Impact of Urban Form and other Characteristics on the Implementation of Urban Road Pricing

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An important note for the reader

Abbreviations and Acronyms

ALS	Area Licensing Scheme
ANPR	Automatic Number Plate Recognition
BOP	Bay of Plenty
CBD	Central Business District
CC	Congestion Charging
COE	Certificate of Entitlement
CUPID	Coordinating Urban Pricing Integrated Demonstrations
DSRC	Dedicated Short Range Communication
EFC	Electronic Fee Collection
ERP	Electronic Road Pricing
ERPFS	Electronic Road Pricing Feasibility Study
eRUC	Electronic Road User Charging
ETC	Electronic Toll Collection
GHz	Gigahertz, measurement of radio frequency
Giro	General interbank recurring order
GPRS	Ministry of General Packet Radio ServiceTransport
GPS	Global Positioning System
GWRC	Greater Wellington Regional Council
HOT lanes	High-Occupancy Toll lanes
HOV lane	High-Occupancy Vehicle lane
LOS A or B	High level of service
NOK	Norwegian Krone, currency unit
NO_x	Nitrogen Oxides
NPV	Net Present Value
O & M	Organisation and Management
OBU	On-Board vehicle Unit
PCN	Penalty Charge Notices
PM_{10}	Particulate Matter of 10 micrometres, or less, in diameter
ROCOL	Road Charging Options for London
RP	Road Pricing
RUC	Road User Charging
SMS	Short Message Service
TfL	Transport for London
TLA	Territorial Local Authority
TSP	Toll Systems Project
VEP	Vehicle Entry Permit
VKT	Vehicle Kilometres Travelled
VPS	Vehicle Positioning System
WIM	Weigh in Motion

CONTENTS

Executive summary

This report was prepared as part of the Land Transport New Zealand Research Programme 2005/2006. The purpose of this project is to review congestion charging schemes overseas and assess their applicability to New Zealand cities, in particular; Auckland, Wellington, Tauranga and Christchurch. From this initial research, the report provides direction, from overseas best practice, on the congestion charging systems that suit the urban form and Travel Demand Management (TDM) requirements of the cities studied in New Zealand.

The impact of traffic congestion in major cities worldwide is of growing concern. Developing countries can no longer build their way out of a congested road network, so the use of charging as a TDM tool is becoming more common. There are two different types of charging for use of road infrastructure, Road Pricing and Congestion Charging. This report defines the distinction between these two different charging methods.

Road pricing has long been proposed as an efficient and equitable method for charging for road infrastructure use and to fund road infrastructure or transport projects. Road Pricing is used to generate funds to re-invest in other road infrastructure projects, the rates are set to maximise revenues and diversion onto alternative routes is not desirable as it reduces the revenue collection.

Congestion charging on the other hand is used to reduce peak hour vehicle traffic, with revenue generated being invested into alternative transport modes such as trains and buses. It requires variable charging rates to discourage vehicles from using key routes at peak times and encourages travel shift to other transport modes. Charging for road use as a whole can improve transport efficiency by rationing road capacity, including influencing the demand for road capacity as it applies to different road classes, vehicle classes, or peak traffic conditions.

Electronic pricing and related Intelligent Transport Systems (ITS) technologies have matured greatly in recent years with improvements in coverage , ease of implementation, cost, and public acceptance all occurring at a rapid pace. This has lead to charging for road use becoming a more feasible solution.

Auckland has already investigated possible congestion charging schemes and their alternatives, but other cities in New Zealand also suffer from the issues associated with traffic congestion and are looking to international examples for possible answers to the predicted future congestion problems. The cities studied in this report were Stockholm, London, Singapore and Rome. There were several factors that were considered when examining these international examples:

- Characteristics of the urban form that influenced the scheme design.
- Use and modification of the existing e-toll systems to deliver an enforcement solution.

- Results of the measures against the project objectives.
- Elements of the system that have been modified, or are planned to be changed in subsequent projects.

Following the investigation of these initiatives and concepts, the following observations were made about the international cities investigated:

In Rome, the city is characterised by a network of often narrow streets creating significant restrictions to traffic movements. These features however, have also been used in the development of the solution utilising the urban form to establish zonal gateways. The system is described as an Electronic Gateway System and uses bypasses, park and ride, bus services and public transport to support access into the historic parts of the city thereby reducing the impact of vehicle pollution on the historic buildings. The Electronic Gateway System also recognises the need for special treatment of local business and medical trips and provides free home zone movement. The system is provided using transponder based verification which is proving to be more efficient than the labour intensive and currently less reliable Automatic Number Plate Recognition (ANPR) approach. By improving access rights for local businesses and limiting the adverse affects on tourism in the central area, the scheme is widely viewed as a success.

Singapore is the oldest of the congestion charging schemes studied and is characterised by a small central business district in a high density city. The geographic layout of Singapore did not require any special measures such as bypass routes to be implemented. Being an island state, Singapore benefits from a relatively small and controlled vehicle fleet, so introduction for the current Electronic Road pricing (ERP) system provided a more efficient and cost effective means of collecting and enforcing the congestion charge compared to the original paper based system. The migration to ERP, bringing with it the option to charge based on time of day and route, and giving the option to continually adapt these conditions has improved the spread of peak demand.

The urban form of the centre of London provided a relatively straightforward solution to the scheme design, with the natural bypass of the inner ring road forming a natural boundary to the charge area. The London scheme is an area charge with all vehicle movements inside the zone being captured during the charging period. It has seen an increase in average traffic speeds, a large reduction in traffic entering the zone, and a modal shift to public transport services. The scheme uses ANPR, which enabled it to be implemented relatively quickly. With an extremely large vehicle fleet, this simplified the system and eliminated the need for full fleet installation of transponders. London is however currently experimenting with and considering a move to transponder technology in the future.

In Stockholm, the urban form with its location and limited water crossings has greatly influenced the scheme design. It is a cordon design with special concessions for bypass traffic. With no obvious bypass route, the strategic road network and main freeway were used as free routes. This type of scheme is of particular benefit to cities that do not have natural bypasses as is the case with London’s inner ring road. The Stockholm scheme was complimented by significant investment in public transport and new and extended bus services. The scheme was established as a full scale trial, and the results of public opinion monitored throughout.

Relating these observations to the considered New Zealand context, we looked at the cities of Auckland, Wellington, Tauranga and Christchurch. There has already been a review into the possibilities of Congestion Charging in the Auckland region. Traffic congestion is a significant problem for Auckland with population and vehicle numbers growing. The key issues that would influence any potential scheme design are most closely related to the Stockholm example with congestion experienced on primary arterial routes restricted by water crossings. The shape and form of an Auckland scheme would be influenced significantly by the restricted transport corridors and it may be necessary to provide some specific free through routes.

In Wellington, the regional transport network is characterised by an arterial road network of limited capacity with relatively high levels of public transport use. Traffic congestion in Wellington is also less of an issue than in many comparable cities due to the compact city with short travel distances and a good level of connectedness. The key issues that would influence any potential congestion charging scheme design are most closely related to the Singapore example with a small high density central business district and an easy to define charging area. Also, as with the Stockholm and London examples, the shape and form of a Wellington scheme would need to consider the need for a bypass and/or free through route to provide access to and from the southern suburbs and the airport.

Tauranga is one of the fastest growing cities and regions in New Zealand and continues to grow more rapidly than forecast. The key issues that would influence a potential charging scheme for Tauranga would be similar in some respect to Auckland and most closely related to the Stockholm example in that there would need to be special concessions for bypass traffic. There would also be some potential application of features from the Italian systems due to the seasonal tourist demand and the many work districts around the region with no specific CBD.

In Christchurch there has historically been a very good transport system with little congestion. In recent years however, traffic demand has grown in the region driven by increased economic activity, population increase and good access. The urban form is that of a flat landscape surrounded by the foothills of the Southern Alps, this creates unique air quality problems in the winter months form the use of wood burners combined with vehicle pollution. The road system is based on a grid network, and the key issues that would influence a congestion charging scheme are similar in some respects to Wellington and most closely related to the Singapore example due to the small central business district. There would also be some potential applications of the zonal nature of the Italian systems for local businesses.

The key common issues identified from this study of international cities were that the main objectives were to reduce congestion, improve trip time reliability and reduce emissions throughout the wider city. This is achieved through the management of peak demand, encouraging travel by alternative modes and at off-peak times. Another issue that is highlighted by all of the examples is the need for a targeted improvement of public transport services to provide an effective alternative to the private vehicle as a means of travelling into a city centre.

Abstract

The purpose of this research report was to review the use of congestion charging schemes in relation to the urban form of a selection of international cities. The study concentrated on Singapore, London, Stockholm and Rome and drew comparisons to the New Zealand environment, particularly Auckland, Wellington, Tauranga, and Christchurch.

