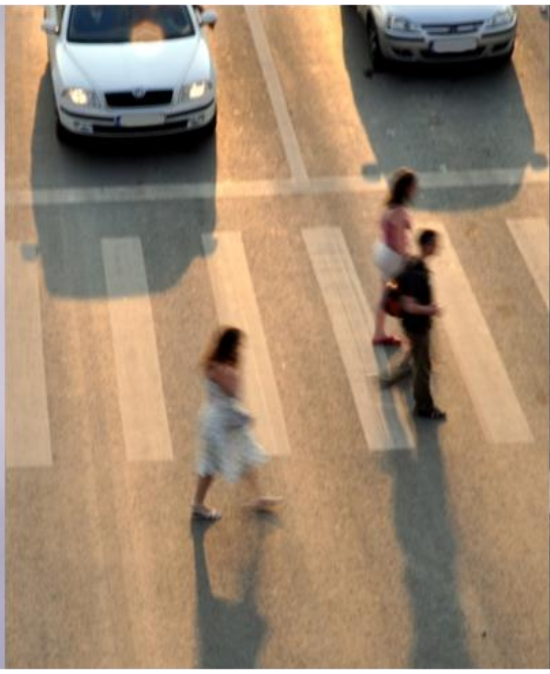

Introduction to Congestion Charging

A Guide for Practitioners in Developing Cities

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

of the Federal Republic of Germany

Disclaimer

Acknowledgement

This report is a product of knowledge and experiences from many experts who contribute to the discussion of methodology development, data collection and process, and results evaluations. We would like to extend our special thanks for their review and contribution to Steve Kearns (TfL), Armin Wagner (GIZ), Peter Jones (UCL) and Manfred Breithaupt (GIZ).

Introduction to Congestion Charging

A Guide for Practitioners in Developing Cities

Dirk van Amelsfort, Viktoria Swedish ICT

The Project Context

The economic growth of the People's Republic of China (PRC) over the past three decades has had some undeniably positive effects on the country's development. But it has also led to a massive increase in motor vehicle travel and associated traffic problems, especially in large cities. In Beijing, more than five million cars cause severe local air pollution and traffic congestion as well as increasing parking problems and accident costs. In addition, transport GHG emissions have become a key challenge for sustainable development in the PRC and on a global level. Neither roadway expansion nor the development of new car technologies alone can solve these problems; in fact, these strategies often reduce one problem but increase others. Transport Demand Management (TDM) offers sustainable solutions which help achieve multiple planning objectives.

On behalf of the *Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety* and the *Beijing Municipal Commission for Transport* (BMCT) the *Beijing Transport Research Center* (BTRC) and GIZ (*Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH*) implement the Sino-German project 'Transport Demand Management in Beijing'. The project aims to build capacities in the Beijing municipal authorities, to quantify and model the impact and benefits of various TDM strategies. In 2013 and 2014 the project supported local partners in Beijing to explore scenarios for introducing congestion charging. This guide reflects lessons learnt from this exercise.

The technical Beijing Sustainable Urban Transport project, supported the Beijing Municipal Government in finding suitable and sustainable solutions to its urban transport problems. Three main types of strategy options were examined: (i) TDM strategies including restricting vehicle ownership and usage, parking pricing, and charging schemes; (ii) infrastructure improvement strategies; and (iii) traffic operation improvement strategies. The congestion charging schemes analysed in the project are reflected in this guide.

Abbreviations

ALS	Singapore Area Licensing Scheme
ANPR	Automatic Number Plate Recognition
BMCT	Beijing Municipal Commission for Transport
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BOT	Build–operate–transfer
BTO	Build to order
BTRC	Beijing Transport Research Center
CBA	Cost–benefit analysis
DSRC	Dedicated Short Range Communication
ERP	Electronic Road Pricing
GHG	Greenhouse Gas
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GNSS/CN	Global Navigation Satellite Systems/Cellular Networks
GPS	Global Positioning System
IU	In-vehicle Unit
NLOS	Non-Line of Sight Multipath
OBU	On-Board Unit
OCR	optical character recognition
P&R	Park and Ride
PT	Public Transport
RFID	Radio Frequency Identification
TDM	Transport Demand Management
TfL	Transport for London
UCL	University College London

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Introduction

This guide is intended for policy makers interested in congestion charging as a potential policy to mitigate congestion in cities. The term 'congestion charging' is used to describe a distance, area or cordon based road-user charging policy around congested city centres as it has been introduced in Singapore, London or Stockholm. It does not cover priced-managed lanes which became popular in the United States in the last decade.

The report attempts to provide concise information for early stages of scheme definition and development and guides through key decision-making processes. Its final objective is to describe how to develop the conceptual idea of 'charging' into a solid and feasible policy. It is split into modules, of which different audiences can choose those chapters, which may appeal to them, depending on how far the idea of congestion charging has matured for you and your organisation. If you want to know what congestion charging is all about, start reading at chapter 1. If you know the basics but need more information on how to get there, start at chapter 3.

The focus of the background part (chapter 1 and 2) is on explaining what congestion charging is without using the usual scientific terminology. It provides summaries of the effects in some of the good examples and it explains political and public resistance towards congestion charging. If you are completely new to congestion charging and still doubt if it is effective and lack information on good examples, this is the right place for you to start reading.

The second part of this guide (chapter 3 to 6) focusses on the process and steps that are necessary in order to create a suitable congestion charging policy for your city or region. First, the overall process and steps are discussed and in following chapters the detailed aspects of the process are considered. Depending on your current state of knowledge on congestion charging you may either want to skip the detailed chapters, as they may not yet be of interest for you, or if you are looking for detailed information continue to one of the specific chapters.

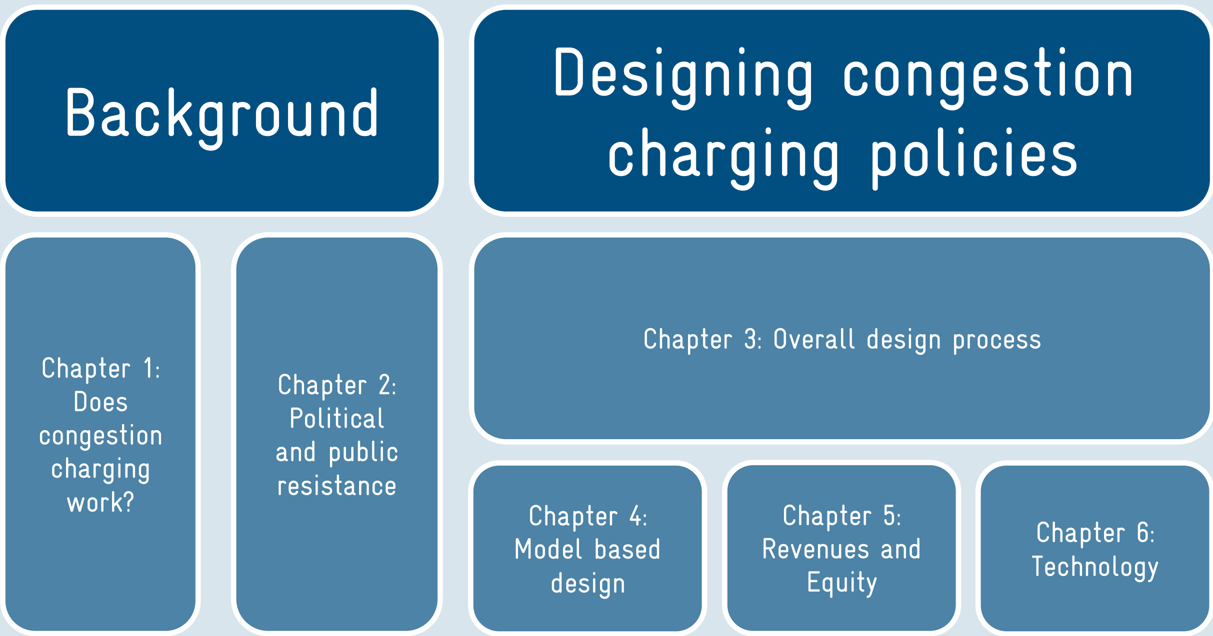


Figure 1: Modules of the guide can be found in these chapters

1 Does congestion charging work?

Every road has some limits on its capacity, in this example we say 1,500 cars per hour. If 1,400 cars try to use the road, there are no capacity problems and everything works fine. Traffic may flow slowly, but people get to where they want to go to within a reasonable time. During rush hours however there may be 1,600 cars attempting to access the road at once. Then congestion occurs and traffic slows down to a crawl. This affects not only the last 200 cars joining, but also the 1,400 original drivers.

If there is a way to persuade 200 of the 1,600 drivers to shift their road usage outside the rush hour period or perhaps even to take the bus instead, heading for another place or spending the time to making a telephone call instead of driving immediately, then the remaining 1,400 will be able to enjoy short and predictable journey times.

One way of persuading some drivers not to drive is to outright ban it. For example, by only allowing odd licence plate numbers on odd dates and even numbers on even dates. But this has the obvious drawback that it disregards the driver's desire to travel. An alternative way of dealing with issue would be to impose a fee on every driver that wants to use the road during the rush hour. The fee could be set to such an amount that precisely 200 drivers might decide to do something else than driving on this particular road during rush hour. Besides, if all societal costs would be included in the fee, it should be set much higher. Those travellers paying the charge can enjoy not being stuck in queues and the ones not willing to pay and choosing to do something else can enjoy not having to pay. The income from these fees can be used for example to improve public transit, invest in bicycle infrastructure or to resolve other infrastructure bottlenecks.

If more people access a road than its capacity would actually allow, then some method will decide who gets to use it and who doesn't. If no scheme is implemented, the usual method is queuing. And while a queue can appear an equal way of distributing the resource, it has a clear downside - the time people spent queuing is lost time for the driver, who is not able to use it for something more useful. If a small fee scheme is implemented instead of a queuing up to manage traffic flows, then the money can be collected and used for other purposes. In a nutshell: Charging does not only eliminate traffic jams, but we are able to collect money perhaps for new buses and better roads.

The general premise of congestion charging

Each traveller makes travel decisions which are in his/her own best interest. But these decisions also have consequences for others. When people drive cars, they contribute to road damage, emit harmful pollutants, noise and vibrations and cause delays for others. Considering this, the travel decision of one individual imposes costs on others. In most transport systems the costs imposed on others are not fully paid for by the traveller. Congestion charging is a way to put such costs on drivers.

With regard to congestion, there are several important issues to understand and consider:

1. **Throughput of a road decreases with too high levels of demand.** As demand for a road increases and approaches capacity, the throughput of this road is highest. If heavy congestion occurs and traffic flow stalls, the capacity of the road becomes significantly lower. This implies that the same road is capable of higher throughput when traffic flow does not stall.

2. **The relationship between traffic flow and travel time is non-linear.** Every extra vehicle on a road leads to a higher increase in travel time than the previous vehicle. This also implies that it is not necessary to reduce the number of vehicles by half in order to reduce congestion by half.
3. **Congestion is both temporal and spatially bound.** Congestion occurs at specific points in the network and at specific times. This implies that policies combatting congestion need to be adaptive to time and place in order to be most efficient.

Background – Marginal social cost pricing

The principle of marginal social cost pricing is displayed graphically below. The vertical axis represents the travel costs while the horizontal axis represents the traffic volume. The demand for traffic increases when costs decrease and vice versa. This relation is shown by the demand curve. For individual travellers the direct travel costs can be interpreted as the sum of all costs, such as travel time, fuel costs, parking, etc. As more travellers enter the system and increase the traffic volumes, the travel costs will increase, since travel time increases. Therefore the direct average cost for a traveller is also depending as well on the overall traffic volume. Where the demand and the direct average cost curves intersect, the untolled equilibrium is reached. That equilibrium is to some degree a stable traffic situation that is normally planned for, yet with day to day and seasonal variation.

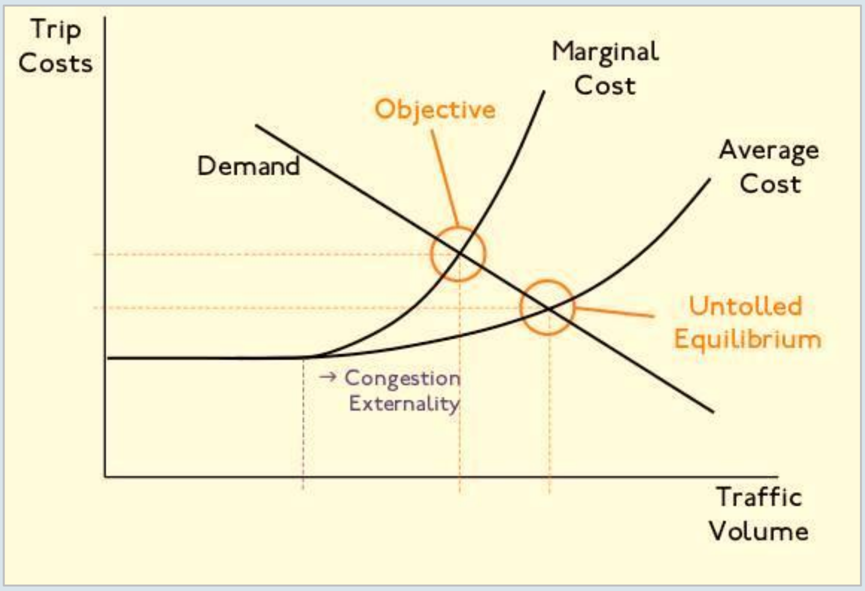


Figure 2: The impact of external costs on the demand and supply equilibrium.

But direct average user costs faced by travellers do not give a true figure of the real costs for the society, as it does not take into account, that drivers impose costs on others. When taking the external costs into account, the experienced travel costs will be higher and increase more rapidly as traffic volumes increase. The marginal cost curve includes these external costs and indicates the cost that each extra vehicle will impose on itself and the system. Therefore the curve intersects with the demand curve already at a lower traffic volume. The new equilibrium assumes that people would take all costs into account, which would in turn result in a lower overall demand. The objective of congestion charging in its purest economic form is to increase the travel costs from the level of un-tolled equilibrium to the point of optimal equilibrium. This will reduce traffic flows and congestion.

