds and better quality of the air.

The cities that were successful in the implementation of the scheme have applied the theory of traffic congestion as a way to decrease excessive congestion and pollution within the city centers and to eliminate the economic inefficiency that excessive congestion causes. By charging the drivers a congestion fee, they become aware of the congestion cost aspects they impose on society, and society will benefit of a welfare gain.

When the charges were applied, the city centers experienced less pollution, which proved that the marginal costs rise to drivers when there is environmental improvement. Therefore, when the marginal costs were raised by the congestion charge, the drivers became aware of the cost their actions (joining an already congested road) impose on society. Thus, achieving one of the objectives of congestion charging.

Portugal was the member of the EU that expanded its road network the most between 1990 and 2010. For that to happen, the Portuguese Government made use of PPP, which has the advantage of integrating different phases of the project and, therefore, reducing the costs and time spent. On the other hand, the projects might be developed without thorough economic analyses that might lead to renegotiations, which was the case of Portugal.

Before the renegotiations, the drivers were not charged to drive in the SCUT roads ("No Cost to the User" roads). Unfortunately, this model was too financially heavy on the Government. Therefore, the model had to be extinguished and replaced for a new model where the roads are tolled.

After the renegotiations, the ex-SCUT model was established to raise public revenues, where the drivers were now charged to drive on the roads. Moreover, the way that the risk was shared between the Portuguese Government and the private companies was changed. Now, the traffic risk was borne by the Government. Another advantage the concession companies got from the renegotiations was an increase in the revenues. Therefore, the charging tolls brought economic, social and environmental losses to society from the decrease of utilization of the ex-SCUT, which was later proved by the result of the CBA.

For the Metropolitan Region of Porto, the road pricing scheme was not as successful as in the other cities studied in this dissertation. The charged roads did not have the effect of making the drivers aware of the costs they are imposing on society by joining an already congested road. The drivers opt to take the secondary roads, which have smaller capacity but are not tolled, even though those roads correspond to the longest path and are more congested. Thus, the primary roads are underused.

The CBA of the case of Porto showed that Infrastructures of Portugal obtained a positive net profit from charging tolls, which lead to negative user costs. The CBA also displayed that the environmental externalities are worse after the renegotiations because the drivers spend more time stuck in traffic in the secondary roads, therefore the cars emit more CO_2. Time lost at the secondary roads represented a huge negative impact on the CBA. The result of the CBA showed that the net present value is negative and, therefore, the introduction of the ex-SCUT model did not bring improvement to the Portuguese society.

It is possible to conclude that the location of the charging tolls was not made in a rational manner by following a thorough economic analysis. The current distribution of the tolls is contributing to an imbalance of the distribution of modal split between the individual transport and public transport. This results in increased congestion in the region of the city of Porto, which are proved by the analysis done on the mobility patterns of the region.

It is needed to relocate the traffic from the secondary roads to the primary and underused roads. It is not logical or economically efficient to charge the same amount both on uncongested roads and congested roads. Therefore, it is necessary to rethink the locations and amount charged of the tolls. Moreover, changes in the road pricing model with huge investments in public transportation and other modes of transport, such as bicycles, would be greatly beneficial for the mobility of the city of Porto.

The next step would be proposing a new road pricing system for the city of Porto, where the location of the tolls and the price charged would make sense from an economical and financial point of view. Also, the new location of the tolls would contribute to a better balance between the use of public and individual transportation. A thorough research and study would make the road pricing system in Porto successful, as in the cities showed on chapter 3, where the Porto society would have social, economical and environmental benefits.

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