Through the evaluation of the international systems, this research intended to highlight the benefits and characteristics that could be used to manage the increasing congestion, and provide better travel demand management solutions in New Zealand. In particular, the research benchmarked the technology used in relation to the travel patterns, geography and urban form.

1. Introduction

The impact of traffic congestion in major cities is of growing concern worldwide, and as the more traditional means of addressing this problem are exhausted, the use of charging as a demand management tool is becoming more common.

Road Pricing (RP) or Congestion Charging (CC) can be defined as 'umbrella' terms used to describe the application of pricing to roads and infrastructure. They are defined to include a number of well known charging mechanisms that governments at various levels use to manage demand, or to raise revenues. These include;

(i) charging for the cost of congestion,
(ii) marginal social cost pricing,
(iii) heavy vehicle charging,
(iv) road taxes and fees and
(v) tolling.

The objective of congestion management is often a major driver in the consideration of road pricing policies and applications, as seriously congested road networks can cost the economy/community billions of dollars annually.

Road pricing has long been proposed as an efficient and equitable method to pay for road use and to fund road infrastructure projects. However, there is an important distinction between charging for revenue generation as opposed to pricing roads to provide congestion relief.

These two key objectives differ in several ways, as summarised in Table 1.1 below.

Table 1.1 Objectives of urban road pricing policies.

Revenue generation	Congestion management
Generate funds. Rates set to maximise revenues or recover specific costs. Revenue often dedicated to road infrastructure projects. Traffic diversion to alternative routes and modes not desired as it reduces revenue collections.	Reduce peak-period vehicle traffic. Used as a TDM (travel demand management) strategy. Revenue not dedicated to road infrastructure projects. Requires variable charging rates (i.e. higher during congested periods). Travel shifts to other modes and times considered desirable.

Road pricing can improve transport efficiency by rationing road capacity, including influencing the demand for road capacity as it applies to different road classes, vehicle classes or peak traffic conditions. It can be a useful travel demand management mechanism, with effective pricing schemes having the ability to change travel patterns by exposing road-users to the marginal social cost of their travel choices. Pricing can affect all stages of travel decision making from choosing to make a trip to destination choice, mode choice, time of travel choice and route choice.

Electronic pricing and related Intelligent Transport Systems (ITS) technologies have matured greatly in recent years, with improvements in coverage, ease of implementation, cost and public acceptance occurring at a rapid pace. This has led to a gradual improvement in the overall feasibility of road pricing.

In the next five to ten years, road pricing is expected to expand in terms of its range of application in reducing congestion, toll road developments and heavy vehicle charging. Over this period, emerging pricing technologies will enable merging (or efficient combinations) of these partial applications into pricing schemes that significantly improve efficiency of travel patterns.

In a broader sense, they will also improve the efficiency of resource use – such as investment decisions in transport infrastructure and road users' allocation of time. More efficient travel patterns are likely to promote greater accessibility (due to reduced congestion) while at the same time providing opportunities for better management of mobility. Trip choices that optimise mobility (mobility defined here as desire for more dispersed travel patterns) would be made in an environment which exposes users to the full (marginal) social cost of their travel choices.

The primary area of concern in New Zealand is Auckland which is already investigating possible Congestion Charging schemes and alternatives. Other cities centres also suffer from the issues associated with traffic congestion and are looking to international examples for possible answers to the predicted future congestion problems.

The purpose of this project is to:

- Review the congestion charging schemes overseas and assess their applicability to New Zealand cities, in particular; Auckland, Wellington, Tauranga and Christchurch.
- Provide direction from overseas best practice on the use of congestion charging systems to best achieve the results that suit the urban form and travel demand requirements of the cities that are being studied in New Zealand.

2. Purpose of the Research

The specific urban form, travel demand and transport characteristics of any urban areas have a major influence on the types of solutions employed to address transport issues.

The significant investments involved in developing and implementing Road User Charging in any form lead to a need for thorough planning and assessment of options to ensure that any solution implemented is effective, economically viable and achieves a suitable level of public acceptability.

The purpose of this research is to examine the types of road pricing approaches and systems used in a range of international examples, and to consider the issues raised in a New Zealand context. This will include an assessment of issues such as the systems objectives, the urban form of the example cities, and other characteristics unique to those cities that have influenced the system design. The research:

- defines the types of road pricing system (including technology, pricing scheme and management aspects) that have been implemented in the four selected cities;
- defines the urban form and other characteristics that have contributed to the success or otherwise of those systems;
- relates those contributing factors to the urban form and other characteristics of New Zealand's major urban centres; and
- draws conclusions on the best approaches for implementing urban road pricing in New Zealand, based on the analysis of contributing factors to success such as urban form.

2.1 Understanding the key issues

An understanding of the key issues surrounding congestion charging and urban form will help guide future policy and strategy decisions in New Zealand. To address this, an assessment of the current understanding of the key issues related to transport and congestion impacts was developed early in the process, to help define and assess solutions and/or policies that may lead to the development of potential solutions in the future.

These key issues range from the specifically related congestion problems to the broader efficiency of the transport network, and effects on the economy where a reputation for congestion and inconsistent travel times has developed.

Issues that go hand in hand with congestion in urban areas are the air quality and noise aspects of increasing population and car use. New Zealand has a growing population and is more heavily reliant on the automobile as a mode of transport than many countries, so it is only a matter of time before increasing congestion causes more serious air quality problems in urban, built up, or geographically sensitive areas.

In many cases internationally there has been an approach of waiting to fix a problem after it has become more serious. There is an opportunity in New Zealand to combat future congestion issues and related problems before they become a more serious issue.

A review was undertaken of international applications, policies and objectives, considering issues ranging from congestion, delays, and air quality to the broader efficiency of the transport network, and effects on the economy.

The following summaries list some of the key issues that have influenced this system, set out under four broad categories.

- Project drivers
- Specific project purpose or role
- Policy and legislation
- Project benefits and outcomes

These are expanded later in the report with specific reference to the projects examined.

2.1.1 Project drivers

The principal objectives, issues or problems that led to a specific project or program being developed.

- Managing traffic on limited road space.
- An incomplete transportation hierarchy.
- High levels of congestion.
- A requirement to increase accessibility.
- Cost in economic terms of the congestion in an urban centre.
- The effects of emissions levels on air quality and public health in an urban centre.
- Provision of increased resources for public transport.

2.1.2 Specific project purpose or role

What specific system is set up to charge for use of road space, and for what purpose.

- Reduction of congestion in city centre areas.
- Raising of revenue to invest in alternative modes of transport.
- A trial to assess the viability and public reaction to congestion charging before any final system implementation.
- Meeting the requirements of the forward plan or transport strategy for the region.
- Protection of historic buildings from the effects of stationery traffic and the air pollution it produces.
- Pricing by time of day to encourage people to change their travel methods and times in order to avoid ‘rush hour’ congestion.

2.1.3 Policy and legislation

The role of policy and legislation as a solution and as a facilitator of other projects.

- Results of the project have led to legislation being introduced after benefits have been seen.
- Unsuccessful attempts at vehicle taxation led to the alternative approach of congestion charging.

- Short timeframe for implementation due to political restrictions affected project approach.
- Before unveiling the new scheme, a full scale trial is implemented to assess public opinion and test political options.
- Policies directed toward sustainable mobility for the future using all modes of transport.

2.1.4 Project outcomes and benefits

Specific benefits and outcomes sought.

- Reduced congestion.
- Improved consistent trip times and reliability of journeys.
- Reduction in quantity of cars during the peak times.
- Improvement of air quality and particulate matter concentrations.
- Improving the urban environment.
- Provision of more resources for public transport.

3. Congestion Charging and Road Pricing Strategic Issues

This section provides a review of the key issues involved in the planning, justification, implementation, and operation of RUC/Congestion Charging schemes from around the world.

This worldwide experience provides a base from which to investigate the New Zealand context which will be examined in more detail later in the report.

3.1 Scheme objectives and performance

International experience reveals that the successfully implemented schemes targeted specific objectives to resolve 'problems' recognised by the public, stakeholders or governments. Many that have failed are part due to disagreement on the scale or need for RUC/Congestion Charging.

Singapore suffered serious congestion and, with a strong centralized authority, has made demand management a core part of its transport strategy over the past 40 years. Today the public understand the role and benefits of ERP and COE policies, their application and the monitoring of network level of service. Road traffic speeds are maintained by adjusting charges based on monitoring of level of service and by a complementary road and public transport infrastructure and management programmes.

In London the business sector and elements of the general public recognised congestion as a leading problem for the city and pushed for its resolution. In general, the scheme is seen as successful and the congestion relief perceived. The recent charge increase from £5 to £8 was not as well received and was arguably not seen to be needed by the public at large. The linking of the charge increase to worsening congestion was not as explicitly communicated to the public as in the quarterly review operated in Singapore. In London the un-congested overnight travel conditions benchmark the target for the Charge Zone (roughly 2 minutes/km average), however in practice a lower level of service is tolerated through the day.