Given the enormous amount of research about congestion, it may seem rather surprising that so little implementations exist around the world. This could be explained by fear that congestion charging may not work and will not be accepted. The feeling that people have no option when going to work other than by car and do not have an alternative may prevail. But if this is obviously not true for all groups of travellers and also not all trips are work related. The examples of Gothenburg, London, Milan, Rome, Singapore and Stockholm demonstrate the feasibility and effectiveness of the policy.

Further reading on case studies is available in a wide range of publications. A recent and detailed description of experiences in London, Milan, Singapore, Stockholm and New York was published by the Energy Foundation in English and Chinese: www.efchina.org/Reports-en/report-20140814-en

Traffic effects of congestion charging

First, it is important to realise that no rule of thumb for traffic effects exists. When mostly data for London, Stockholm and Rome was available, some people suggested that congestion pricing was able to reduce traffic volume by 20%. In fact, traffic volumes may decrease in a range of 10-30 %, depending on the design of the system. But even more important indicators are the reductions in travel times, travel time variability and vehicle kilometres travelled (see Table 1).

Table 1: Traffic effects of different congestion charging schemes

	London	Singapore	Stockholm	Milan	Gothenburg	Rome
Traffic volume	-16% (2006) -30% chargeable vehicles, +25% busses, +15% taxis, +49% bicycle -21% (2002-2008)	-44% after ALS -10%-15% after ERP compared to ALS - 20%-30% for other extensions of the system	-20% across the cordon	-34% (-49% in user of heavy polluting vehicles)	-10% across cordon, -2.5% vehicle-km in Gothenburg	-20% over cordon +15% motorcycles
Travel times	-30% delays	speed criteria charge levels between 20-30 kph and 45-65 kph	-33% in delays	-17% in congestion +7% bus speed, +4.7% tram speed	-10-20% reduction median travel time on corridors	+4% in speeds +5% speeds PT
Public transit ridership	+18%	n.a.	+5%	n.a.	+6%	+5%

It is clear that congestion charging has a significant impact on traffic volume, travel times and speeds (which may be increased by 4% and 33%). In general, one would expect that the reduction in volume would be smaller than the reductions in travel times since there is a non-linear relationship between volume and travel times, but this does not appear in all cases. This could be a result of rerouting or increased internal traffic within the charging zone. It is furthermore evident that public transport ridership increases as a result of congestion charging.

Environmental effects

One of the main rationale for supporting congestion charges is reducing emissions and creating a more sustainable transport system. Besides climate change and global warming, which is a problem on a global scale, emission of toxic gasses leads to premature deaths.

Table 2: Exemplary environmental effects

	London	Stockholm	Milan	Gothenburg	Rome
CO2	-16.4%	-13%	-22%	-2.5% (region)	-21%
NOx	-13.4%	-8%	-10%	Uncertain	n.a.
PM2.5	n.a.	n.a.	-40%	Uncertain	n.a.
PM10	-15.5%	-13%	-19%	Uncertain	-11%

Traffic safety effects

Traffic safety effects of congestion charging are not clear from the outset and may be both positive and negative, depending on where in the network changes in volume and speeds do change. In Rome for example, some car drivers shifted to motorcycles, leading subsequently to a higher accident rate. However London and Milan report improvements in traffic safety.

Table 3: Exemplary traffic safety effects

	London	Stockholm	Milan	Gothenburg	Rome
Accidents	-33% (2003-2014) (UK overall around -35%!) -40 - 70 reduction in number of injuries annually	Inconclusive from measurements, from modelled impacts 9%-18% reduction of accidents were anticipated for different roads	-28%	Uncertain	More accidents due to motorcycle increase

Economic effects

The macro-economic effects of congestion charging are at the rationale core of congestion charging. By raising the effectiveness of traffic economic benefits are created somewhere in the economy. The most visible and direct effects of congestion charging are often reductions in travel time and improvements in travel time reliability. These lead to cost reductions for companies and increased flexibility for travellers. An example of indirect benefits may be that improvements in air quality lead to lower health care expenditures. The initial benefits of gains in travel time, may also be converted to other benefits such as converting road capacities to bicycle or public transit capacities.

Table 4: Exemplary Economic Effects

	London	Singapore	Stockholm	Milan	Gothenburg
Surplus	110-150 million USD/year	51 million USD/ year (Initial investment 159 million USD)	80 million USD/year	16 million USD/year	1.8 million USD/year
Hours saved	12,000 (2007)	n.a.	30,000 per day	n.a.	n.a.
Business effects	Negligible	n.a.	+5% in retail sales	No effects on business reported, except for private parking inside zone	No effects on business found
Equity	n.a.	n.a.	Groups that pay more: - Men - High income households - Households with children	n.a.	n.a.
Revenues	352 million USD/year (in 2014)	60 million USD/year	94 million USD/year (2013) plus 12 million USD in penalty charges	28 million USD/year	99 million USD/year plus 9.6 million USD/year in fines
Investment costs	245 million USD	200 million USD (including 68,000 transponder)	Original investment costs: 217 million USD, (with redundancies and DSRC system)	7.5 million USD investment	105 million USD (including consultant costs policy development)
Operating costs	135 million USD/year, in recent years 68 million USD/ year 198 million USD in 2007/2008	12.8 million USD/year (20%-30% of revenues)	n.a.	27 million USD/year	115 million USD/year, 0.22 USD per passage = 21% of charge with low charge period, 10% in high charge period

2 Political and public concerns

Congestion charging may not improve the situation for the average driver. Business trips, freight, couriers and taxi have a direct benefit from congestion charging in the sense that direct benefits outweigh the charges. Also groups that are exempted from paying or that get compensation will experience direct net benefits. But for most people the cost of the charge will be slightly higher than the improvement in travel time. Consequently, many car drivers regard charges as a tax and see the construction of additional capacity as much more appealing than congestion charging. It appears to solve the problem and involves less direct personal costs – while putting higher costs on the society.

Picture 1: A highly developed public transport infrastructure is key to increase public acceptance for congestion charges. The picture shows a bus stop and the ERP gantry in Singapore (Photo: Manfred Breithaupt)

Following the line of reasoning of car drivers only make it impossible to generate a positive momentum for congestion charging, since politicians tend to fight for those issues that will get them positive attention (and votes). Only when taking into account that the majority of people does not drive a car in the city but use public transport, walk or ride the picture will change. Hence, the political decision making process on congestion charging and the subsequent public debate is therefore, often not driven by transport-related arguments, but rather by a set of subjective valuations. How these play out depends then primarily on the side of the political spectrum on which the debater is positioned.

As a consequence, introducing congestion charging is controversial and marked by resistance all along the way. The first category of arguments says that congestion charging is not going to work. The second category questions the analysis as inadequate. Both types of arguments are often only partly valid and can mostly be addressed within the policy design phase. In the following sections the most common arguments are discussed and some potential answers are provided to address these arguments.

2.1 Will congestion charging really work?

Whenever congestion charging is discussed as a policy option, there will be concerns that it will not work in the specific local context. Arguments are that congestion charging (1) is unfair, (2) harms the privacy of citizens, (3) not achieve the intended effects and (4) will damage the economy. All these arguments could be addressed through carefully preparing and investigating the scheme in advance.

Concern 1: Congestion charging is unfair

One of the recurring arguments against congestion pricing is that it is not fair, meaning that low income or vulnerable groups (like disabled people, young adults, elderly, etc.) are affected more than others by the charges. An important factor in how the net effect of congestion charging affects equity is determined by how revenues are used. Eliasson & Mattsson (2006) investigated the equity effects of congestion charging in Stockholm. In Stockholm the group most affected by the charge were high income males. If the revenues are then used to foster public transport, which in Stockholm is used relatively more by women and groups of lower incomes, congestion charging becomes a progressive policy. But the actual effects of congestion charging may be local and could cause problems to specific social groups.

Therefore it is recommended that equity effects and should be sufficiently addressed in the policy design phase. There are methodologies to investigate different types of equity (socially between different groups, spatially between different regions). In the end, the message is that the direction and size of equity effects can be designed and it is therefore a political question about how 'fair' they feel the system needs to be.

Concern 2: It does not respect the privacy of citizens

Privacy of citizens is an important issue that receives significant consideration in most policy development processes. Especially for enforcement purposes, some identification of vehicles and individuals is required; but there is, in essence, neither the need to track people through the network nor to establish identity at each cordon crossing. In London for example enforcement cameras are calibrated for not capturing the faces of drivers. The Big Brother argument may well be a valid concern, but it is not inherent to congestion charging and can be addressed in the technical design.

Picture 2: Cameras recording passing vehicles to enforce London's congestion charge (Photo: Wiki Commons)

A positive example of this is Singapore, where congestion charges can be paid with an anonymous prepaid cash card, where the system is set to only record the number plate in case of a failure in payment, e.g. through the lack of credit on the card. For distance-based charging using GNSS based technologies (see chapter 6), the public often thinks that vehicles need to be tracked in real time, but even here much of the privacy can be maintained by putting the charge algorithm in the vehicle and reporting only charges to the back-office.

Concern 3: It will not resolve congestion and air quality problems

It is often argued that congestion charging will in fact not relieve of congestion because of too much latent demand or that, since people do not have any alternatives, they just have to keep on driving and pay the charge. There is no empirical evidence to support either of those arguments. Certainly there could be effects of substitution in the congestion charged zones, e.g. travellers that place a higher value on their time might return to peak periods despite the charge since they are willing to afford it. But it cannot be expected that in London, for example there would not be a latent demand moving in to take the freed-up road space. If these mechanisms were of significance, this would have already noticed in at least some of the cities which have introduced charging.

As cities grow and income levels rise, it is, surely to be expected that congestion charging policies need adjustments over time. Especially in small cordons with many options of rerouting, travel demand effects may be low and rerouting may lead to an increase in travelled vehicle kilometres and thus only relocate the congestion.

A further argument is that people do not have an alternative to the car and that, prior to the introduction of congestion charging, substantial improvements to the public transport system need to be made. Certainly most of the cities that introduce congestion charging do have a reasonable level of public transport, even if citizens may not have perceived it that way. It is, however, also apparent that the reductions in car traffic may only partly lead to a shift in using more public transport, also in the exemplified cities that have already got a good public transport.

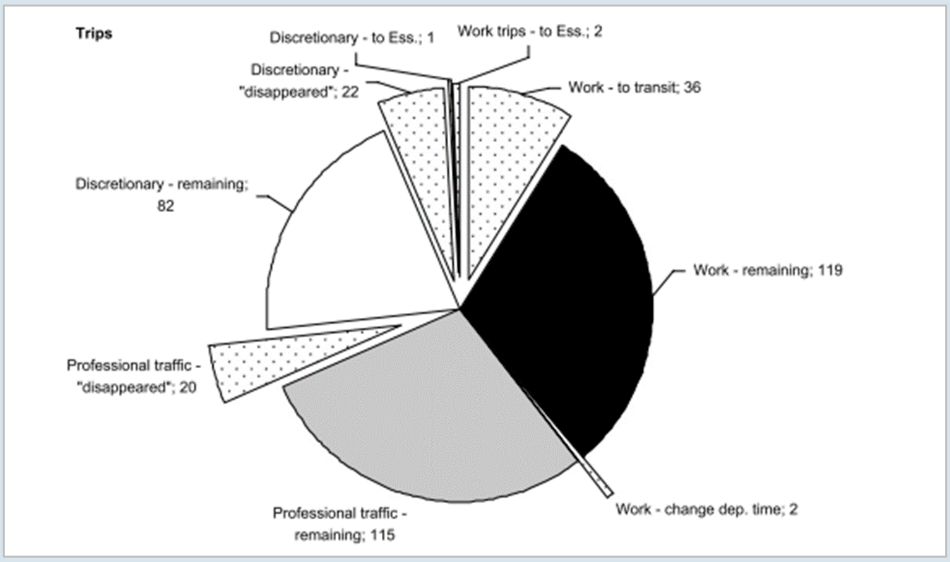


Figure 3: Behavioural changes to congestion charging in Stockholm in 1,000 trips (Börjesson et al., 2012)

Figure 3 illustrates how travellers in Stockholm adjusted their travel behaviours as a result of congestion charging. The numbers in the figure represent the amount of daily changes in 1,000 trips. The only group that switched to public transport were commuters and, in total, 9% of the trips changed to public transport. The effect of these 9% of trips on available capacities in public transport must not be underestimated. Yet the main point is that congestion charging forces people to be creative and come up with alternatives they had not considered before.

Air quality problems in cities arise from different sources and, in most cities, transport is an important source. As congestion charging often reduces the total demand travelling by car, both in trips and vehicle kilometres, it will reduce overall emissions.

Picture 3: Two photos taken in the same location in Beijing in September 2014 on a clean-air and a polluted day (Photo: Wikimedia Commons)

As air quality improvements and GHG emissions are usually not the main objective of congestion charging congestion charging can certainly help if it is designed to do so. There are also different types of pollutants which are emitted by different types of vehicles to consider. Especially if concentrations of certain pollutants are too high in specific areas and/or streets, (congestion) charging can target these areas and reduce pollution.

Concern 4: It will damage the economy

The fear of many city officials is that congestion charging has the potential to harm local economies. That is especially an issue since often one of the key responsibilities of local government organisations is to develop the local economy. The underlying rationale is that by imposing charging costs on businesses and their customers, the costs for business increases and eventually reduces the profitability and at the same time reduces the number of visiting customers. There is no empirical evidence that congestion charging negatively affects the local economy; in fact, it should achieve the opposite. It is also the case that local retailers generally underestimate the importance of public transport users to their commercial activities. Congestion Charging acts a stimulus to enhance public transport and therefore will benefit the local economy in the following way. Since transportation becomes more efficient and travel times become reduced and more reliable, better travel will often become an important net beneficiary. Trips with a high value of time such as commercial trips are faster as a consequence of the charge and thus provide a net benefit to the economy compared to the trips with a lower value of time such as private trips. Also, the reduction of cars entering a zone is certainly not equal to a reduction of people entering a zone. Some zones have become more attractive because of the reductions in traffic.

Figure 4 shows part of a city ranking table that PricewaterhouseCoopers produces yearly as it tries to score cities on different criteria to identify which cities have the best opportunities for the future. As the figure shows, Singapore, London and Stockholm are all in the top 10. Looking only at transport criteria, Singapore is number 1 in the world, London number 6 and Stockholm number 8. Many of the other cities in the top 10 are, or have been considering, congestion charging.