The planned expansion into neighbouring Kensington and Chelsea was partly driven by a need to resolve congestion there but also by local residents wishing to be inside the scheme in order to benefit from discounts. Congestion is more widespread in London and other areas may, in theory, require demand management measures.

In Italy, in the hearts of cities with ancient street patterns of high heritage and cultural value, the objectives are a mix of environmental, historical and congestion related issues. The electronic gateway schemes introduce several new ideas in controlling access to the historic business districts of the several cities that have implemented the scheme.

In Stockholm the charge is regarded as a traffic congestion and environmental tax. Whilst politically led, the six month trial formed the basis of a referendum to permit the public to decide on the need and justification, albeit based on a particular scheme.

It is interesting to note that, in most cases, after initial resistance, the general public has recognised the travel benefits of Congestion Charging schemes, which is critical if many of the other key implementation issues and concerns are to be offset.

3.2 Congestion charging and equity

As cited in a report by Booz Allen (2006), equity is perhaps the most commonly cited issue around RUC. The imposition of a charge at point of use raises questions of fairness:

- “What about those who have no alternative route?”
- “What about low income groups?”
- “What about residents?”
- “What about those elsewhere who don’t pay?”
- “What about exemptions? Discounts?”
- “How will it affect other factors such as house prices?”

These are valid questions and policy makers have several tools available to them. Their task is to address some of these areas of concerns and make a scheme fairer and thus more sellable. These include:

- Provision of an alternative route, ‘bypasses’, are available in both the London and Singapore charge zones. The Italian electronic gateway schemes also advocate bypasses but can accommodate strategic routes through the urban centres with their access zone designs.
- Exemptions for certain categories of users – low income groups, delivery vehicles and residents. The actual choice reflects the politics of a situation. In Singapore practically nobody is exempt. The London scheme would have struggled to proceed without the support of residents living within the cordon, so they pay only 10% of the charge. Taxis are discounted 100%, as are public buses despite being operated by private companies. In Italy a wide range of travellers are exempt on social grounds.

Congestion charging equity can also have a dynamic component that can be used to encourage behavioural change. Charging cars and using the money to improve buses has completely different equity impacts from charging cars to reduce fuel tax.

The literature provides many references that touch on these topics:

- May (1992) describes concerns that cordon pricing will affect those making short journeys and living close to cordons, as well as those who have no choice but to travel by car.
- Parsons Brinckerhoff (2001) demonstrates a correlation between HOT lane users’ income and usage.
- Wellington Regional Council presents a very generalised view of the potential winners and losers in the case of tolling an existing road or bridge drawing upon the work of Gomez-Ibanez (1992).
- Borins (1988) cites that one of the most critical reasons for failure of the initial Hong Kong scheme was the distribution of winners and losers.

- The MVA Consultancy as cited in Austroads (2000) states "for some households…the introduction of congestion charging would be a significant and unavoidable increase in costs".
- The Auckland Evaluation of Road Pricing Study provides a fair assessment of several scheme designs and portrays the costs and benefits of each.

3.3 Congestion charging and land use

Also in the report from Booz Allen (2006) it is stated that congestion charging schemes will inevitably have impacts upon the geographical areas and economic sectors that they interface with. Opponents of schemes often raise objections such as "…it will drive down house prices", "kill the city centre" or "destroy local businesses".

The evidence that any of these things occur is patchy. Herve Commeignes (1991) describes how area pricing was not introduced in the US for fears it could affect retail trade, but then cites that the experience in Singapore would not bear this out – other factors drive the economy far more strongly than road pricing. So far in London the business community seems to largely support the scheme (49% in favour with only 16% openly against). Despite one high profile retailer claiming it has lost trade, evidence from London First (2003) suggests that 71% of businesses feel the congestion charge's effect upon their business has been neutral.

There is even contention amongst researchers as to what should be expected of road user charging in terms of the impacts upon land usage:

One line of reasoning holds that the traditional under pricing of highways encouraged urban sprawl and that correct pricing would encourage dense development around urban centres. An opposing line of reasoning holds that congestion pricing would facilitate continued decentralisation because it would reduce the attractiveness of an area affected by pricing especially if other competing areas are unpriced….(TRB 1994).

3.4 Final use of congestion charging revenue

Booz Allen (2006) cite that the end use of any revenue raised is mentioned at length in the literature, with people seeking a tangible benefit from a charge. This could be in the form of:

- time saved,
- provision of a facility that they would not otherwise have had, and
- investment in other sectors of the economy.

Sapokta (1997) noted that the use of revenue topped the list of public concerns. This was borne out in Ison (2000) - cited by Santos (2000) – in which respondents were asked if they would support a select road pricing scenario. The majority (88.7%) were hostile to RUC in any form if no use of the money was specified. When specific policy options were outlined for the revenue then the support rose to 54.6%.

This figure bears out the rough orders of magnitude shown in work undertaken by the New Zealand Automobile Association (Research Solutions 2003) and by the New Zealand National

Economic Development Office (1991) which showed 70% support of road pricing for all respondents surveyed provided the revenues were invested in roads or public transport. Odek & Bråthen (2002) cite the policy behind the use of the toll revenues as critical:

There is reason to believe that an upgrading of the public transport system together with the implementation of the road user charge would cause an initial improvement in public acceptability…In Norway large tollbooths in uncongested road systems have not been removed after the roads are paid for but have been used to finance roads elsewhere in the region…this can result in lack of public confidence.

In London, work in the early 1990s by May (1992) showed that road pricing was only acceptable to 43% of the population in a general sense but this rose to 62% of the population if the revenue would be used to improve London's public transport system. A separate UK-wide survey by Jones (1991) identified that road pricing (with no defined revenue usage) in cities was generally only supported by 30% of people who were of the opinion that "something needed to be done", whereas once the revenue was used to reduce accidents, improve conditions for pedestrians and cyclists, and increase investment into public transport, the figure rose to 57%.

References coming from the United States broadly offer the same conclusions although support levels are of a lower order than those outlined by European commentators. Harrington et al. (2001) outline how a survey carried out by the South California Area Governments (SCAG) suggests that the public will respond favourably to congestion pricing proposals that address the issues of revenue redistribution and motorist's route choice. A promise to return a portion of the revenues (in benefits) increased support by around 7%. Plans to use the revenue to fund an extra high occupancy lane produced the greatest support although recent dictates by Transport Secretary Norm Mineta of the USA indicates that the USA will be more actively addressing congestion by the conversion of HOV lanes to HOT lanes or priority lanes.

3.5 Congestion charging perceived as dual taxation

Some people regard RUC as dual taxation as they perceive that they are already giving the government money for the construction and maintenance of new roads and that any extra charge is unfair and yet another 'tax' for which there will be no tangible benefit.

In London the surplus revenues were very clearly hypothecated into a fund to improve public transport and traffic management as integral complementary measures to the Congestion Charging Scheme. In Singapore the COE was reduced by S$200 per annum as a 'sweetener' following implementation of ERP for the first five years of operation.

The most obvious ways to counteract this form of objection is through revenue hypothecation (targeting the funds) and revenue neutrality (not making a profit). Both are effective but incompatible. Toll roads are a very clear example of revenue hypothecation – without the tolled revenue streams the concession company which built the road could not afford to pay back the capital borrowed to construct the road nor cover their operating costs.

Further, if a private company is to be involved, a profit margin would also be required over and above the recoup of costs.

The literature covers the topic reasonably comprehensively. Santos (2000) cites the need to restructure the charging scheme in an obvious way or to obviate the perception of dual taxation – moving more towards a variable charging mechanism with a small fixed component. DeCorla Souza (1993) offers the opinion that a section of the public will always see congestion pricing as yet another tax increase. Odeck and Bråthen (2002) describe how road user organisations in Oslo opposed the toll ring as yet another tax when road users were already contributing NOK 2.5 billion in taxes but only NOK 300 million of this was being spent on roads.

3.6 Public acceptance

As cited in a Booz Allen report (2006), an issue with charging using a technology is the public's concern that the technology works, and that they do not lose money or value through technical flaws. A study in Holland found that one of the major reasons for the abolition of the national Dutch motorway charging system was a concern over the unproven nature of the technology. Likewise, in New Zealand, the findings of the eRUC Feasibility Study was objected to by Land Transport New Zealand (LTNZ) for being overly optimistic of the proposed GPS on-board unit which used a combined GPS and DSRC technology.

This problem is not new. Herve Commeignes (1991) describes how in 1989 a survey carried out in Sydney about the use of electronic tolling on the Harbour Bridge indicated that people had little trust in the technology and that 30% of the respondents perceived reliability and accuracy as their greatest concerns. This points towards a need to demonstrate that the technology of choice works consistently and without errors.

3.7 Privacy and enforcement

As detailed in the report from Booz Allen (2006), user charging particularly with regard to violation enforcement and billing can involve issues of privacy. Essentially when an automated system can allow the tracking of a person's whereabouts at specific times of the day, privacy considerations are bound to arise. Parsons Brinckerhoff (2001) cite:

although electronic toll collection has proven very popular among drivers, some perceive the electronic tracking of vehicles as an invasion of privacy.

The major problem associated with privacy is when third parties have access to a person's mobility or usage information. Pre-payment options obviate this problem to some degree. Privacy can also be protected by linking electronic toll collection (ETC) transponders with a generic internal account number that does not reveal a driver's identify and legally prevents other organisations from accessing information.

3.8 Institutional issues of congestion charging

Another well documented issue is whether a city or state possesses the appropriate institutional and governance structure required for the development, procurement and operation of a complex RUC system. Booz Allen (2006) cite that if the political decision-making structure or process and government bodies are fragmented, then obtaining consensus and allocating responsibility is a concern. It would seem that a single empowered entity is thus a potential critical success factor. For example, in London, Transport for London was specifically set up for this purpose and Singapore has a single layer of Government.

Furan (1999) stipulates that there are currently no technical impediments to the implementation of inter-operable RUC systems. Rather it is the administrative and legal matters that need to be typically overcome. DeCorla-Souza (1993) cites:

...inter-jurisdictional issues as a barrier to scheme progress and highlights one key problem, namely that many arterial roads are federally owned but the remaining roads are the responsibility of local government. To implement a region-wide pricing strategy it is necessary to tackle difficult issues such as the setting up of institutional mechanisms for implementation, getting agreement on toll rates for select location and sharing revenues amongst the various bodies involved.

3.9 Legal issues of congestion charging

Very often congestion charging schemes require complicated legislation. Booz Allen (2006) state that the legislation required may be to allow a government body to own a particular asset or to prosecute for certain traffic violations. It could also be to transfer responsibility for an asset from one government body to another. In addition a set of legal issues surrounds toll-funded specific infrastructure, e.g. toll roads, because of the risk-sharing game between public and private sectors.

TRB (1994) details how toll road authorities that collect tolls electronically need to migrate to automatic photo-based enforcement yet often do not have legislation allowing such evidence to be used. In the United States, Illinois was the first state to convict a driver on the basis of photographic evidence; in Dallas (North Tollway) following the commissioning of the link it was found that photographic evidence of toll road infractions would be inadmissible in court.

Odeck and Bråthen (2002) describe how in London the ability to initiate the Congestion Charging Scheme was underpinned by the 2000 Transport Act. In fact the specific legislation for the London Scheme was promulgated and passed in parallel with the scheme design and implementation at some political risk. In New Zealand, the 2003 Land Transport Management Act does allow for tolls to be imposed on new roads to contribute to their funding, but not on existing roads.

The ERPFS addressed legal issues concerning the ERP scheme and concluded that there were no major obstacles except the establishment of the policy in the legislative process. The time line to implement such a framework was estimated to be 3 to 7 years.

3.10 Political risk

Booz Allen (2006) state that the majority of references cite political risk as a reason for a scheme not developing past the discussion phase. Political risk is a relatively loose term but it can broadly be taken to mean anything that may have a strong detrimental effect upon an administration's position of power.

The cases of London and Singapore are noteworthy here. When The Area Licensing System, the forerunner of the current Electronic Toll Collection (ETC), was introduced in Singapore in the 1970s no democracy per se was in place so the position of the government was never vulnerable. Interestingly enough, despite this, selling the scheme intensively to the public was still needed. In London, Mayor Livingstone first canvassed the public to assess the most acceptable form of congestion charging before using the scheme as the centre of his successful 2000 election campaign. This mandate enabled him to implement the scheme expeditiously His more recent re-election shows that congestion charging has proven to be a vote winner not a vote loser.

Deloitte Consulting (2003) performed a global congestion charging survey and found that lack of political support was the major challenge to implementing congestion charging. Santos (2000) cited an official in Cambridge stating "all political parties knew they would lose the following election if road pricing were implemented". Goh (2002) cites that 'political nervousness' caused the stall of the Hong Kong road pricing schemes both in 1985 and more recently in the ERPFS in 1997-2001.

3.11 Identification of critical implementation factors

3.11.1 Introduction

This chapter summarises the key factors associated with Congestion Charging schemes in operation today principally Singapore and London, and at the same time the key stumbling blocks associated with schemes that are currently shelved or in abeyance.

3.11.2 Candidate crucial implementation factors

Three major sources have been drawn upon here to set the scene:

1. the work carried out by the Swedish National Roads Administration in 2002,
2. the Road Charging Options for London (ROCOL) report (2000) undertaken as part of the development of the London congestion charging scheme, and
3. "Congestion Charging in London" by Martin G Richards, OBE.

1. The critical factors flagged by the Swedish Roads study are:

   a) The charge/revenue must be needed.

   b) The public needs to know where it is going.

   c) There must be broad political agreement.

   d) The charges must be part of a strategy.

   e) Regional benefits must be obvious.

f) Distrust of the motives of the politicians must be overcome.

g) Charges must be sensibly designed.

h) The public should be involved during the scheme development process.

i) There needs to be one decision making authority.

2. The ROCOL Working Group stated schemes should be:

a) achievable,

b) sensible,

c) predictable,

d) adjustable,

e) responsive, and

f) capable of implementation.

3. Martin Richards, a member of ROCOL, noted some key lessons learned from the London experience, which were:

a) Foresight – as above the ROCOL scheme provided a firm foundation for the London scheme.

b) Leadership and courage – the role of Mayor Ken Livingstone in driving the scheme through was critical.

c) Stability – consistent overall policy basis; party and policy changes were frequently the demise of schemes in Europe and N. America.

d) Decisive and speedy action – a rapid implementation to get results, even though not perfect.

e) A balanced package – part of an overall strategy with complementary mitigating measures.

f) Robust scheme – sound and fair to the public.

g) Sound research and analysis – thorough research and information sharing, followed by full before and after monitoring.

h) Good legal framework.

i) Single authority – controlling all (subsequently) urban transport.

j) Cooperation – all organisations.

k) Adequate funding – for overall strategy.

l) Pragmatism – implementation of less than perfect scheme better than deferment.

m) Technical competence.

n) Project management.

o) Broad public support.

p) Congestion charging not a license to print money – cost side as critical as revenue side.

q) Use of revenues – reinvestment in transport essential.

r) Enforcement – ensure compliance.

As can be seen, the Swedish Roads report offers more elaborate caveats than the ROCOL report which flags generic and more practical advice, whilst Richards is able to draw on experience of 40 years of discussion and development of the London scheme followed by 3 years of operation.

3.11.3 Key project views

This list of factors was checked against other ERP/RUC/Congestion Charging projects some implemented, some presently shelved.

3.11.3.1 Singapore

Singapore's area licensing scheme was introduced in 1975 and the scheme was upgraded to full electronic road pricing in 1998. There is little doubt that the scheme has been successful – traffic levels are down, average speeds are up and public transport usage has increased dramatically. The critical success factors have been:

- Revenue neutrality - government not generating a positive net return from a scheme, well-planned public relations campaigns from the beginning.
- A public perception that congestion was set to worsen and "something needed to be done".
- The use of proven technology.
- A strong political position (only one tier of government exists and strong political protest is not part of the culture in Singapore).
- The inclusion of the charging scheme as part of an overall transport improvement package (revenues were hypothecated).

3.11.3.2 London

London's scheme was implemented in February 2003. By 2004 congestion was down and there had been few system glitches. The scheme has however, generated far less money for public transport than originally forecast – the costs of administering the enforcement side have been far higher than envisaged. The critical success factors for the scheme are:

- The broad political consensus was that "something had to be done".
- A range of exemptions from the charge ensured that the scheme was largely fair.
- Existing mature technology was used.
- A single entity with full legal powers was responsible for development and delivery.
- A credible public transport alternative was available and revenues were ring fenced for public transport improvements.
- Free bypass routes available.

3.12 The PRoGRESS project

PRoGRESS – Pricing Road use for Greater Responsibility, Efficiency and Sustainability in cities. The PRoGRESS project was a major European demonstration project on urban road pricing that took place over a four-year period from June 2000 to May 2004. It was supported and part-financed by the Directorate General for Transport and Energy (DGTREN) of the European Commission under the Growth programme in the Fifth Framework for Research and Technological Development.