		Intellectual capital and innovation	Technology readiness	City gateway	Transportation and infrastructure
30	London	200	107	172	112
29	New York	186	98	137	95
28	Singapore	148	91	153	139
27	Toronto	190	73	98	118
26	San Francisco	195	96	109	89
25	Paris	204	75	143	114
24	Stockholm	192	105	96	111
23	Hong Kong	158	100	151	99
22	Sydney	181	71	119	80
21	Chicago	174	86	93	91

Figure 4: City ranking according to PricewaterhouseCoopers, 2014

Another perspective on business and local economy is that the number of cars entering an area is of less importance for economic development and growth than the number of visitors and workers entering an area. Analysis in London showed that only the number cars entering the zone changed, but not the number of people coming into the zone. With the increased use of other transportation modes or spreading the demand temporally, it is actually possible to increase the overall number of people that are able to visit. This was the focus when Stockholm introduced its policy on transportation policy, shifting to more efficient transport so the limited available urban space can be used by more people.

Even if congestion charging will probably in the end be an enabling factor for economic growth and city development, there is a genuine concern about specific businesses in specific sectors. One example might be private parking operators inside a cordon which may see a loss in revenue streams. Dealing with specific businesses or sectors will be a local and specific issue.

2.2 Is the proposed scheme designed adequately?

If above described concerns are addressed through a feasibility study and careful research on international good practice, there will be always concerns that challenge the analysis. This second category of concerns includes arguments like (5) the model used to analyse impacts on transport demand was outdated, (6) zones are not adequately defined, (7) charges are too high and (8) the chosen technology is wrong. These arguments may be addressed through careful and detailed design of the congestion charging scheme.

Concern 5: The model used is outdated

Opposition may not only come from laymen in the field of transport but even from experts on transportation. One of the recurring objections is that the transport model that was used for forecasting effects is flawed. Obviously it is very important to use a well-established and valid model to produce a forecast of effects; but even these models will not perfectly represent reality. A model is a simplified representation of the reality that can be used in supporting decisions. However it is important to note, that the results of models should not overtake the political decision making process and that their results should not be used without interpretation.

Picture 4: Sign at the Crescent street entrance of the London Congestion Charge Zone

As with many transport policies, the evaluation or assessment of the validity of a model after the introduction of a forecast model is often not a well-established practice and therefore leaves considerable room for further improvements. Eliasson et al. (2013), however, attempted to analyse how well the forecast model for the Stockholm congestion charge represented the actual effects. In this case, at least, a normal static modelling framework with underlying discrete choice models for travel demand was sufficient to make policy decisions, even though there are many ways the model could be improved.

Concern 6: The zone is wrong

Most congestion charging policies are zone-based, meaning that travellers are required to pay if they enter a specific spatial area. As soon as the defined charging areas become public there will be a distinction about people living inside and outside the zone and usually not all inhabitants in either group consider this boundary, which seems to them chosen arbitrarily, to be the best zone definition.

Once again it is important to have a macro-economic view on congestion charging when designing a zone that is best for the city as a whole, though also finding compensation for severely affected groups on a micro level. Regarding compensating groups, it is good to have a perspective that every vehicle contributes to congestion and no exemptions are made. Exemptions of paying the congestion charge have an impact on cost effectiveness and may increase the operating costs on the system. Exemptions should only be considered as a last resort if the alternative is that congestion charging might otherwise not be introduced at all. To conclude however, it would still be the better result to have a congestion charging system with exemptions in place than to have only studied a congestion charging systems without eventually implementing it because it failed on the lack of political support.

Concern 7: The charge levels are too high

People will always oppose congestion charging with the argument that the charge level is too high and that exemptions or discounts should be applied to certain groups. But it is possible to determine objectively what appropriate charge levels should be and this social CBA analyses should be based again on using transport model forecasts in the policy design process. This will determine the economic effectiveness of a specific congestion charging policy and thus will determine if a charge is too high or too low from an economic perspective. But in general it is questionable if the transport sector is the place in the national economy to make corrections to a social problem or if it would be better to combat these social inequalities using other policies such as income tax, subsidies, etc. and let the transport sector optimise itself.

Concern 8: The choice of technology is wrong

Any objection to the technology chosen is often related to cost, privacy and user friendliness. All are valid arguments and, in deciding what technology to use, these and other aspects should all be considered. The public often focuses on the initial investment cost of the system, but in making a technology choice we do recommend to focus rather on the life-cycle costs of different systems.

2.3 Towards political acceptance

In general public acceptability is only slightly affected by socio-demographic characteristics such as income, gender and education. The higher the charge, the lower the public acceptability is, and travellers with a higher value-of-time perception have a higher acceptance of congestion charging (Hamilton, 2011a). Even if a high value of time may correlate with income levels, these two things are not the same.

Basic political beliefs are also of importance in the acceptance. Congestion charging is not only closely associated with taxes but also with positive environmental action. Depending on individual political beliefs, acceptance may either increase or decrease.

The five most important factors affecting public acceptance (Hamilton, 2011a) are as follows:

1. **Experience:** The more experience people have with congestion charging, the higher the acceptance.
2. **Dislike of government intervention:** People with political views that government should intervene as little as possible will be more likely to oppose congestion charging.
3. **Interest in environmental issues:** People with (political) views that the environmental problems are severe and need to be addressed will favour congestion charging more.
4. **Value of time:** The higher the perceived value of time of an individual, the higher the acceptance for congestion charging. The higher the value of time, the more benefit travellers get in return for the paid charge.
5. **Frequency of car use:** The more travellers use their cars, the lower the acceptance level.

One of the most important explanations of acceptability for congestion charging is experience of congestion charging. This implies that acceptance levels for congestion charging may not be constant over time - especially a before and after experience effect should be noticeable in empirical data. Figure 5 shows how acceptability is expected to develop over time.

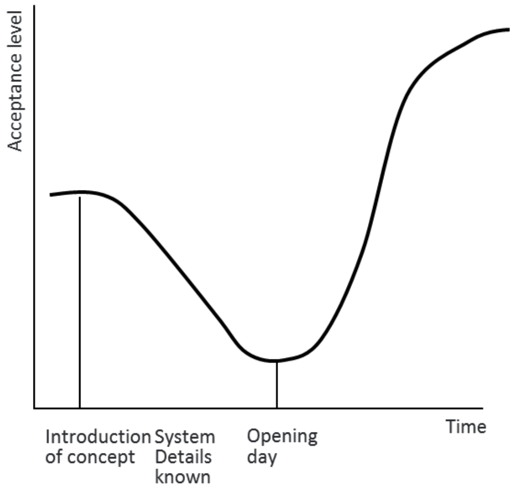


Figure 5: Development of acceptability for congestion charging, based on Goodwin, 2006 and CURACAO, 2009

At the time congestion charging is introduced as a concept in combatting congestion and environmental problems, the attitude of people is that this policy is beneficial. At this time it is not yet clear how a congestion charging policy would affect them personally. Also, opponents have not yet started their media campaigns against the charge. As soon as details of the policy become known and the opposition initiates their campaigns, acceptance levels decline. Just prior to introduction, or more generally, prior to a point in time where people know there is no turning back, acceptance levels will be at its lowest. As soon as congestion charging policies become active - assuming all technologies function and the system is appropriately designed - people will find the system more acceptable. In most cases acceptability rises above a 50%.

Table 5: Development of acceptability for example cases (CURACAO, 2009)

Place	Before	After
Stockholm	21%	67%
Bergen	19%	58%
Oslo	30%	41%
Trondheim	9%	47%
London	39%	54%

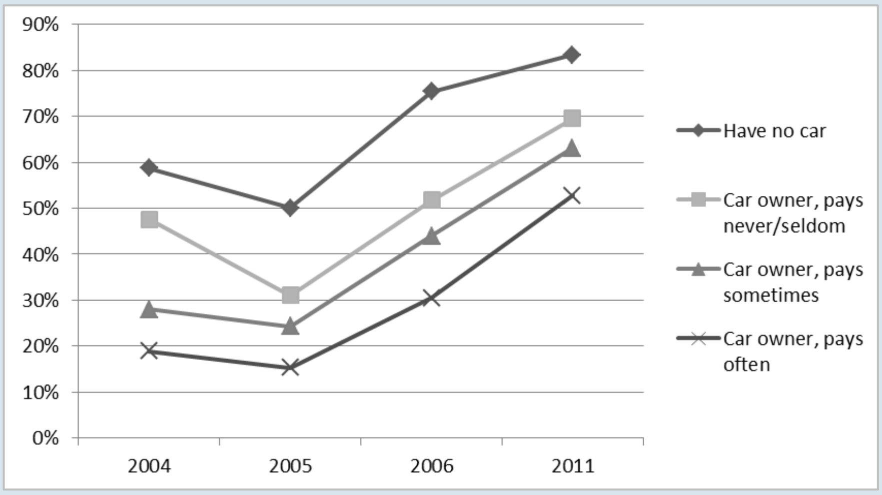


Figure 6: Acceptance, mode use and payment frequency for Stockholm from Eliasson, 2014

Figure 6 shows changes in acceptance levels over time for Stockholm where 4 different groups are identified, namely people who have no car, car owners who never/seldom pay congestion charges, car owners who sometimes pay charges and car owners who frequently pay congestion charges. The figure illustrates that in all these segments the acceptance levels increase over time, even if the initial level before introduction might be quite different.

Case Study London: Communication strategies

In July 2000, the Mayor published a discussion paper 'Hearing London's Views', which included the idea to introduce a congestion charging scheme in central London. It was sent to nearly 400 stakeholders and formed the basis of the Mayor's 'Draft Transport Strategy' published in January 2001. On 23 July 2001, TfL made the *Scheme Order*; this document provides the legal basis for the implementation of the scheme and sets out in detail its key aspects. The *Scheme Order* was sent to more than 500 stakeholders to consult them on the finer details of the Mayor's proposals and was advertised widely through a range of different media channels. Having listened to people's views, a number of modifications to the original scheme were suggested. In February 2002 the Mayor of London decided to go ahead and developed a *Communications Strategy* on the need to both inform and persuade the public of the rationale for introducing congestion charging. Main elements were:

1. Information about Congestion Charging being published in the London-wide evening newspaper (Evening Standard), local newspapers, radio/television adverts and road shows.
2. Regular meetings with and presentations to the Greater London Authority (GLA), regular meetings with London Councils, local borough councils, commercial and trade bodies.
3. Public Meetings with community and resident associations in areas up to 3 miles outside the zone boundary, where residents were especially concerned about the impact of the scheme on their journeys and on their residential areas. TfL staff did attend a significant number of these meetings even if mostly opposition was expressed not all concerns could be addressed.

Source: International Best Practices for Congestion Charge and Low Emissions Zone (Energy Foundation,2014)

3 Policy design process

While the previous two chapters presented background information the following chapters change the focus to the practical question, how to get to a solid and effective policy. This is needed as developing a congestion charging policy is not a straightforward task. Typically, congestion charging has an effect on the whole network and not as other measures such as adding road capacity or managing intersections that only have a local impact. The challenge is that not every charging policy will deliver positive effects and the effects of alternative solutions thus need be investigated. Since the complexity of behavioural responses and the consequences of these on network performance are almost impossible to estimate with expert assessment or cigar box calculations, a transport demand model is prerequisite for an sound analysis. The design process is then further complicated with operational, institutional and financial aspects.

The importance of the design process is demonstrated by a number of unsuccessful examples. The reasons for failure can be manifold but usually include the following:

- Those that are less successful have either focussed on a specific geographical zone from the outset or a specific technological solution has been pushed. Both restrict an objective design.
- There are also cases that have not specified the policy objectives and constraints sufficiently and may consequently experience difficulties when trying to judge alternatives. The issue is that there are no clearly defined indicators for the most desirable outcome.
- Lastly, the driving force for congestion charging may be rather raising the revenue instead of transport efficiency and environmental gains. These schemes may end up with public acceptance issues and are harmful for the transport system and economy.

This chapter tries to outline a generic approach for a policy design process. The three main phases are policy development, implementation, operation and adjustment. Figure 7 shows the entire process as well as some of the major actions within three main phases. In each of these different phases specific political decisions mark the end and beginning of the next phase.

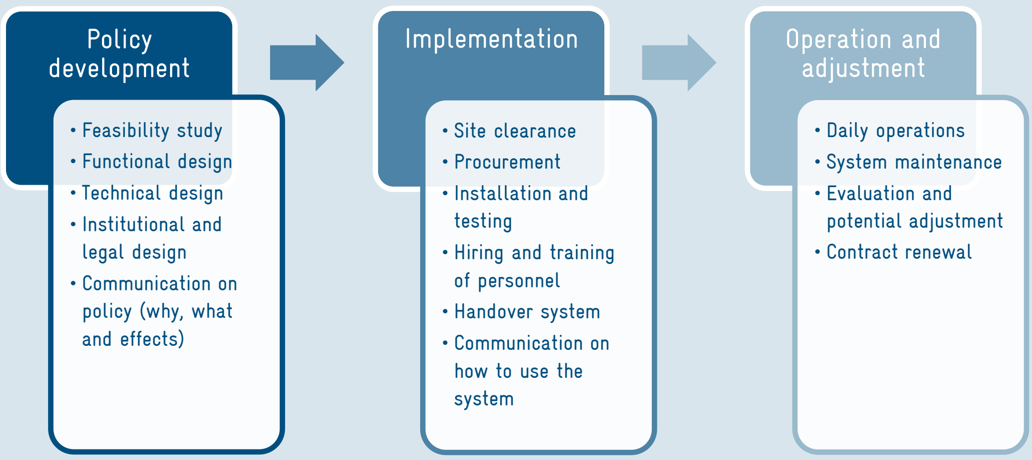


Figure 7: Policy design process for congestion charging

3.1 Policy development phase

In the overall process from idea to introduction many steps need to be taken. In the policy development phase the following steps can often be distinguished, even if there may not always be a clear start and end between these steps. Often the process is not entirely technically and "paper-based" but rather consultative. The involvement level of the public varies between countries and cultures.