The eight European cities involved were:

- Bristol (UK)
- Copenhagen (Denmark)
- Edinburgh (Scotland)
- Genoa (Italy)
- Gothenburg (Sweden)
- Helsinki (Finland)
- Rome (Italy)
- Trondheim (Norway)

The PRoGRESS project consortium comprised 29 organisations drawn from six countries. It was co-ordinated by Bristol City Council in the United Kingdom.

The main goal of the PRoGRESS project was:

To demonstrate and evaluate the effectiveness and acceptance of integrated urban transport pricing schemes to achieve transport goals and raise revenue.

The PRoGRESS project was based on progressing and evaluating urban road pricing initiatives in the eight PRoGRESS cities. Originally, the eight PRoGRESS sites were intended to comprise:

- One existing road pricing scheme already in operation;
- Four new road pricing schemes;
- Two demonstration schemes to simulate charging systems; and
- One modelling study.

However, three of the envisaged new road pricing schemes had to alter their local focus during the course of the project to become demonstration schemes (with the approval of the European Commission). This was necessary due to time delays resulting from the essential political process surrounding the implementation of a real scheme.

The eight PRoGRESS sites all successfully delivered operational schemes, demonstrations or modelling studies as required. These were thoroughly assessed in accordance with an evaluation plan developed in co-operation with the CUPID thematic network, and the results were pulled together at a European level to reach conclusions and recommendations for future development and use of road pricing schemes.

From the project experiences with real charging schemes, demonstrations, and modelling and research exercises in the eight cities, the project consortium gained a wealth of valuable information on a range of aspects of road pricing. Some 60 lessons learned were identified from the results of PRoGRESS, and recommendations were made about how future RP implementations in European cities could take account of those lessons.

These experiences provide useful information to European and national governments, to industry and to research organisations. The lessons learned and recommendations are summarised in the following tables:

Table 3.1 PRoGress Project – consultation and information.

Lessons learned	Recommendations to city authorities and other stakeholders
There is weak support for road pricing as an isolated measure.	Present road pricing as part of a strategy.
It is hard to find support for full-scale schemes.	Consider running demonstration projects as a first step.
Support tends to erode as more detailed plans are presented.	Be aware of this risk and discuss it with politicians and other stakeholders at an early stage.
It can be difficult to communicate scheme objectives.	Emphasise providing information on the scheme objectives and traffic effects of the scheme.
Businesses in city centres are often against road pricing.	Communicate closely with businesses so that their fears and concerns can be addressed. Assure them of close monitoring and the possibility for later redesign.
Extensive communication is needed.	Make a complete information and consultation plan early in the implementation process and allow a large budget for this work.
It can be difficult to communicate changes in an existing scheme.	Provide abundant information before changes are made and use several channels for the information, including roadside variable message signs.
Good availability of information is needed even in field trials.	Thorough information is needed both before and during project implementation as well as when the schemes are running.
It is hard for trial participants to understand different scenarios.	Avoid letting the same person try different scenarios in field trials and instead let different participants try different scenarios.
The press acts as both opinion makers and opinion reporters.	Apply a pro-active approach and formulate a positive information strategy for the contacts with media.
Simple schemes are easier to communicate.	Apply simple schemes initially, as long as they can still satisfactorily meet the objectives, and then gradually improve them.

Table 3.2 PRoGress Project – legal and institutional issues.

Lessons learned	Recommendations to city authorities and other stakeholders
An unclear legal framework can complicate the debate and the decision process.	In cities where the legal framework for road pricing is not clear, it is recommended to address legal issues at an early stage of the process.
The legal situation may limit the possible scheme designs.	Cities facing limitation of scheme designs due to the legal framework need to either adjust the legal framework (which can be very time-consuming) or adjust the scheme design.
Introducing new legislation can lead to delays.	Delays due to changes in the legal framework and/or the approval process should be anticipated when developing a time schedule for implementation of a charging scheme.
Regulation of revenue use can be important for successful implementation.	Ensure that guarantees are given on how revenues will be used and who will control them, either through legal regulation or through agreements with government.
The traffic situation may change during the operation of the system.	Observe traffic flows and travel behaviour at certain intervals over time and run continuous panel surveys.
Using an ‘arm’s length’ company can work well.	Consider if this solution is suitable in that particular city.

Table 3.3 PRoGress Project – transportation policy.

Lessons learned	Recommendations to city authorities and other stakeholders
Distance-based systems give greater flexibility for transportation policy.	Follow the development of GPS-based systems in order to decide when it can be a practical tool for road pricing in urban areas.
Uncertainty has to be handled.	Form a strategy for how a fact-based dialogue on advantages and disadvantages of road user charging can be achieved.
Use of revenues must be settled before implementation.	Present to politicians facts on the impacts and likely acceptance of schemes, so that an early decision can be made on how revenues should be used.
Funds are needed before implementation.	Get a clear commitment at an early stage that funding will be provided for necessary improvements in the transport system to be in place from day one of the scheme.
Transportation policy must deal with social equity.	Analyse effects of road pricing together with other pricing instruments such as costs for parking, public transport fares, and park and ride.
Transportation policy must deal with impacts.	Undertake separate analyses and separate consultation exercises with the business sector for the business sector.
A winning idea is to confirm earlier strategies.	Use road pricing schemes to strengthen previously defined transportation strategies and objectives, so that over time they may then be considered as a part of the city infrastructure.
Implementation in London supports other cities.	Learn from other cities that have gone along with full-scale implementations, and cite their real life experience in information and communication

	materials.

Table 3.4 PRoGress Project – technology and transactions.

Lessons learned	Recommendations to city authorities and other stakeholders
GPS based systems have been shown to work.	Develop the technology further and in doing so pay consideration to learning from the demonstrations that took place in PRoGRESS.
GPS based systems may not be mature enough for full-scale systems in urban areas.	Use more mature techniques (DSRC and/or ANPR) if the road pricing scheme is to be implemented in urban areas in the very near future.
GPS based equipment does not always work properly.	Undertake extensive testing of prototypes before implementing the final product and consider augmentation by dead reckoning and map matching techniques.
There are many pitfalls in field trials using advanced technology.	Check that log data are collected properly several times during field trials and carry out thorough analyses at an early stage as the trials progress.
Avoid allocation of functionality to the on-board unit with GPS based systems.	Allocate all functions except the journey recording to roadside or central systems.
New equipment is often blamed for car malfunctioning.	Try to identify and solve such problems during testing of the prototypes, but also be aware that there is a risk for this reaction anyhow.
GPS based equipment is not distracting and integrity may not be a big issue.	Refer to the PRoGRESS experiences if and when the issue of surveillance is brought up in the debate preceding the decision on which technology to use.
GPS-based systems are too advanced to be needed for zone charging.	Consider ANPR or DSRC technologies, which are proven to function well, and should be compared on a cost and ease of implementation basis with GPS to arrive at a final decision.
DSRC works successfully.	Use DSRC technology (or pure ANPR systems), as long as it is not crucial for the fulfilment of the scheme objectives to use distance-based systems.
ANPR works well but does not recognize all vehicles.	ANPR can be used as an alternative to DSRC solutions - it may be cheaper and easier to implement since it requires no in-vehicle equipment, but is probably more expensive to operate.
Non-detection and incorrect reads in ANPR systems can be reduced.	Include overlapping fields of view for the cameras and consider twin front- and rear-facing cameras.
Operational costs differ between payment channels.	Promote the use of low-cost payment channels such as the Internet or SMS-based systems.
License purchasing systems can perform well.	The operation of license purchasing systems does not have to be a major concern, apart from the fact that it may be rather costly.
It is difficult to standardise on-board VPS equipment.	Harmonisation of distance-based EFC should be based on harmonisation of the message containing the time-stamped travel path.
For DSRC, standardisation has come a long way.	Adapt to the new standard wherever it has been completed.
There would be benefit if the DSRC EFC service can be included in the GPS systems.	Include the European DSRC-based common EFC service in every GPS system as an interface to the numerous existing and emerging systems all over Europe.

Table 3.5 PRoGress Project – enforcement.

Lessons learned	Recommendations to city authorities and other stakeholders
It is difficult to enforce large GPS based systems at present.	Use one of two imperfect alternatives - either onboard monitoring of the GPS based system enforcement by mobile and stationary checkpoints.
The chosen subject of control has big consequences for the system design.	Base the control system on verification of performed payments and not the functionality of the on-board equipment.
ANPR works well for enforcement checks and is more efficient than manual checks.	Use ANPR-systems for enforcement with the enhancements described above.
Registration of licence plates can be done manually.	Enforcement does not have to be fully automatic in small-scale schemes with a short planned lifetime.
Illegal access to charged areas can be due to insufficient information.	Put a lot of effort into information, especially when changes to the scheme are applied.
Penalty management can often be co-ordinated.	Examine the possibility to co-ordinate the handling of penalty charges from road pricing with the handling of penalty charges for parking violations.

Table 3.6 PRoGress Project – user acceptance.

Lessons learned	Recommendations to city authorities and other stakeholders
Surveillance is not a big issue.	Communicate, to the public and the press as well as to politicians, the fact that surveillance has not been a big issue at the sites.
Verify that traffic problems are actually solved by road pricing.	Focus on traffic behaviour rather than political issues before implementation and communicate clear and distinct facts on effects on traffic behaviour.
Support tends to increase after implementation.	Undertake measures to increase options for people influenced by the system when it is implemented.
Misconceptions easily arise.	Map the possible misconceptions, give extensive and clear information on how these topics are going to be solved.
Aesthetic issues are important.	Involve an architect or urban designer when planning for roadside equipment.
Easy payment channels are requested.	Facilitate payments by supplying several purchase channels with high accessibility.
Time to become accustomed to scheme should not be underestimated.	Approve a fair time schedule - a short time schedule may undermine the possibility to use road pricing to solve traffic problems in the foreseeable future.

4. Road User Charging and Congestion Charging Background

4.1 Road user charging and congestion charging

Road user charging (RUC or road pricing) can be defined as an 'umbrella' term that is used to describe the application of pricing to roads and infrastructure. The definition includes a number of charging mechanisms used to manage traffic and road use, or to raise revenues. These include (i) charging for the cost of congestion, (ii) marginal social cost pricing, (iii) heavy vehicle charging, (iv) road taxes and fees and (v) tolling.

Congestion management objectives are often a major driver in the consideration of road pricing policies and applications. Seriously congested road networks are a significant constraint to any city's economy, and appropriately targeted Road Pricing or Congestion Charging is now a proven and effective instrument for dealing with this type of congestion.

Congestion Charging can improve transport efficiency by rationing road capacity, including influencing the demand for road capacity as it applies to different road classes, vehicle classes or peak traffic conditions. Effective pricing schemes can change travel patterns by exposing road-users to the marginal social cost of their travel choices. Pricing affects all stages of travel decision making from choosing to make a trip to destination choice; mode choice; time of travel choice and route choice.

4.2 Functional requirements

The basic function of any congestion charging or road pricing system, and supporting technologies, is to collect payment from users within the framework of the scheme. This framework can vary significantly depending on particular local conditions, strategic, legal and policy requirements, and the nature of the outcomes that the scheme seeks to achieve. As these types of facilities have evolved in recent years the capabilities and/or limitations of the technologies available have often played a major role in shaping functional design. As the capabilities of technology have increased, the flexibility of congestion charging schemes to more directly address the key transport objectives has improved. In the same way that some technology limitations have (and still do) restrict some desirable scheme functions, the rapidly developing capabilities of new technologies can also offer options that may previously have not been considered.

Whatever system or technology solutions are adopted, the collection of payment from users within the framework of any congestion charging or road pricing scheme must include consideration of the following nine functional requirements.

1. **Informing** – providing adequate information to users and potential users (often defined by legislation).
2. **Detection** – detecting, and in some cases measuring, each individual instance of use (e.g. vehicle entering a zone).

3. **Identification** – Identification of the user, vehicle, or in some cases numbered account.
4. **Classification** – measuring the vehicle to confirm its class, aligned with the classification framework for the scheme.
5. **Verification** – cross checking processes and secondary means of detection, to assist in confirming transactions, reducing processing costs and providing a backup for potential enforcement.
6. **Payment** – pre and post use collection of payment from users based on verified use.
7. **Enforcement** – providing the means to identify and prosecute violators, and/or pursue violators for payment of charges and/or fines.
8. **Exemptions** – providing the facility to manage a range of exemptions within the context of the scheme.
9. **System Reliability & Accuracy** – providing all of the above through cost effective systems and technologies that can meet the required levels of reliability and accuracy, minimising revenue leakage and fraud.

4.3 Available technologies

The following is a list of potential candidate technologies for the primary system (the system that provided the main means of vehicle identification and or tracking), based on consideration of a combination of currently operating systems, developing new technologies and standards.

Along with the more advanced technologies this list also includes basic systems such as Paper Based and Manual facilities; this is partly for completeness, but also to assist in better illustrating and describing the basic functions for a simple system, that will improve understanding though the later more complex options.

The list comprises

1. Paper based systems
2. Manual toll facilities
3. DSRC schemes
4. Vehicle positioning systems (VPS) e.g GPS, Galileo
5. Image based or ANPR systems
6. Cellular telephone and Pico-Cell systems
7. Combinations

In addition to these primary systems there are several related sub systems for which a range of technology options exist. They include:

1. Vehicle classification systems (e.g. laser, video, digital loop, axle detection treadles).
2. Telecommunications, roadside and centralised control facilities (e.g. in unit, controller based processing).
3. Automation of operations (e.g. payment and enforcement processing, account setup and management).
4. Secondary enforcement systems (e.g. scene image capture, mobile and portable enforcement).
5. Payment systems.

6. DSRC systems.
7. OBU distribution facilities (e.g. vending machines).
8. ITS integration.

4.4 Summary descriptions

The following section sets out the candidate primary technologies, including a brief description of each and a summary of how the main functions are addressed by each.

4.4.1 Paper-based systems

Paper-based systems essentially require that road users, who wish to use (or keep) their vehicles within a defined area during a defined time period, to purchase and display a supplementary licence or permit. This usually takes the form of a paper licence that can be displayed on the windscreen or dashboard of the vehicle.

There are two main options available for implementing paper-based schemes;

- Entry permit schemes – where vehicles need to display a valid licence sticker to enter (or leave) a defined area (the restricted zone).
- 'True' area licensing schemes - where vehicles need to display a valid licence to travel or park within a defined area.

The distribution of permits or licences is usually managed through a combination of existing retail outlets, and other system operator channels such as vending machines, web and phone based mail order.

4.4.1.1 Examples

(i) Singapore's Area Licensing Scheme (ALS), operated from 1975 until 1998 required car drivers entering the CBD during the morning peak to pay three Singapore dollars per day (with exemptions for vehicles carrying four or more people. This was managed using a paper based (sticker) system, stickers being purchased for each day and placed on the inside of the windscreen. Under this system drivers were able to travel into and around the priced area several times in a day without having to pay multiple charges. Enforcement of the system was addressed using checkpoints where officials inspected each vehicle to ensure a valid license was displayed.

Figure 4.1 ALS sticker.

(ii) Parking management schemes use a range of paper based systems to collect and enforce the payment of parking charges, based on time of day, length of stay, location and vehicle class. Examples include:

- Pay and Display – used in most developed cities across the world; this system requires vehicles to display a valid ticket that is dispensed via roadside vending machines. With advances in technology these devices are now provided with live communications connections that enable them to manage variable charges by time of day, parking location and class; as well as providing a range of payment facilities including SMS-Text, credit, debit and smart cards.
- 'Coupon' or 'Voucher' parking – common in many urban centres in the UK, US and Europe, this type of system requires that parked vehicle display a valid coupon or voucher for the zone, time period or class of vehicle. These systems are generally used in areas where restrictions apply to a relatively large area, and where parking durations are longer. It operates in a similar way to 'Pay and Display' but removes the need for on site payment and issuing machines. Instead coupons are made available though retail outlets and/or mail.

(iii) On-street equipment and environment. The majority of street based equipment required for paper based systems is generally provided for the distribution of permits or licences, and signage. The need for, and location of, permit or ticket vending machines varies by system, but in most cases can be installed to suit the local environment.

The use of on-street vending machines would be the most intrusive application, where they may need to be installed to provide convenient access to a relatively large area. However the more advanced units can be installed with built in mobile communications and solar power units that require no direct connections to street services, and are relatively small.

4.4.1.2 Summary comparison with functional requirements

Considering this type of system against the functional framework described in 4.1 provides a base level assessment of its key strengths and weaknesses, and those of the current technologies used.

1. **Informing** – providing adequate information to users and potential users (often defined by legislation) For on street parking applications, providing adequate information to users is generally addressed simply though signs and instructions on the payment machines. In areas where no vending devices are used (e.g. coupon and voucher parking) roadside signs provide information on the restrictions and often where permits can be purchased. For moving vehicle schemes signage is also the main method of informing drivers of the restrictions, and as these types of schemes are generally unsuitable for variable pricing scenarios, the use of VMS would be unlikely. In most cases information would also be promoted through public media to improve public understanding and acceptance of the systems.
2. **Detection** – detecting, and in some cases measuring, each individual instance of use (e.g. vehicle entering a zone). In the case of parking schemes detection is simply a case of wardens recognising that a vehicle is parked in a particular zone. Devices are available to detect vehicle presence and alert wardens when a vehicle has exceeded time restrictions. These are described briefly in section 4.6 Sub System technologies. For moving vehicle schemes (such as the Singapore ALS) detection of vehicles is again

a manual function, although the use of simple vehicle detection systems may also be used to alert officials of vehicles approaching a check point.