Figure 8: Phases in introducing congestion charging

In the **feasibility study** the focus is mainly on identifying if congestion charging makes sense at all and to identify both opportunities and barriers that define the complexity of the remainder of the process. If there is no legal basis for congestion charging yet, a legal process will be needed that results in a congestion charging enabling law. In a feasibility study, simplified calculations of the effects of different typologies of congestion charging solutions are often included to identify both, the potential of congestion charging for a city as well as the political constraints that may arise when confronted with these initial ideas. At the end of a feasibility study there is often a political GO – NO/GO decision on whether congestion charging is a potentially productive policy that needs to be investigated and designed in more detail.

In the **functional design** step, the actual congestion charging policy will be determined. In other words, it will include where congestion charging will be, who needs to pay, how much to charge (at what time), etc. In this step the traffic, economic, environmental and social effects of different policy alternatives will be tested and compared until a consensus on the 'best' policy is reached.

Partly parallel to the functional design, a technical design needs to be developed. In the **technical design** the details of how the system will work need to be defined, such as how vehicles are detected and identified, how the charge is determined, how people will pay the charge, how the system can be enforced and how people can contact the operators with questions and complaints. The technical system is often a combination of road side equipment (and/or in-vehicle equipment), a back-office system and a customer service centre. Which technological solution is best depends on the functional design. So the technical design will lag somewhat behind the functional design. Detailed technical specifications cannot be determined until the exact locations of roadside equipment needs are known.

The technical specifications also depend on the **legal and organisational framework** of the congestion charge. The legal basis for the congestion charges or for vehicle identification, in general, may impose certain technological solutions. In some countries it is necessary to have front vehicle images that allow identifying the driver. In other countries there may not be a dependable licence plate database because of weaker legislation and institutions. It is important to identify what the legal framework is for identifying, charging and enforcing congestion charges. Such a legal framework may already indicate the organisations that need to be involved but also which potentially new institutions need to be created. These legal and institutional processes can be very time consuming.

Case Study Sweden: Institutions

In Sweden the congestion charges are legally formulated as a national tax. This requires the involvement of the national tax agency and their existing legal framework for enforcement. The license plate database is controlled by the Swedish Transport Agency. The Swedish Transport Administration is in control of the infrastructure. In practice, the Swedish Transport Administration takes care of the necessary roadside equipment, the Swedish Transport Agency runs the back office and charges and invoices vehicle owners and the tax agency is only involved in collecting the revenues from the Swedish Transport Agency. See further at:

- Swedish Tax agency: www.skatteverket.se
- Swedish Transport administration: www.trafikverket.se
- Transport for London: https://www.tfl.gov.uk/modes/driving/congestion-charge

Once there is a clear picture of the functional design, the technical design and the legal/organisational framework for the congestion charges, a political GO – NO/GO decision arises on whether or not to proceed and implement the congestion charges. Only after a GO decision has been made and the actual legislative work has been implemented, then technical systems can be procured. If legislative processes are not straightforward and risks exist that the necessary legislation may not be passed or needs to be amended, it is not advisable that the procurement is being conducted simultaneously during the legislative process. This may lead to large cost overruns as it happened in Sweden (Hamilton, 2011b).

Putting all the different steps together in a time line (see Figure 8) is showing that, by using an approach that minimises risks (meaning that important steps are not done simultaneously), the time from feasibility study to the operational system is about 3.5 years. This can be problematic with 4 year election cycles. System operations should preferably start about a year before elections so that positive effects can be shown, rather than having elections at the moment when public acceptance is at its low point as shown in Figure 5. Being able to build on an existing legal framework clearly saves a substantial amount of time.

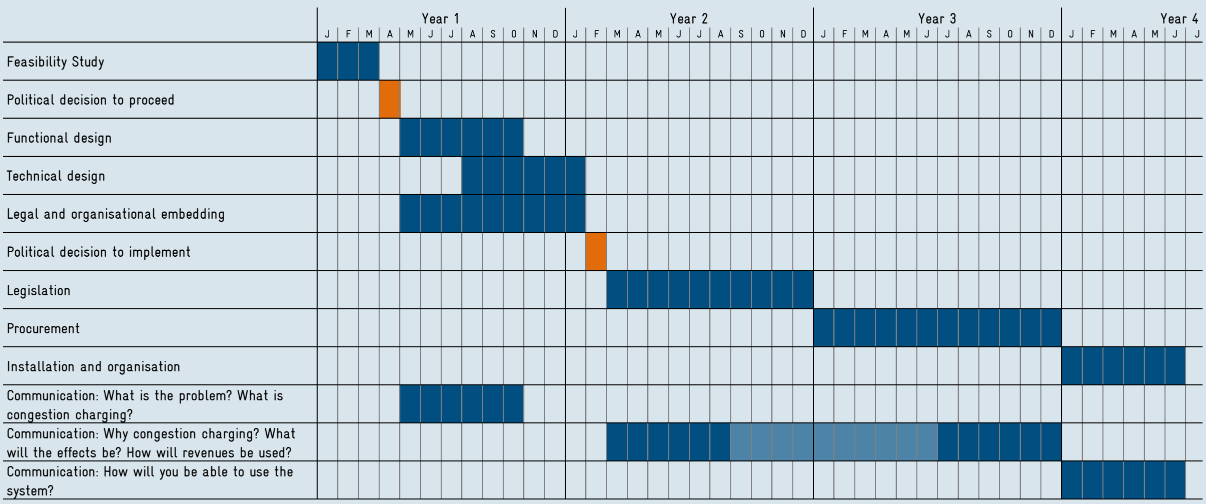


Figure 9: Typical time line

Figure 9 also shows indicative planning for communication with the public. To what extent public consultation is required might be already described by planning legislation, but it is generally good to communicate about at least three topics:

1. **Problem awareness.** What are the congestion and environmental problems in the city? What does this mean for people on an individual level?
2. **How congestion charging can contribute to solving problems.** What is congestion charging, why does it work and what effects do we expect to get from congestion charging? How will system revenues be used and what is being done to improve alternative methods of travel?
3. **How drivers use the system.** If users decide to drive and pay, how does the system work? Will the user receives an invoice; does the user need to self-report, how can the user pay and how much time does he/she have before being fined? Who can be contacted to answer questions?

3.2 Feasibility study

The objective of the feasibility study, or perhaps the orientation round, is to collect information with respect to the current background of the transport system, legal framework and institutional issues and to identify whether congestion charging is a sensible policy and determine what barriers need to be overcome. It is advisable to investigate some preliminary congestion charging policies and their potential effects in order to see if political objectives can be met. This will also help identify political constraints. Practical issues within the feasibility study relate to creating access to relevant data sources and assessing the state and availability of transport models.

Chapter 1:	Background and objectives
Chapter 2:	State of the transport system, traffic conditions and other modes
Chapter 3:	Political objectives and constraints
Chapter 4:	Initial assessment of effects potential congestion charging policies, need for supportive measures and the use of revenues
Chapter 5:	Assessment of the legal framework and barriers for identification, charging and enforcement
Chapter 6:	Potential technological solutions and preliminary cost estimates
Chapter 7:	Policy recommendations and work plan

For a more detailed list of potential questions to answer in the feasibility study see Appendix A.

Figure 10: Typical contents of a feasibility study on congestion charging

In order to make congestion charging a sensible policy, certain conditions need to be met. With respect to the transport background there needs to an identifiable level of congestion and a sufficiently large portion of the car demand needs to be chargeable. The availability of travel alternatives, or potential to provide these in the future, is another important aspect. The topology of the network and the potential for rerouting to avoid paying needs to be investigated as this may lead to the transfer of congestion to other locations rather than solving congestion problems. Regarding the legal framework it is important to identify *if* and *how* cars (and potentially their drivers) can be identified, what legislation is in place to allow charging on existing infrastructure and what legal possibilities exist for enforcing payment of the charges. Specific issues surrounding the quality and ownership of licence plate databases need to be addressed.

Identifying prerequisites: The role of the feasibility study

The feasibility study must identify if basic prerequisites for successful implementation can be met. The basic prerequisites can be defined on different levels.

Firstly, congestion charging can only be implemented if

- It can be imbedded in a legal framework (existing or new).
- Institutions are strong enough to ensure reliable vehicle identification and charge payments. This may not be the case in countries without a real-time up to date license plate database or with higher levels of corruption.
- Institutions are able to ensure that technological and organizational implementation actually detects, identifies, charges, enforces, fines vehicles and has suitable payment options for users.

These first level prerequisites however do not ensure a sensible policy. So secondly, sensible congestion charging can only be achieved if

- There are measurable levels of externalities like congestion and environmental problems.
- Within the driving population a sufficiently large part will be charged and this part of the population will be sufficiently sensitive to charges (non-compensated by others).
- A model based design process is used to identify suitable charging policies that make sense.

These first two sets of prerequisites ensure a working and sensible congestion charging policy. Thirdly however a set of prerequisites may be defined to ensure public support in the long run.

- Provide noticeable benefits (travel time savings, reliability, air quality) for paying users.
- Make the system easy to understand and use by the public.
- Explain and demonstrate that the generated revenues are not lost for society but will be used for financing some other policy/investment that has high public support.

The content of a feasibility study suggests that a variety of competencies are needed in order to answer the basic questions. Besides the content matter that requires a certain expertise, it is important to maintain a link with political decision makers in order to clarify the objectives and constraints while the process evolves. The interactions between experts and political representatives may not be that straightforward to organise as these groups often do not speak the same language. A project manager is needed who can 'translate' political views into concrete objectives and requirements and who can put calculation and research results into a political context.

Besides the project manager and political representative mentioned earlier, some specific competencies are needed which include transport planning, legal expertise, technology experts and a communications expert. Depending on the size of the city, the number of each of the suggested team members may change. Large cities might have specialised transport planners that only focus on modelling or only on public transport. Legal expertise may be divided between tax and traffic legislation, etc. Instead of one political representative, different representatives from a governing coalition may be involved.

3.3 Functional design

Once a political decision is made that congestion charging is a potential policy that has political backing, a more detailed process on the design of the congestion charging policy can be started. An important next step is then to specify the functional design of the policy. Designing a congestion charging policy is an iterative process in which the consequences of different options are assessed using specific investigations and transport modelling and where the resulting discussion gives input to new and altered policy alternatives to investigate. It is a process that often diverges in the beginning, testing different system topologies, but it soon starts focusing on a specific system type to design in more detail. Hopefully some initial assessments of different congestion charging policies from the feasibility study can be used to streamline this iterative process.

At the starting point of the process (Figure 11) are the policy objectives as specified in the feasibility study and the identification of problems the congestion charging policy needs to solve when comparing the actual state of the transport system with the set policy objectives. From these problems, initial charging concepts can be defined, forecasts of effects can be produced and, in the end, these effects can be judged and compared to the objectives. From there, objectives may be adjusted, additional political constraints may be introduced and new charging policies may be defined.

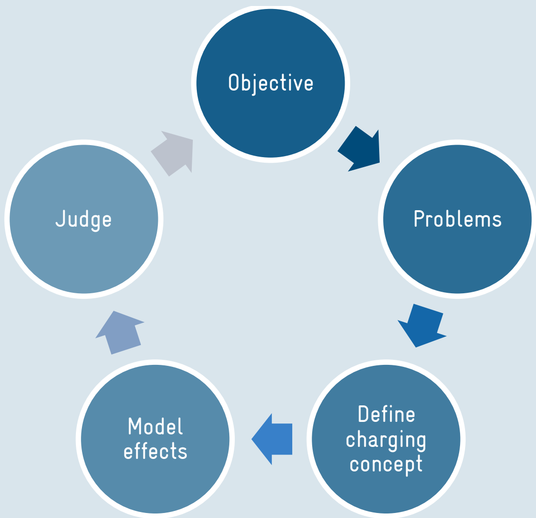


Figure 11: Iterative design process for congestion charging policies

This process may seem trivial but it requires a certain cooperation and level of understanding between transport professionals and decision makers. These two groups do not necessarily normally engage in discussions and mutual understanding and trust needs to be built up. During the process, policies that are highly effective but politically unsupported as well as politically desirable but highly ineffective policies will be identified. In the end the design process needs to find the politically desirable, but most effective, policy. The process is time consuming and requires personnel resources. In both Stockholm and Gothenburg about 50 - 80 different charging policies were evaluated before settling on one. Running many different scenarios is not just about finding the best one given the political constraints, but it is also about preparing for questions and scrutiny from the opposition as well as building confidence through sensitivity analyses.

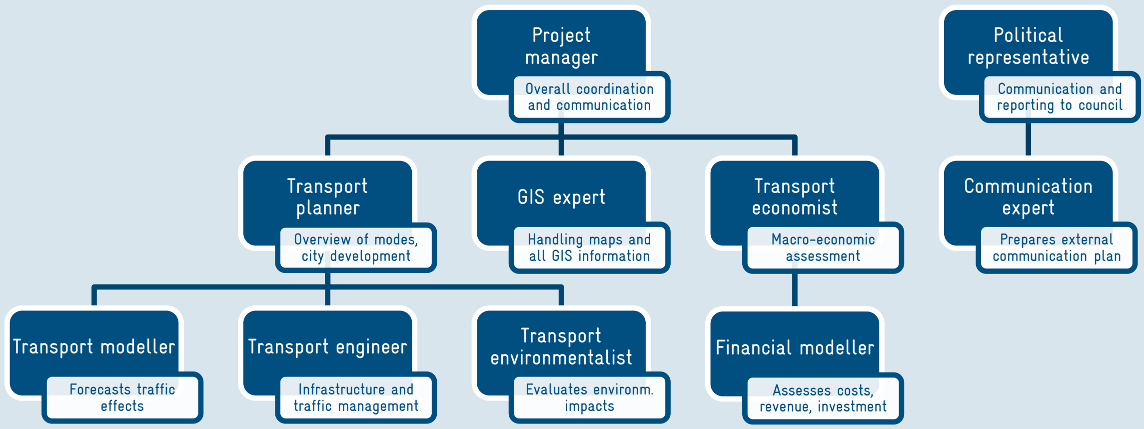
Chapter 1:	Political objectives and constraints
Chapter 2:	Overview of approach and investigated alternatives
Chapter 3:	Discussion of traffic, economic, environmental, social effects of an investigated alternative
Chapter 4:	Comparison of alternatives
Chapter 5:	Policy recommendations

Figure 12: Typical contents of the functional design

The functional design phase will therefore explore alternative design options for the charging policy itself (where, when, who and how much to charge) as well as an exploration of technological solutions, the legal framework for the policy and the potential business model. Outcome of the functional design will lead to recommendations on the congestion charging policy for the city and will form the basis for a political decision for implementation of the policy. Based on the results from this phase the parallel process of designing a communication strategy with the public can also start.