3. **Identification** – identification of the user, vehicle, or in some cases numbered account. The identification of parked vehicles is again a manual process carried out by wardens, and is based purely on the license plate of the vehicle. If fines issues are not paid the owner of the vehicle is pursued using the motor vehicle registry. In some cases clamping or towing a vehicle effectively removes the identification issue, as the owner/driver must then make contact with the enforcement agent to pay any fine and recover the vehicle.
4. **Classification** – measuring the vehicle to confirm its class, aligned with the classification framework for the scheme. With paper based parking or area licence schemes the classification of the vehicle is a manual task carried out by wardens or check-point officials. The classification can therefore be easily aligned with vehicle license based classification systems.
5. **Verification** – cross checking processes and secondary means of detection, to assist in confirming transactions, reducing processing costs and providing a backup for potential enforcement. For this type of system the need to cross-check and provide backup enforcement information is reduced to simple procedures followed by wardens to complete violation tickets correctly; recording time and location of violation etc, and retaining any required evidential information.
6. **Payment** – pre and post use collection of payment from users based on verified use. Payment for paper based schemes is generally made through retail outlets where licenses or permits are purchased, or at vending machines. This provides for a range of customer payment options, including cash, charge cards and cheque. In some instances SMS payments are also provided for through vending machines.
7. **Enforcement** – providing the means to identify and prosecute violators, and/or pursue violators for payment of charges and/or fines. Enforcement processes for this type of system are based on issuing violation tickets against the vehicle license plate, similar to regular parking offences, with a system of fines, debt collection and prosecution processes in place to pursue these. A key point of evidence in this situation is the paperwork filled out by the warden, who is the primary means of proving the identity and location of the vehicle.
8. **Exemptions** – providing the facility to manage a range of exemptions within the context of the scheme. Exemptions are relatively simple to manage within a paper based scheme, as the checking of permits and licences is done manually. Exemptions are generally based on additional special vehicle permits displayed in the windscreen.
9. **System reliability & accuracy** – providing all of the above through cost effective systems and technologies that can meet the required levels of reliability and accuracy, minimise revenue leakage and fraud. The use of manual processes, while improving some elements of accuracy also leads to increased cost, and while common for parking enforcement, their use with moving vehicle systems increases delays and is not cost effective. Also the collection of revenues through external retailers and vending machines can be expensive and have high levels of leakage.

4.4.2 Manual toll facilities

Manual toll facilities, toll booths or plazas have been used around the world for many years and essentially comprise payment points at which drivers pay a charge using cash, vouchers, charge cards or smart cards. Due to the amount of space required for conventional toll booths in dense urban road networks, the congestion (worsening) caused by the need to slow down or stop to pay, and the associated negative public perceptions, this method is generally not considered appropriate for urban road pricing. The development of automated payment machines has helped to reduced the costs of manual collection, but these variations on a manual system still operate in much the same way, with similar problems.

4.4.2.1 Examples

(i) Durham City road user charge scheme. One (if not the only) 'manual' based congestion charge schemes currently in operation is the Durham City scheme implemented in 2002, which uses a system of bollard gates and "manual" payment machines.

Drivers are required to pay the designated charge when exiting the city centre zone before the bollard gate will open. These gates are also manned by an official, and drivers unable to pay are allowed to pass but incur a fine.

(ii) On-street equipment and environment. The street based equipment required for a manual system would be significant, and include potentially charging booths, additional lanes to increase throughput, and gates at all entry points. There would be a need for sufficient space to install the required equipment and access to power, communications.

For a small and restricted application such as Durham City this has been possible as the scheme is designed to restrict traffic to a minimum, and so requires the processing of relatively low volumes. For a more extensive central city environment the impact of toll booths and the related infrastructure would have a major impact on the urban environment.

4.4.2.2 Summary comparison with functional requirements

Considering this type of system against the functional framework described in 4.1 provides a base level assessment of its key strengths and weaknesses, and those of the current technologies used.

1. **Informing** – providing adequate information to users and potential users (often defined by legislation). As with paper based scheme, for manual charging systems providing adequate information to users is generally addressed simply through signs placed before the entry to the zone an/or instructions on payment machines. In most cases information would also be promoted through public media to improve public understanding and acceptance of the systems.
2. **Detection** – detecting, and in some cases measuring, each individual instance of use (e.g. vehicle entering a zone). In the case of manual facilities detection is simply a case of toll booth operators recognising that a vehicle is at the booth, for automated lanes a range of detection equipment can be used to register the presence of a vehicle. These are described briefly in section 4.6 Sub System Technologies.
3. **Identification** – Identification of the vehicle, user, or in some cases numbered account. The identification of vehicles in most manual toll situations is not required, as post enforcement is not necessary. However the Durham example illustrates that in

some circumstances violation fines may need to be issued, and in this case the vehicle license plate will be the main form of identification, recorded by the attending official.

4. **Classification** – measuring the vehicle to confirm its class, aligned with the classification framework for the scheme. In manual toll situations classification of the vehicle is done by the toll both operators. Where automated toll machines are used a range of technologies are available to check the vehicle class. The capability and accuracy of automated classification technologies are issues that need to be considered when developing the classification payment structure, as the ability to measure some class specific characteristics is limited. These technologies are described in more detail in section 4.6.
5. **Verification** – cross checking processes and secondary means of detection, to assist in confirming transactions, reducing processing costs and providing a backup for potential enforcement. For manual systems verification systems are generally focused on the task of matching revenue to recorded traffic, due to the high instance of cash leakage and fraud.
6. **Payment** – pre and post use collection of payment from users based on verified use. For manual systems most payment will be made at the time of use, although some systems include pre-purchased vouchers. Post payment is not an option. With a manual system customers payment options can include cash, charge cards, and in some cases accounts.
7. **Enforcement** – providing the means to identify and prosecute violators, and/or pursue violators for payment of charges and/or fines. Not generally required for manual systems as each vehicle is checked before passing.
8. **Exemptions** – providing the facility to manage a range of exemptions within the context of the scheme. Exemptions are relatively simple to manage with a manual toll facility, as the checking of permits and licences is done manually. Exemptions are generally based on special vehicle permits displayed in the windscreen.
9. **System reliability & accuracy** – providing all of the above through cost effective systems and technologies that can meet the required levels of reliability and accuracy, minimising revenue leakage and fraud.

The use of manual processes, while improving some elements of accuracy also leads to increased cost, their use increases delays and is not cost effective. Also the collection of revenues can be expensive and have high levels of leakage.

4.4.3 Image based tolling/automatic number plate recognition (ANPR) technology

ANPR technology is commonly used on most electronic tolling facilities around the world, both in free-flow and toll lane based situations, although most often as an enforcement back up to DSRC or VPS technology.

ANPR is based on images taken of vehicle number plates and processed through recognition software to identify the vehicle. Some systems can use front and/or rear located cameras to capture the images and so improve identification rates. Once identified the required charge or permit checking processes are undertaken in a similar way to other systems.

A key issue with ANPR facilities is the level of reliability of the plate reads. Even the best systems in current use are capable of read rates of around 98% in good conditions, but this can reduce as a result of problems such as light reflections in the image, dirty or damaged plates. This leads to the need for manual checking of those that cannot be automatically read and can add significantly to processing costs.

4.4.3.1 Examples

(i) The London congestion charge is the only facility that currently relies entirely on ANPR on a large scale, and it is worth noting that the London Scheme is effectively an area licensing scheme with the ANPR system effectively used here as an enforcement system. Several other toll facilities provide ANPR-only account options to users, but most with additional administration fees to cover the increased cost of processing these types of transactions in comparison to their alternative DSRC based accounts.

The London scheme being an ‘area’ charge system also requires ANPR stations within the designated zone, at fixed locations and on mobile enforcement units.

(ii) On-street equipment and environment. The street based equipment required for an ANPR system would include pole and/or gantry mounted cameras and illumination devices. In some cases these are combined into one unit and depending on the overall system design there may be a requirement for additional cameras (front and rear), classification devices, and independent verification counters.

Typical ANPR camera & illumination device.

Combined unit.

Figure 4.2 ANPR gantry mounted devices.

In addition to the camera mountings some form of system controller would be required in the vicinity of each installation. This controller would be similar to a traffic signal controller, requiring full power and communication connections via a purpose designed base unit, connected via ducting to each camera location. Again depending on the nature of the system the communications connections may need to be to a dedicated or a leased fibre-optic network, and the power supplies may need UPS facilities for the on street equipment.
The location of camera sites around the network would be relatively flexible, and the impact of the pole and/or gantry supports adapted to the local environment.

The location of camera sites around the network would be relatively flexible, and the impact of the pole and/or gantry supports adapted to the local environment.