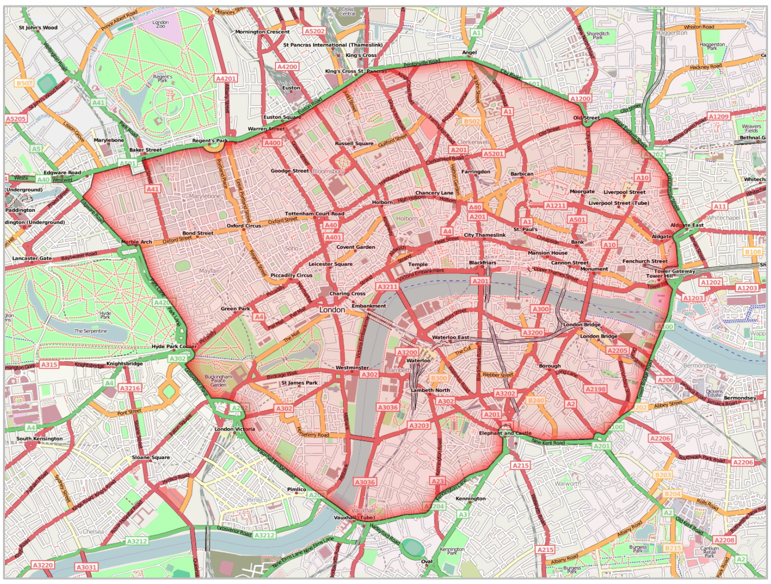
In the functional design the congestion pricing policy will be specified in detail. In order to determine the effects of a potential policy solution, a team of different experts is needed. Again, the number of team members may vary with city size. Besides the different experts, a project manager and connections to the political decision making level are crucial for ending up with a politically supported and sensible policy.

Suggested team composition for the functional design



3.4 Technical design

As the functional design step proceeds and starts to converge, it will become apparent what type of congestion charging policy should be aimed for (for example, distance-based, multi cordon, single cordon or area charging, etc.). Given the typology of the congestion charging policy, a technical design needs to be developed that operationalises the functional design in a dependable and economic manner. Through the feasibility study, political and legal requirements and constraints may have been formulated that now need to be taken into account. The precision of detection and charging of vehicles may be specified by law (especially if congestion charging is to operate under tax legislation), payment channels may be set by political constraints and even the design of roadside equipment may be dictated by aesthetic requirements. The objective of the technical design step is to produce technical specifications for different system components that will be part of a later procurement phase for technical equipment as well as processes such as land acquisition, extension of telecommunication and electrical networks, etc. The technical design will also produce a detailed



Picture 5: London congestion charge zone

cost and risk analysis to be included in the overall cost benefit analyses and financial modelling that is conducted within the functional design step. Besides a clear link with the functional design step, the technical design also has a clear link with the legal and organisational step. Information is needed on legal requirements and limitations, for example, regarding allowed forms of vehicle detection and identification. The technical design team also needs to provide the legal team with information about the technological solutions in order to identify the best procurement and business model setup.

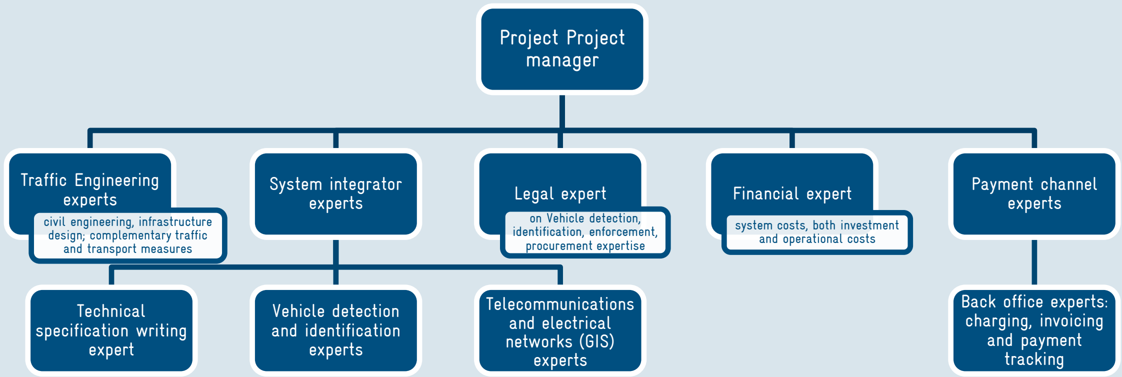
Many nations have predefined processes on how policy plans are operationalised in a technical (or detailed design) phase. Especially when system components will be procured later on, a set of formal procedures will often be in place. Apart from these formal procedures, the technical design step is recommended to include at least the following components displayed in the suggested table of contents for a technical design:

Chapter 1:	Objectives and constraints
Chapter 2:	Overview of technological solutions given the functional design
Chapter 3:	Roadside and in-vehicle functions: System design for vehicle detection and identification
Chapter 4:	Back office functions: System design for charging, invoicing and payment tracking, which payment channels may be used?
Chapter 5:	Enforcement system design
Chapter 6:	System design for integration, testing and personnel training
Chapter 7:	Design, planning and cost estimates for supporting infrastructure measures. Such as Identification of exact locations of control points for road side equipment, telecommunication and electricity connections and land ownership. Also identification of distribution and installation strategies for on-board equipment. (if applicable), road side and back office systems.
Chapter 8:	Financial calculation and time schedule (Design, plan and cost calculation for required infra-structural support measures and investments) as well as operational costs.
Chapter 9:	Recommendation

There should be a number of appendices with the technical specifications of the components. The chapters only discuss, compare and recommend alternative technological

Figure 13: Typical contents of the technical design study

Suggested team composition for the technical design



3.5 Legal and organisational design

The necessity and complexity of the legal and organisational step in the policy design depend very much on the existing legal and institutional frameworks. In countries and cities with strong institutions and existing legislation on charging for existing roads as well as legislation on the detection and identification of vehicles, this step may be a non-issue. In cities where no dependable licence plate database exist and where no legislation enabling congestion charging, this step might be the greatest bottleneck within the entire process. It is therefore important that the existing legal framework is thoroughly examined in the feasibility study. The legal constraints will have consequences for both the functional and the technical design and vice versa. The functional design process may lead to requirements for adjusting existing legislation and even new legislation.

The relationship between national legislative framework and regional or city legislative structure is also important in that cities/regional areas may be able to enact their own laws or they may have to rely on national laws being applied in their geographical areas. Specifically in Europe, even EU directives and legislation may be applicable.

Depending on the existing legal framework and institutional circumstances, topics within the legal and organisational design step may need to be addressed.

Hence, a suggested table of contents for the legal and organisational design should then include the following chapters:

Chapter 1: Envisioned congestion charging policy and technical systems

Chapter 2: Legal framework for automatic detection and identification of vehicles (Is it already possible to identify drivers through for example number plates under the current legislation or are new laws necessary?)

Chapter 3: Legal framework for charging, invoicing and enforcement of congestion charges (Are the current laws sufficient or are changes necessary, also to enforce payments or to stop/check vehicles?)

Chapter 4: Organisational setup for congestion charging implementation and operation

Chapter 5: Recommended procurement method for technical systems (What type will provide the best value for investing, combined low political risk

Chapter 6: Recommendations and time schedule for legislative processes (Where necessary legal frameworks are not yet sufficiently in place)

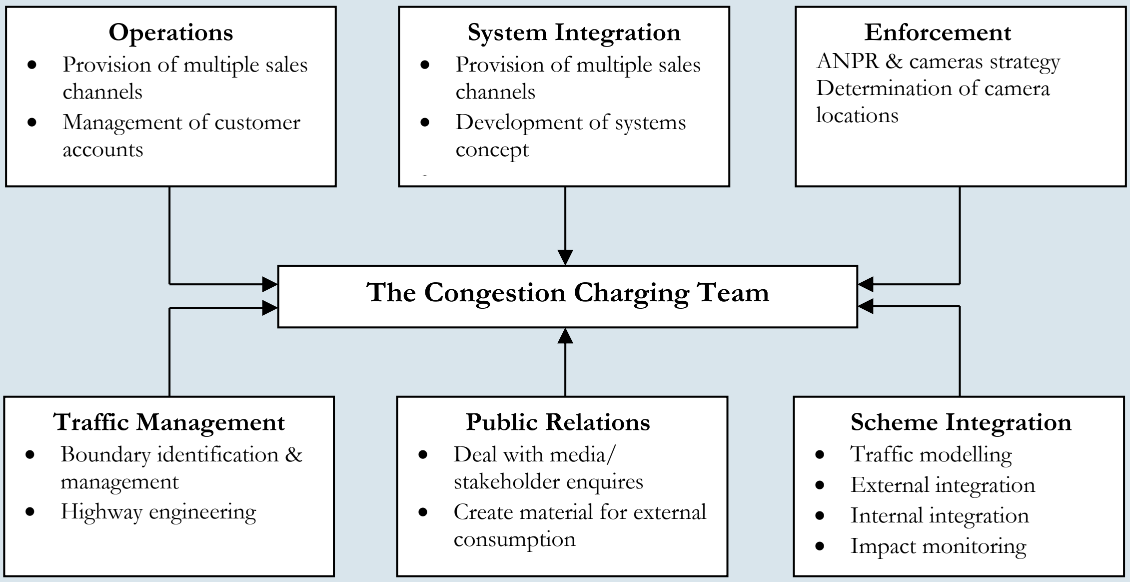
Appendices with suggested legal text should be included where required.

Figure 14: Typical contents of the legal and organisational design

Suggested team composition for the legal and organisational design

Case Study: Transport for London Congestion Charging team

In July 2000 the Mayor asked Transport for London to investigate the options for implementing a congestion charging scheme in London. This led to the creation of a team committed to fulfilling the Mayor's election promise. The team was also supported by a dedicated project management function and general procurement capability.



Source : International Best Practices for Congestion Charge and Low Emissions Zone (Energy Foundation, 2014)

4 Model based design of charging policies

In the previous chapter the need to forecast the potential effect of different congestion charging schemes was explained. Forecasting, analysing and discussing potential design is actually the core of developing successful charging policies. Both politicians and transportation engineers tend to overestimate their competence in understanding the transportation system and their ability to propose a good congestion charging design. It is possible to implement charging schemes that actually result in the situation deteriorating rather than helping it, therefore a solid design is of greatest importance. This is why a single chapter in this guide is devoted just to the model based design of charging policies.

Designing congestion charging is not purely an academic exercise in which a mathematical optimisation routine will provide the answer. These exercises are also a useful input to the process but they will often be too abstract and ignore the political reality and user comprehension of the system. The transportation model is the centre for discussion about performance of the transportation system and the effects of congestion charging. This implies that there needs to be some level of understanding about and commitment to the model. This also includes an understanding that no model is perfect, it does not absolve the decision maker of responsibility and it is provided for decision support, not to provide a definitive answer.

Besides the actual transportation model that will produce a forecast of traffic and public transport effects, additional models will be needed that use these traffic effects to calculate the environmental, economic and safety effects of policies. The transportation model will be used to assess the impact of design alternatives that vary in geographical scope and charge levels and the levels of differentiation of the charge levels in time, vehicle types, etc. This chapter will first discuss the basic requirements of transportation models and then some specific considerations about defining appropriate geographical boundaries and charge levels.

4.1 Basic model requirements

There are many different types of transportation models in the world, and this guide does not have the objective of making an international comparison of modelling guidance. In essence, there is quite a substantial base of empirical evidence about what aspects of travellers' behaviour that congestion charging affects, and the better the model is in explaining this behaviour, the better the forecast will be. The major behavioural adjustments are then: route changes, departure time changes, mode changes, destination changes, mobility changes (car ownership, PT pass, bicycle ownership), and changes in activity schedules. A transportation model for forecasting the effects of congestion charging will therefore preferably have the following components (in which costs are an explanatory variable for behaviour):

- Route choice / Assignment model
- Time of day /(Departure time model)
- Mode choice / (P&R) model
- Destination choice
- (Activity/tour-based /) trip generation model
- Car ownership model

In this list, the items between parentheses probably make the model more accurate, but do not stop developing congestion charging policies if your model does not have these capabilities. The departure time choice will become more important if policies of interest have strong differentiation of charges in time or high heterogeneity in values-of-time for different periods. A P&R model might be important if extra investments in P&R are to be done as part of the supporting policies or if P&R is already an important 'mode'. Activity and tour-based models will describe in more detail what activities people engage in each day and how this leads to a demand for transport. Activity based models forecast all the activities people engage in during a day, at what locations, and with what duration. Tour-based models construct tours, that are more aggregated common combinations activity chains starting at home and returning at home in the end. The car ownership model will become more important if the policy is expected to have a component of differentiation related to the type of vehicle (such as emission class).

Obviously people have different preferences and constraints regarding their travel needs and this heterogeneity of the population should be addressed in the behavioural models for travel demand. This is mostly done by identifying homogeneous groups of travellers based on combinations of socio-economic characteristics (income, employment status, education, age, gender, etc.) and the trip purpose. Specifically for route choice it is important to use multiple classes of users with different values-of-time. There is also evidence that dynamic models will be better for forecasting effects on travel time changes (Engelsson, 2013), which also have a major impact on social cost-benefit analyses. Calibration, validation and calculation times of these type models may however be restrictive. Lastly, not all travellers may need to pay the congestion charge; in that case these exemptions may need to be addressed in different demand segments of the model.

Not all the behavioural changes occur at the same time and the long-term strategic equilibrium models will provide forecast of effects after all the behavioural responses have occurred. In Stockholm, for example (Eliasson et al., 2013), the destination adjustments for commuters were included in the forecasts, but it was not really expected that people would change jobs directly after introducing congestion charging. Since the political risk is mainly in the first year after opening it is recommended that both a charging day 1 scenario and a congestion charge year 5 – 10 scenario be modelled. For the design of the scheme, only the latter is really important, but for communication of effects to the public, the first is very important.

Lastly, there are different modelling practices around the world; some are more data-driven where exact calibration of the model to the current measurements is very important, while others are more model-driven where explaining behaviour is more important. Mostly a mix is used, where behavioural models are used first which are then 'calibrated' to the measurements. This latter process may reduce the explanatory power of the model and it is advised to discuss which parts of the model are based on behavioural explanation and which parts on data calibration.

4.2 Geographical boundaries

The economic theory of congestion charging would suggest that each road segment has a different price at different times depending on demand levels for that road segment and its available capacity. This would mean a congestion charging system where it is unclear how much each traveller needs to pay until the last road segment of the trip has been entered. It is unrealistically complex and it will never be introduced. The question is then, how can a charging policy be developed, that is understandable to the public, yet delivers results as close as possible to the theoretical optimum?

Instead of charging single road segments, the most used approach is to group roads in an area or zone. There can be multiple zones, such as in Rome, where different charges are applied at different times. The alternative is to maintain the charge per road segment concept but to have only a limited number of different tariffs or to charge per kilometre/mile.

In identifying geographic boundaries of the congestion charging policy it is good to recognise the existing natural, institutional or socially perceived area units (quarters, neighbourhoods, etc.). At the same time you must realise that any concession on the design for the purpose of understandability for public and political acceptance is a loss in efficiency (people need to pay more to get the same effect). As always, political acceptability will be a factor in determining areas, zones, cordon locations etc.

Zone/cordon or area charging

All the congestion charging schemes implemented so far, within our narrow definition, use this type of simplification and geographic boundary of congestion charging. A zone/cordon charging mostly refers to a situation where traffic pays when crossing the boundary of the zone/cordon; this can be inbound, outbound or both. It implies that travellers within the zone/cordon do not pay, which constitutes the principal difference from area charging under which even the people travelling within the area are charged. At first sight, charging levels of the zone/cordon charging may be lower but what people pay per day will be higher than the charge of a single passage as multiple passages may need to be made.

Area charging is often defined as a 'Once per 24 Hour' charge, while zone/cordon charging as a per passage charge. Using this definition for area charging causes the marginal cost of an extra trip into the area on a specific day to be zero and this may reduce efficiency of the area based charging. Alternatively the inter-zonal traffic in zone/cordon charging is not charged, which may also result in reduced efficiency. Enforcement may become more expensive for area based charging as vehicles that are not crossing the boundary (travelling only within the area) are not automatically detected and additional enforcement cameras (either stationary or mobile) will be needed inside the zone. The system needs to track vehicles in time (entry and exit), which requires a higher accuracy of the technology used and mobile enforcement vehicles that drive around for detecting vehicles inside the zone.

In principal, an area charge could be formulated at a different time window than 24 hours, for example 4 hours. Parking charges may be considered an extreme of area based charging; the area only covers the parking place and the time base is per minute/hour. A major benefit of area charging over parking policies is that parking policies often are incapable of affecting all the vehicles when privately owned, non-chargeable parking capacity exists. Parking policies also do not affect through traffic. It is also important to note that Congestion Charging and parking policies can operate in tandem, complementing or competing with one another. While public parking can be used as an effective demand management measure, private parking operators may for example lower parking tariffs after introduction of congestion charging to attract more customers, thus reducing the effectiveness of the initial policy.

When should each type be used? - when there is substantial inter-zonal traffic causing congestion, which is more likely to happen as zone sizes increase, area based charging becomes more attractive. London and Milan use area based charging; Stockholm, Gothenburg and Singapore use zone/cordon charging.

Distance based charging

Distance based charging stays close to the theory of congestion charging and is in concept, therefore, very attractive. In principal, it would be possible to monitor where and when different road segments are used and charging the use according to economic principles. Distance based charging would also reduce the potential negative side effects of re-routing around an area/cordon/zone to avoid paying.

There are, however, some serious practical drawbacks as to which technology is the most appropriate. Using distance as a charging base requires the recording or reporting of the distance travelled by individual vehicles. The odometer is not sufficient in this case, not in the least because different areas will be charged differently. Also the recorded distance needs to be sent to a back office which requires communication between the vehicle or user and the back office itself. Lastly, this system needs to be enforced and just photographing licence plates does not provide guarantees on correct reporting of distances.

There have been different proposals for technical solutions for distance based charging (for example, using cellular networks), but combined GNSS and mobile communication based methodology is the dominant solution. This solution requires a GNSS receiver plus a mobile communication device per vehicle which makes distance based charging an expensive solution. Additionally GNSS reception in dense urban areas is not without problems making reliable distance measurements problematic.

Case Study Germany: Technical Solution:

Freight tolling in Germany is one of the examples where GNSS distance based charging has been applied. Germany is obviously a large area compared to congestion charging for cities and with a relatively low number of vehicles. In cities it will often be the other way around with small areas with a large number of vehicles. This kills the business case for GNSS solutions in cities. However, with new cars potentially being factory-equipped with necessary devices, or even by using smart phones that already have the necessary technology, future breakthroughs may be achieved. Singapore, the U.S., Belgium and Germany are exploring distance-based charging for private vehicles but only Singapore as an actual city congestion charging system. The other systems' objectives are to raise revenues from either foreign vehicles (Belgium, Germany) or to increase revenues as gas taxes as a source of funding die out (US).

4.3 Charge levels

Besides the geographical boundaries of the congestion charging policy the differentiation of charge levels is the second important design variable. In the end, a combination of policy objectives and constraints including political acceptability as well as price sensitivity of travellers determines the right price level. This is an iterative process in which different price levels are tested. In order to determine a starting point for a first estimate on appropriate charge levels, different methods can be used.

- Use elasticity estimates and current cost levels to find a charge level that corresponds with desired levels of reduction of demand.
- Use analyses of delays and (distribution of) values-of-times to find a cut-off charge level at which the charge would be higher than the value-of-delay for a set of travellers.

Differentiation of charge levels

In developing a charging policy it is surely advisable to keep the policy simple and understandable by the public; on the other hand, it may be necessary to differentiate the charges at different times, locations and for different types of vehicles in order to achieve the desired policy objective, in an efficient way, of recognising among others the differences in economic value of different transport. Traffic is heterogeneous and one single charge level may not affect different individuals sufficiently, while it may affect others too much if the charge were to be raised.

Vehicle types

A common differentiation of road user charges is to apply different charges for different types of vehicles. Some examples are:

- Taxi and other public transport vehicles are exempt. This happens mostly because of political concerns about creating attractive public transport alternatives when congestion charging is introduced. If public transport is fully government-owned, charging public transport would only make sense if it is expected to lead to a higher efficiency in operations; otherwise it would just be an expensive method of transferring funds between governmental organisations.
- Emergency vehicles are exempted. This is an almost standard exemption resulting from political constraints.
- Trucks are charged differently. In some cases trucks may be exempted from the charges as they are deemed economically important or other regulatory measures may already be in place as to when trucks can enter the city. In other cases trucks are charged at a higher rate, either because they cause more damage to the infrastructure (a factor of about 10), because they have a higher value-of-time (a factor of about 3), or because they contribute more to congestion (use more capacity, a negative factor of about 2.5).
- Foreign vehicles are often exempt. This is simply because collecting charges outside of administrative boundaries would be too costly.
- Government vehicles are exempted. Some cities and nations have high penetrations of government vehicles. This could be anything from transport for high officials to garbage collection. If the government department has a separate financial administration and the charges would create an incentive to be more efficient, than the government vehicles should be charged. If such governance structures do not exist, charging government vehicles would again only become an expensive way to transfer funds between government agencies.
- Motorcycles can be charged differently. They, at least in some contexts, contribute less to congestion or have higher emissions and safety risks. In some cases motorcycles may be exempt because the absence of front licence plates means the information cannot always be captured using ANPR

Time of day

The second common form of charge differentiation is by time of day. There are several motivations for differentiating charges by time of day. One motivation is that traffic is composed of different mixes of trips during different periods of the day. Commuter trips are dominant in the morning and afternoon peaks; business and shopping trips may be dominant between peak periods and leisure trips in the evenings. Since these different trip purposes will be accompanied by different sensitivities to charges, the charges may need to be differentiated for different periods of the day. A second motivation is that, as the charge level should be dependent on congestion levels, the charge should be higher in peak hours.

There are three principle levels of differentiating charges by time of day, including the no differentiation alternative. Secondly, and most commonly used, is a schedule-based differentiation where the charge levels for different periods are announced and published for a certain period in advance. Thirdly, and applied mostly for priced managed lanes in the U.S., is dynamic pricing where the charge level is calculated based on prevailing travel conditions and updated every couple of minutes. This is closer to the economic principals of congestion charging but also the most difficult for travellers to understand. Dynamic pricing is simplified when used in single corridors rather than entire networks, and the use of lower and upper boundary charge levels and fixed intervals also restricts the complexity.

Picture 6: Charge levels are different depending on the time of the day in Stockholm, Sweden (1 Kr equals to about 0.85 RMB)

Place

The third form of charge differentiation would be to apply different charges at different locations with the defined geographic scope of the charging policy. This applies only to cordon/zone charging and distance based charging policies. For area charging it would simply imply defining a new area with a different charge level. Within cordon/zone charging, different entry and exit points may have other charge levels depending on, for example, congestion levels in different areas of the city. For distance-based charging, in principle, each road segment could have a different charge.

Two examples exist in Sweden. In Stockholm, people living on the Lindingö Island east of Stockholm are exempted from paying the charge if they only traverse through Stockholm and it is not their destination. In Gothenburg, travellers that pass the cordon twice or more within an hour pay only once, alleviating the cost for through traffic. In both cases the exemption was made because the political perception was that these groups did not have alternatives for their travel and should be exempted.

4.4 Key indicators for appraisal of alternatives

Transport models tend to generate a vast amount of data and in some way these data need to be aggregated so that different alternative policies can be compared. Each country or city may have established different practices for this but in essence there are essentially four main categories of effects:

1. Traffic/ transportation
2. Environmental
3. Economic
4. Social, distributional and equity

An appraisal of congestion charging policies can also be compared to an appraisal of alternative policies, like new infrastructure investment, TDM measures, etc. In essence however, congestion charging is a measure that corrects the prices in the transportation market and it will probably be less efficient to invest in other policies without correcting the underlying problem of wrong transport prices. Even though revenues of congestion charging do not impact a societal cost benefit analyses, it will probably be of some relevance that governments do not need own funds to introduce congestion charging, but they probably will need funds for alternative policies.

Traffic / Transportation effects

The objectives of the congestion charging policy are probably formulated in terms of improvements in traffic conditions. These could be reductions in delays, queues (and their weighted severity), (weighted) congestion indexes, average travel speed, etc. Whatever political measure for traffic improvement is chosen, it will be important to report back on how alternative designs perform regarding this measure. In general, or if political objectives are not specific, a number of indicators can be used to communicate and summarise the traffic effects:

- Maps with how traffic volumes and speeds change in the network
- Tables with changes in traffic volumes, speeds and saturation for important roads or routes
- Changes in mode shares (both based on trips and distance)
- Changes in vehicle kilometres travelled and average travel distance
- Changes in traffic volumes across the charging boundary

Environmental effects

The environmental effects of congestion charging are an important factor in a decision making process surrounding congestion charging. In fact, in some cases, the local air quality or reduction of GHG emissions may be a driving political force for introducing charging. Which environmental indicator to use depends partly on local regulations and legislation surrounding air quality and emissions of GHGs. If the environmental effects depend on the changes in traffic conditions it would be advisable to create a link between the transport and environmental modelling that is needed.

- Key indicator for local air quality:
    - changes in estimates of premature deaths
    - number of kilometres of roads not meeting emission norms
    - number of inhabitants exposed to above-norm emissions
    - cost for mitigation measures
- Key indicators for GHG emissions
    - Tonne emissions per year, potentially per vehicle type and traffic state

Economic effects

Ideally the appraisal of alternatives is based on (social) cost benefit analyses in which all the benefits (travel time savings, reduced emissions, etc.) and costs (investment and operating costs) of the alternatives are determined and monetized, if possible. Many countries have established practices on what elements should be included in a CBA and how these elements should be valued. These calculations are often complex and time consuming and may not be practically feasible in an interactive policy design process.

A simpler calculation which provides useable insights about the benefits of a congestion charging policy is to calculate the changes in consumer surplus compared to a do-nothing alternative. The consumer surplus changes reflect how much worse or better off all travellers are when introducing charging. The charges are, in this case, a cost to the users and thus mostly the total consumer surplus changes will be negative. The gains in terms of travel time savings in general do not outweigh the costs of the charges for the travellers. For society as a whole, however, the charges are not lost, but they become revenues and can be spent on creating benefits for citizens somewhere else in the economy. Correcting for the total paid charges therefore gives insight into the net benefits of the congestion charging system to society.

Selecting the best scheme is a trial-and-error process based on criteria such as:

- How the scheme meets policy objectives and constraints
- Improvements in traffic performance indicators
- Horizontal and vertical equity indicators
- Changes in consumer surplus
- Cost-benefit analysis

5 Equity, exemptions and revenue use

In many situations the perception is that congestion charging is a regressive measure targeting lower income groups more than higher income groups. However, the research on equity provides an unclear picture and one of the main questions is how to use the revenues. In many cities the negative effects of congestion, traffic safety problems and air pollution affect the lower income groups much more than the higher income groups and, in fact, congestion charging could in many cases be used as a 'Robin Hood' of taxes by making car driving more expensive for the richer part of the population, while the lower income population benefits. Especially when revenues are used for investments in public transport, cycling infrastructure, noise and vibration mitigation in houses, etc., the lower income groups can be the main beneficiaries of the congestion charging policy. It is a political decision on how equitable the congestion charging system will be, not a generic attribute of the policy that cannot be affected.

(Litman, 2014) provides a useable description of equity issues in transport and how they can be studied and measured. A quote from this report:

> *"There is a long history of incorporating vertical equity objectives into transport pricing with targeted discounts that benefit lower-income people. Adam Smith (1776), the founder of modern economics, wrote that, "When the toll upon carriages of luxury coaches, post chaises, etc. is made somewhat higher in proportion to their weight than upon carriages of necessary use, such as carts, wagons, and the indolence and vanity of the rich is made to contribute in a very easy manner to the relief of the poor, by rendering cheaper the transport of heavy goods to all the different parts of the country."*

5.1 Equity issues

In discussing the equity of congestion charging there is often an underlying and implicit discussion if the current state of the transport system is equitable or what an appropriate absolute level of equity should be. When focussing on congestion charging or any other transport policy, the equity discussion revolves around how the introduction of the policy affects equity. In essence, equity effects are about identifying how the cost and benefits of the policy are distributed throughout the population. There are two types of equity to consider - one in which different socio-economic groups of people are affected differently and one in which different people within one socio-economic group may be affected differently because of their geographic location.

(Eliasson & Mattsson, 2006) researched the equity effects of the Stockholm congestion charges and found that the charges were progressive (affecting higher income levels more than lower income levels) mainly as a result of investing the resulting revenues in public transport improvements. In a study from (Tonne, Beevers, Armstrong, Kelly, & Wilkinson, 2008) on the air quality effects of the London congestion charges, they report that: 183 years of life per 100,000 population were saved. In London overall, 1,888 years of life were gained. More deprived areas had higher air pollution concentrations; these areas also experienced greater air pollution reductions and mortality benefits compared to the least deprived areas.

The London congestion charges were thus environmentally progressive with higher gains for the less affluent groups in London.

5.2 Exemptions and Discounts

In all congestion charging policy design processes sooner or later there will be discussions about exemptions and discounts. If the objective of the policy is to reduce congestion, then any exemption or discount will lead to a loss of efficiency. This implies that those who do pay need to pay and adjust more in order to achieve the same effects. Congestion is, however, seldom the only objective or at least other political constraint that plays an important role. The most common exemption is probably to exempt emergency vehicles (police, ambulance, fire brigade and military).

Exemptions for environmentally friendlier cars are popular as well. Since technological developments may move quickly and uptake of these vehicles can be substantial when subsidised, the policy needs to be flexible and be able to move the boundaries of what defines an environmentally friendly car. Exemptions and discounts should furthermore only apply to this type of car for a limited number of years. Note that even zero emission vehicles contribute to PM 2.5 through brake, tyre and road wear and the energy they use might result in emissions at the locations where the power is generated.

Exemptions and discounts for vulnerable groups may also be applied. Travellers with disabilities, for example, are much more dependent on car transportation for daily life participation. The question arises, though, about where compensation for these groups is best targeted. Perhaps general compensation, reduced income tax, etc. may be more appropriate and a dispensation only for congestion charging.

Introducing area or cordon charging inevitably creates a boundary between people that are inside and people that are outside. Depending on how the policy is designed, this may lead to substantial differences in charges to be paid for those two categories. In some very specific cases exemptions may be appropriate if a boundary divides a community/district into two parts; mostly, however, exemptions seem to be made for political reasons. In London, the discounted charge rate for inhabitants inside the congestion charge area is solely a political one. The exemption for the Lindingö Island east of Stockholm is also partly political and partly legal.

Regardless of the exemptions and discounts that are applied for a congestion charging policy, it is advisable to make them time-limited from the start. As time progresses, new inhabitants will move in and old ones will move out. The exemptions and discounts were put in place because the system would impose too much extra cost for those already there, but as new inhabitants move in, congestion charging will be the status quo. It is good to be able to evaluate periodically if exemptions and discounts are still needed and since it is hard to take away something that has been given, it is easier to give the exemption/discount again after expiration.

5.3 Revenue use

Probably the congestion charging policy will generate a net revenue stream which should be used to improve society as a whole. All the research done shows that the use of revenues plays an important role in the decision making process for congestion charging. The different uses of revenues affect political and public acceptance and they may correct imperfections in the chosen system and can affect the equity effects.

Improve political and public acceptance

It is important to communicate to the people that the revenues will be used for something positive. Apparently people tend to think that the money might be wasted. Their acceptance can then further be improved by using the revenues for something that people either have very strong opinions about or which is in their self-interest. Since the population is heterogeneous, different groups may be affected by different uses of revenues and a portfolio of different revenue uses is therefore to be recommended. As a conclusion, revenues should be spend on the following:

- Improving the environment (if environmental problems are found to be really important);
- Resolving important bottlenecks (for serving self-interest motives of drivers);
- Improving alternative modes such as public transport or cycling infrastructure

Case Study Sweden: Improving the alternatives for driving a car

Car travellers are more inventive in how to adapt than they think themselves, and more inventive, than transport planners tend to think about them. Stockholm investigated if and how much people changed their behaviours by using questionnaires as well as actual measurements. People underreport how much they changed compared to reality; especially their reduction of trips by combining activities was a source of underreporting. In the end, however, all the implemented systems have seen a shift from car to public transport and, in order to facilitate this shift and not make current public transport users worse off (by increased crowding), the revenues can be used to invest in alternatives to car use, e.g. public transport, bicycle infrastructure, work-at-home IT infrastructures, etc.

Picture 7: Panorama view over Stockholm, Sweden, seen from the City Hall Tower

No matter how the revenues are used, it will affect the equity outcomes of the system. Investments in car infrastructure will most likely be of benefit to higher income car travellers, while investments in public transport will benefit lower income travellers. Besides being a consequence of how revenues are spent, steering the equity effects of the congestion charging policy may actually be the specific ulterior motive for introducing congestion charging as mentioned before in this chapter.

Complementary measures to mitigate imperfections of the system

No system is perfect and, especially for cordon and area charging policies, the boundary issues that may occur, may warrant the use of revenues for correcting imperfections. Every charging scheme needs implementing complementary measures in locations near the zone boundary. These means to discourage traffic from rerouting to charge free areas by introducing traffic management measures such as road closures in certain streets near the zone boundary; creating one-way streets; introducing schemes to limit heavy goods vehicles, particularly in residential areas; implementing bus priority measures to make bus usage more attractive relative to private car usage. It will also mean investing in revised signal settings and junction layouts around the zone. Regulating parking outside the zone may also be important so travellers do not park around the boundary and walk/cycle/use public transportation to enter the zone in specific places where you do not want to facilitate this behaviour. There may also be specific business sectors that may be affected and may need to be moved or compensated, for example private parking companies and car maintenance garages inside the zone.

6 Charging technologies

There are a limited number of technological solutions currently on the market. In general, congestion charging requires a free-flow detection and identification system with high levels of accuracy and low potential for fraud. This chapter will discuss the pros and cons of different technological solutions. Beside the technological solution, it is important to decide how to procure the technical systems and who is going to operate it. If the private sector will be involved, decisions have to be made on how it gets paid and how risks are allocated.

The technology for congestion charging consists of different components. First, the vehicle needs to be detected and identified, then the appropriate charge needs to be calculated and charged to the vehicle, the vehicle owner needs to be notified and, lastly, payments need to made. This whole process requires documentation and enforcement systems that need to be in place to reduce non-identification, tampering with charge calculations and non-payment. Not all of these steps may be appropriate in all situations. In this chapter the different components of the charging technology are discussed. Even if manual and paper systems still exist, this chapter is limited to automated free-flow charging systems.

6.1 Vehicle detection and identification

The vehicle detection and identification are often supplied using the same company and could possibly be considered to be integrated systems. A distinction needs to be made between GNSS-CN systems and zone/area based systems. In GNSS based systems the vehicles will be identified using a unique ID that is part of the on-board unit and detection is not necessary as vehicles will self-report. For zone/area based systems vehicle detection and identification is mostly done using gantries with equipment installed above the road. The vehicle detection is based on either laser or video systems and identification occurs through either licence plate recognition or some transponder technology. A transponder is a device in the car that is able to communicate with the roadside equipment in the gantries.

Automatic Number Plate Recognition (ANPR) / Virtual licences

There is no system in operation that works without ANPR. Even if it might not always be used for identification of vehicles it will still be needed for enforcement purposes. ANPR is a technology that uses cameras - often mounted on gantries or poles - to produce images of the licence plates of vehicles. The image captured is processed using optical character recognition (OCR) software, which automatically creates a digital record of the licence plate. This automated process usually is not successful on 100% of the licence plates and additional manual labour is often needed to complete the records.

Having digital records of the licence plates then requires a database of licence plates and personal details of the vehicle owners in order to make billing of charges to individuals possible. In cities or countries with no or incomplete records there may be strategies for the use of ANPR technologies using the value of the vehicle as collateral for outstanding debt (Hamilton, 2012).

Case Study: Electronic Road Pricing System in Singapore

The Electronic Road Pricing (ERP) system is a dedicated short-range radio communication system (DSRC) using a 2.54 GHz band. The three components are the: (a) In-vehicle Unit (IU) with a smart card called CashCard, (b) ERP gantries located at control points across the road and (c) Control Centre.

In-vehicle Unit (IU)

The IU is a pocket dictionary-sized device powered by the vehicle battery and fitted permanently to the lower right hand corner of the vehicle's windscreen or on handlebars of motorcycles and scooters. The IU has a slot for receiving a prepaid stored value contact smart card. The smart card, called the CashCard, is issued and managed by a consortium of local banks. The CashCard is reusable and can be topped up with cash at petrol stations or automated teller machines. There are different IUs for different classes of vehicles, i.e. for cars, taxis, light goods vehicles, heavy goods vehicles, buses, motorcycles, and emergency vehicles. This is necessary because the ERP charges are different for different classes of vehicles.

Electronic Road Pricing (ERP) gantries

The ERP gantries are a set of two overhead gantries mounted at each control point. They are generally at a height of 6.1 m above road level and placed about 12 – 15 m apart. The first gantry carries two radio antennae per lane. The antenna communicates with the IU of approaching vehicles. The first gantry also carries two enforcement cameras per lane, facing away from the traffic, calibrated to take the digital images of the rear licence plate of violating vehicles. On the second gantry directly above narrow black and white bands painted on the road surface are optical sensors. The sensor camera holds the black and white band image when the road is empty. It detects a moving vehicle and measures its width by the interference in this image caused by a moving vehicle. The second gantry also carries a second set of two radio antennae per lane, which again communicates with the IU of the approaching vehicle. The logic for controlling all the gantry equipment is placed in a local controller in the vicinity. The local controller transfers data continuously with a central computer at a control centre by using leased telephone lines.

Picture 8: Automatic tolling gantry of Singapore's Electronic Road Pricing system in 2008

Control centre

The control centre houses the central computers and peripherals. The centre receives the records of all ERP transactions and records any faults in the equipment and digital images of violating vehicles. The ERP transactions are stored for cash settlement at the end of the day. The digital images are sorted and the registration numbers picked up by an optical character recognition system for follow up on issuing summonses for violators or inspection notices for those vehicles experiencing errors. Given the critical importance for continuous operations, standby maintenance crews are sent out to check and rectify faults by the Control Centre.

Sources: International Best Practices for Congestion Charge and Low Emissions Zone (Energy Foundation, 2014); www.mhi-global.com/products/detail/electronic_road_pricing_system.html

Dedicated Short Range Communication (DSRC) or Radio Frequency Identification (RFID)

DSRC or RFID are used by toll road operators throughout the world. There are technical differences between DSRC (more used in Europe) and RFID (more used in the U.S.), but these are not important to highlight here and do not change the conceptual functionality. An On-Board Unit (OBU) or tag is mounted on the vehicle's windscreen and communicates with roadside equipment. A DSRC/RFID solution therefore requires a gantry or pole equipped with transceivers to enable the communication with the OBU. The transponder ID, time stamp and potentially other important information is sent to or read by the roadside equipment. There are systems that then directly debit a pre-paid smart card that is placed in the OBU (Singapore) or the identification details are sent to the back office where a charge is calculated and an account is debited.

The key benefits of DSRC/RFID over a pure ANPR based technological solution are that DSRC/RFID (if mandatory) can make automated identification more efficient, thereby reducing operational costs and, when combined with pre-paid cards, create a system in which privacy is guaranteed as long as the charge is paid. Only for enforcement purposes vehicle owners need to be identified. The investment costs will be higher for DSRC solutions, as ANPR will still be needed for enforcement, regardless of who pays for the OBU.

Singapore is currently the only congestion charging scheme in operation that uses DSRC/RFID. Stockholm initially had DSRC capability but it was deemed unnecessary and not cost efficient. London has tested and investigated DSRC technology. In Gothenburg DSRC may be used in the future for foreign trucks as many trucks already have the transponder installed for payment of other infrastructure use on routes to Sweden, Norway and Denmark.

Global Navigation Satellite Systems/Cellular Networks (GNSS/CN)

GNSS/CN systems may also be referred to as Autonomous Electronic Fee Collection (EFC) systems. GPS, the U.S. military satellite positioning system is probably the best known in the world. But also the Russian Federation has a positioning system (GLONASS), also the EU (GALILEO) and the PRC (Beidou) are developing new satellite navigation systems. GPS is already widely used by truck operators for tracking the location of vehicles and in Germany and Switzerland for distance-based charging of heavy goods vehicles. The on-board unit combines a GNSS location system and a communications link, with a digital map either on-board (thick client) or in the 'back office' (thin client). The vehicle's position is used to identify the road segment and thus the correct charge can be assessed.

The main advantage of GNSS/CN based systems is the flexibility in charging regimes, as it enables and has the opportunity to easily change the existing policy. In essence the pricing policy is implemented completely through software instead of roadside equipment and thus new roads can be added, removed and changed on a daily basis if necessary. GNSS/CN also enables distance based charging policies which are theoretically attractive.

The downside of GNSS/CN solutions is that it is expensive and cannot always provide the geographic accuracy that is needed. The cost of the on-board unit is typically 10-20 times more expensive than a tag-based solution. Also the cost of operation is more expensive as software needs to be maintained and updates need to be distributed, especially in the case of thick clients. The geographic accuracy is affected by a physical effect called Non-Line of Sight Multipath (NLOS Multipath). This is an inevitable effect in cities with high-rise buildings and it means that the satellite signal is reflected between buildings before it reaches the GPS receiver. This received signal has travelled farther than a direct signal; as such the receiver believes that it is further away from the satellite than the real position and you get a corresponding large navigational error. Solutions are under development and the issue becomes less prominent, but it is not yet completely resolved.

6.2 Payment channels

After vehicles are detected, identified and charged, a payment of the charge needs to be made. There are many different possible payment channels that can be offered to people and a balance needs to be found between convenience and operating costs. The cheapest payment channel is an automated payment either through the customer's bank account or credit cards. Often the systems start out with a multitude of payment options and over time convert to simpler systems with a strong focus on getting as many people as possible to convert to an automated payment plan.

Case Study: Various Payment Channels in London

There are various payment channels provided by Transport for London (TfL), which account for a high system operation cost. However, they facilitate drivers by offering flexible options and increasing their willingness to pay. The different payment channels are listed as follows:

- Congestion Charge Auto Pay (CCAP)
- Pay online at www.cclondon.com
- Pay by mobile phone text message
- Pay at selected shops and petrol stations *(Discontinued as of August 2014)*
- Pay by phone
- Pay by post

Source: http://www.tfl.gov.uk/modes/driving/congestion-charge/paying-the-congestion-charge
Presentations on Central London Congestion Charging Scheme, by Steve Kearns, TfL

6.3 Enforcement

The entire process of detection, identification, charging and payment needs to be enforced. It will depend on the technology chosen as well as local legal constraints as to how the different enforcement steps are conducted. In most systems an ANPR system is used as a back up to travellers potentially trying to avoid detection and identification. For enforcement of payment, a legal framework is often in place. Since no system is perfect, there need to be procedures for people to be able to appeal charge decisions and these appeals require verification against existing records.

6.4 Central system

The components of the congestion charging technology are held together by the central back office system. Here the links between identification, charging and payments are made and invoices or penalty notices may be issued. A customer service centre is often linked to a central system so that people can ask questions about their payment histories, system functionality, etc. The customer service is not concerned with why congestion charging was introduced, what the effects are, etc. Important issues for a central system are data accuracy, security and privacy. It is not uncommon that central system operators get requests for information from criminal police investigations. How the data in the central system should be handled depends on local circumstances but use outside the domain of road user charging will lead to reduced acceptance.

7 Ten Recommendations for Congestion Charging

This chapter includes a condensed set of recommendations which are partly based on science, but mostly on practical experience.

Focus on impacts. Design congestion charging to alleviate real congestion. Congestion charging should not be about raising revenues. Not all congestion charging designs result in improvements; it is possible to make the transport system function worse.

Do the homework. There is a tendency amongst politicians, experts and technicians to be overconfident in their understanding of the transportation system and knowing what would constitute a suitable congestion charging policy. Designing the congestion charging policy should be a process with the right teams and a suitable budget.

Use models to forecast effects. It is imperative to a have a tool that can forecast and compare the effectiveness of alternative policy solutions. Trade-offs - both political and traffic wise - need to be included in an iterative design process. Rather than building on (political and expert) beliefs or opinions, comparative analyses should be used. But remember models are tools to aid decision making rather than giving definitive and incontrovertible traffic figures.

Prepare to respond to concerns. Whatever congestion charging policy is decided upon, opposition will become fierce and total chaos can be predicted. Commandments 1, 2 and 3 are very important prerequisites, but good communication strategies and political timing are important as well. Do not plan to introduce congestion charging during an election year. Involve the public early to increase problem awareness and awareness of congestion charging as a solution. Public acceptance, however, will in the end only increase to above 50% levels after introduction and this only if the system delivers the promised effects.

Make revenues generated and how the money is spent transparent. Contrary to the general feeling the public might have about the charges they pay, the money is not wasted or lost. People might think this is just a cash cow or money grab by the government so it is extremely important that the process be very transparent and that information on the revenues generated and how they are spent to benefit the public must be clearly communicated.

Invest in alternative travel options. Behavioural change is more easily achieved when suitable alternative travel options exist. The most common one is public transport, but park-and-ride facilities, bicycle infrastructure, flexible working hours, telecommuting, car sharing, and carpooling programmes can all contribute.

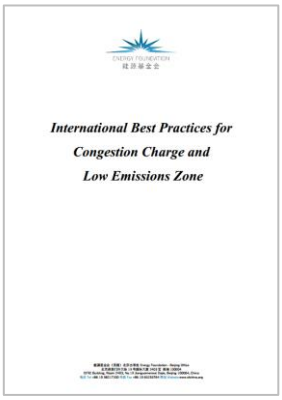
Let the functional design drive the technological solution. The functional design is the result of a consensus-building exercise that confronts effects of alternative solutions with the policy objectives and constraints. The technological aspects should be taken into account in this process as well, but the starting point should never be a specific technological solution which, for example, might be pushed by a city official that wants the city to be innovative or by technology providers that define the need of their product to the city so that their products fits.

Reduce political risk by building in redundancies that can later be removed. Considering commandment 4, proposing congestion charging is not without political risk. These risks need to be minimised where possible and one such possibility is to build in redundancies in the technical systems to reduce the risk of technical failures. However, it is important to be able to remove the redundancies later or, in other words, reduce operation costs as soon as the congestion charging technology has been proven to work.

Make sure people understand how to use the system. Besides communication with the public on the political aspects of congestion charging, it is very important that people understand how the system can be used. This is probably relatively easy for 80% of the population but the other 20% are just as important.

Have a solid legal framework. The opposition as well as individual drivers will try to find legal means and loopholes to either avoid paying the charges or get the policy removed altogether. Before introduction of the congestion charges - but even afterwards - lobby organisations and opposition groups may attempt to initiate legal action either against the system as a whole or against system parts. It could be that the method of identification is found to be illegal or that the procurement of technical systems was not appropriate. Even if these legal actions have no chance of winning, they may have the effect of delaying the introduction during an election year. Once introduced, a minority of drivers will try to find loopholes in the system to avoid paying. Classic examples of this are drivers trying to avoid paying by shielding their licence plates. If a substantial number of drivers can avoid paying and it is not enforced, the system will fall into disrepute.

8 Further Readings

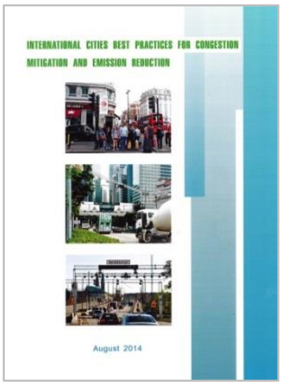

International Best Practices for Congestion Charge and Low Emissions Zone

International best Practices for Congestion Charge and Low Emissions Zone (2014)

This report gives a broad insight in the experiences and recommendations as well as detailed data about worldwide traffic management schemes in English and Chinese language.

Case studies and examples are provided for the London, United Kingdom; Stockholm, Sweden; Singapore; Milan, Italy; the US in general and New York.

Online: www.efchina.org/Reports-en/report-20140814-en

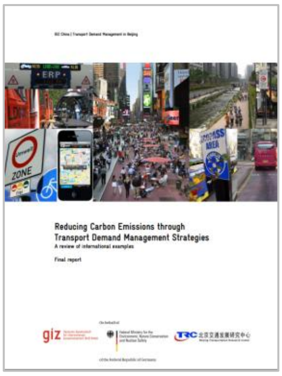

INTERNATIONAL CITIES BEST PRACTICES FOR CONGESTION MITIGATION AND EMISSION REDUCTION

August 2014

International Cities best practices for congestion mitigation and emission reduction (2014)

The study focuses on how to implement utilize Low Emission Zones and Congestion Charging in tackling traffic congestion and air pollution in cities.

Examples are given for Singapore; London, UK and Stockholm, Sweden


Reducing Carbon Emissions through Transport Demand Management Strategies

A review of international examples

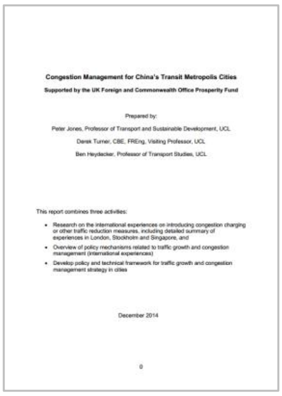
Final report

Reducing Carbon Emissions through Transport Management Strategies (2012)

The report focuses on transport demand management to reduce air pollution and traffic congestion. These include congestion charging, parking management promoting public transport and bicycle use.

Examples are given for Berlin, Germany; Seoul, South Korea; New York and San Francisco, USA; Stockholm, Sweden; Singapore; London, UK; Milan, Italy and Curitiba, Brazil

Online: sustainabletransport.org/reducing-carbon-emissions-through-tdm-strategies


Congestion Management for China's Transit Metropolis Cities

Supported by the UK Foreign and Commonwealth Office Prosperity Fund

Prepared by:

Peter Jones, Professor of Transport and Sustainable Development, UCL

Derek Turner, CBE, FREng, Visiting Professor, UCL

Ben Heydecker, Professor of Transport Studies, UCL

December 2014

Congestion Management for China's Transit Metropolis Cities (2014)

Focused on international experiences this report subsumes research on traffic reduction measures, such as congestion charging. It additionally provides advice on creating strategies for developing policy and strategy frameworks.

The report uses London, UK; Stockholm, Sweden and Singapore as examples.

Online: sustainabletransport.org/?wpdmact=process&did=ODIuaG90bGluaw

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Appendix A: Questions in the feasibility study

Traffic situation background

- How many vehicles are registered in the city/country?
- What is the proportion of vehicles from other regions, other municipalities?
- What permanent monitoring and measurements of traffic are conducted in the city/country?
    - Who owns the data?
    - Examples of relevant data: traffic flows per mode, travel times per mode, travel diaries, OD-measurements, SP surveys, accident registration, etc.
- Where does congestion exist in the city; when, what is the main cause?
- What are important main streets, routes for emergency vehicles, major bus routes, business districts and tourism areas?
- Where is the traffic likely to divert if a charging scheme is introduced? What measures can be taken to mitigate against the detrimental impact that traffic diversion would cause in these locations?
- How do the quality of the bicycle and public transport networks compare to the car in terms of connectivity, travel times, delays, costs, etc?
- What is the modal split for different areas, between districts, layers, etc. both in number of trips and vehicle kilometres travelled?
- What is the proportion of road space occupied by different modes (PCU)?
- To what extent is road capacity used for parking (legal and informal)?
- What parking policies are in place? Is parking organised by the private or the public sector? What are the charge levels; do drivers bear the entire cost?
- What is the cost of gasoline and average fuel consumption of the car fleet?
- What cost and personal effort are associated with vehicle registration and vehicle purchase?
- What does the average car insurance cost per month?
- Are there up to date digital maps (GIS) of current networks, their speeds (free flow and actual), capacities, planned expansions as well as planned urban developments?

Public transportation

- (Digital) Description of current available public transport: mode, lines, capacities, frequencies, prices, shares, occupancy levels, etc.
- Future changes and planned investment in public transport
- Structure of the organisation of public transport.
- Private/public companies and firms or informal routes

Vehicle registration and license plate issues

- What authority is responsible for vehicle registration?
- Who provides license plates? Can license plates be freely produced and sold or are there regulations and fraud minimising technologies for plate production and distribution?
- Can external agencies gain access to license plate records?
- Do license plate records include an up to date link to vehicle owners and their addresses?
- To what extent are there false plates? What is the proportion of false plates?
- What procedures are in place today to identify false plates and reduce the number of false plates?
- What information exists (and what is the quality of information) in describing the vehicle registration and car owner? e.g. owner: name, address, ID, vehicle make, model, year of manufacture, purchase price, emissions or environmental class, previous owners, other relevant information (right to parking, disabled, taxi, car emergency)
- What is the process to change owners? How long does it take?

Identification of legal context

- What would be the legal framework of the charge? Is it a tax or a fee? 'Is the empowerment at the city or national level? Is new legislation needed?
- Are there limitations on who can collect charges, the level of charges, to what extent they can be increased or given discounts (for example, would it be legal to charge cars from other regions or other countries, buses, taxis, motorcycles, public vehicles, etc.)?
- Could the charge vary according to type of vehicle, time of day, direction of travel etc.?
- Control system:
  - What laws exist to protect private integrity such as taking photographs in public places and keeping photos?
  - Enforcement: Which authorities have the right to stop vehicles today, and what regulations and constraints are in place for this?
- If a person is in debt (unpaid tolls), what is the process to collect the debt?
- What authorities need to be involved? What is the relationship between authorities?
- Is it possible that a debt will be associated with a vehicle instead of a person? Can the vehicle be seized or impounded?

Transportation modelling issues

- What base year and forecast years does the model have? Are these years in line with the congestion charging planning horizon? The first year of opening is especially of political importance.
- Is travel demand modelled in sufficient detail and sensitive to charge levels?
  - Choice dimensions: location choices (land use), generation, mobility choice, destination, mode, time
  - Modelling techniques: activity based, discrete choice, gravity models, etc.
  - Explanatory variables for different choices: travel time components, cost components, etc.
  - Travel purposes and socio-economic groups: is this sufficiently detailed?
  - Multimodal models{
    - Separate demand, networks, and assignment for cycling and public transport?
- How is demand assigned to the network?
    - How is route choice modelled? Are costs included?
    - Multiple classes of value-of-time or even distributions of values-of-time?
    - What assignment technique:
      - static- dynamic
      - Deterministic – stochastic
      - Equilibrium? What is the stop criterion?
      - Junction delays?
- Information on population, land use data in the model, and if this information is distributed by population strata, age, gender, etc?
    -
- What effect models exist?
    - Economic evaluation models and guidelines for valuation values?
      - Cost benefit analyses?
      - Values-of-time, values of emissions, accidents, value of statistical life, taxation parameters, etc.
    - Environmental effect models?
      - Emissions
      - Noise and vibration
    - Traffic safety effect models?
    - Social effects and distributional effects?

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Registered offices
Bonn and Eschborn, Germany

GIZ Office China
Sunflower Tower Room 860
37 Maizidian Street, Chaoyang District
100125 Beijing, P.R. China

T +86 (0)10 8527 5589
F +86 (0)10 8527 5591
E info@giz.de
I www.sustainabletransport.org

Author:
Dirk van Amelsfort

Editing:
Urda Eichhorst, Frederik Strompen

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Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Sitz der Gesellschaft
Bonn und Eschborn

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn/Deutschland
T +49 61 96 79-0
F +49 61 96 79-11 15
E info@giz.de
I www.giz.de