Typical cabinet. **Typical camera installations**

Figure 4.3 ANPR cabinet and camera installations.

4.4.3.2 Summary comparison with functional requirements

Considering this type of system against the functional framework described in 4.1 provides a base level assessment of its key strengths and weaknesses, and those of the current technologies used.

1. **Informing** – providing adequate information to users and potential users (often defined by legislation). As with other systems, providing adequate information to users is generally addressed through signs placed before the entry to the zone and/or instructions at payment points. In most cases information would also be promoted through public media to improve public understanding and acceptance of the systems.
2. **Detection** – detecting, and in some cases measuring, each individual instance of use (e.g. vehicle entering a zone). For ANPR systems, in most cases the detection of a vehicle entering the zone is addressed using a separate system such as magnetic loops or lasers. This detection is then matched to the identification process for timing of the transaction. (These detection technologies are addressed in section 4.6 Sub System Technologies.)
3. **Identification** – identification of the vehicle, user, or in some cases numbered account. The identification function is the primary role of the ANPR system, the cameras taking images of the vehicle plate and processing these through recognition software. Once successfully read the plate number is then checked against account or permit records. (In the Italian Access Control schemes plate records are used widely for temporary permit holders.)
4. **Classification** – measuring the vehicle to confirm its class, aligned with the classification framework for the scheme. The classification function of vehicles under an ANPR system is generally addressed using a secondary technology based on some physical measures, such as lasers or digital loops (Section 4.6 Sub System Technologies). However the ANPR read can also be used to check the class of the vehicle from registry records and cross-checked with the physical measures.
5. **Verification** – cross checking processes and secondary means of detection, to assist in confirming transactions, reducing processing costs and providing a backup for potential enforcement. With most ANPR systems a series of verification checks are carried out at each vehicle passing, including matching plate number against account records and classification measures to confirm the validity of the transaction, and determining the need for retention of any enforcement records. A secondary

verification system is also generally provided (for audit and monitoring purposes) to measure traffic and transaction rates, and matching these to revenue collection.

6. **Payment** – pre and post use collection of payment from users based on verified use. The collection of payment for ANPR based systems is addressed through a variety of means. In most cases payment is made through pre or post pay accounts or licenses based on the plate number. Others, such as the Italian Access Control schemes require payment for some permits annually, these managed completely separately from the recording of vehicle movements. Taking the London system as an example, payment can be using a full range of payment methods, including cash and charge cards through retail agents, by phone using credit card, and by SMS through the system operator.
7. **Enforcement** – providing the means to identify and prosecute violators, and/or pursue violators for payment of charges and/or fines. The most common form of enforcement used in most free flow toll systems is based on ANPR technology. Where ANPR is also the primary source of vehicle and transaction identification additional backup ANPR and/or video enforcement systems can be provided. The license plates of offending vehicles provide the evidence of the event and a means of pursuing violators through the motor vehicle registry.
8. **Exemptions** – providing the facility to manage a range of exemptions within the context of the scheme. ANPR systems provide the facility to manage a wide range of exemptions. As each vehicle can be identified individually the plate number can be linked to special exemptions based on the vehicle registration or account status. The Italian Access Control systems illustrate this with special exemption being provided by day and time for users of particular services within the designated zones.
9. **System reliability & accuracy** – providing all of the above through cost effective systems and technologies that can meet the required levels of reliability and accuracy, minimise revenue leakage and fraud. ANPR systems have been in use on toll roads and congestion charging schemes for many years, but mainly as an enforcement facility. The main problems with ANPR systems arise from their ability to overcome physical constraints on the ability to read plates (common examples include light reflections, dirty or damaged plates, and the variety of angles and mounting positions that need to be addressed). Where plates cannot be read automatically manual checking is required which increases costs and processing time. The move to free-flow charging facilitated by ANPR also introduces some additional complexities and costs, including the need for more robust violations procedures, a range of payment options including agents etc, all of which increase complexity and cost.

4.4.4 DSRC free flow toll using transponders and gantries

Dedicated Short Range Communication (DSRC) is the most common form of primary electronic road pricing technology in general use, and is the standard on most free flow tolled facilities.

The technology is based on on-board vehicle units (OBUs), sometimes referred to as transponders, which communicate with gantry mounted equipment at defined charge or check points. The roadside equipment identifies and verifies each vehicle's OBU, and depending on the type of system, either processes a charge from its designated account or confirms its rights of access.

Combinations of toll points can be used to facilitate distance based charging systems, with special charging conditions for particular entry and exit points or times.

In most Multi-Lane Free Flow systems the DSRC system also acts to locate the vehicle within its detection zone using an array of DSRC transceivers.

The enforcement of this type of scheme is generally addressed using roadside enforcement cameras and Automatic Number Plate Recognition (ANPR) technology (described below).

There are a range of different DSRC systems in use (and under development). Some use infrared communications, although this technology has not been deployed widely in higher speed applications, and is not generally considered an open standard. Most are based on microwave communication, the most common systems currently in use are based on a 5.8 GHz frequency, using the European CEN-278 standard. This standard is now ell developed and delivers robust and secure OBU devices that have an average (battery) life of around 5 years.

The next generation 5.9 GHz systems being developed mainly in USA to address a wider spectrum of ITS applications will provide longer range communication and multiple channels. Although not currently in use on any operational charging system, OBUs are planned to become standard installations in all new vehicles within the next decade.

Once established, DSRC systems can be expanded relatively easily onto other routes or across adjacent areas through the deployment of additional toll or check points. However, expanding these types of systems to cover much wider areas is less cost effective, as the numbers of toll points to provide effective coverage increases significantly.

4.4.4.1 On-street equipment and environment

The street based facilities required for a DSRC system would include a range of equipment including:

- pole and/or gantry mounted transceivers,
- in most cases ANPR cameras and illumination devices,
- vehicle classification devices,
- independent verification devices, and
- roadside control cabinets.

The location and street environments would most likely include both multi-lane highway and urban situations.

In the urban environment some street layouts may require local modifications to improve the operation of the system; for example to provide localised separation of traffic from opposing direction streams, and assist in reducing the need for full gantries in street situations. The transceiver/classifier units are generally mounted separately from the cameras to allow the cameras to pick up vehicles in the detection zone, although technologies are available to combine all functions to one location.

A further variation in some arrangements is the use of front and rear cameras that may require an additional camera support structure.

Typical street based DSRC facility **Typical transceiver and classifier**

Figure 4.4 DSRC equipment.

Figure 4.5 Typical street based DSRC installation.

As for the ANPR system, some form of system controller would also be required in the vicinity of each installation, requiring full power and communication connections via a purpose designed base unit and connected via ducting to each location.

Figure 4.6 Typical roadside controllers.

The issues of urban street-scape 'clutter' can be seen as a problem with this technology, although through good design this can be kept to a minimum, as illustrated by the Italian Access Control systems and the recent London DSRC trials.

Figure 4.7 Italian Access Control Systems.

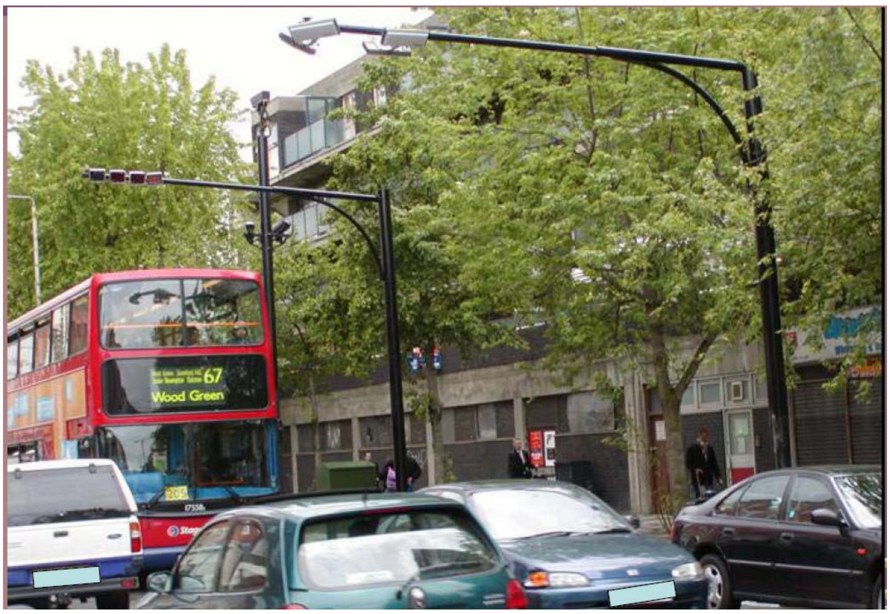


Figure 4.8 London DSRC Trial

In multi-lane situations an array of transceivers and classifiers will be required, generally mounted on purpose built gantries or potentially on existing structures. Figures 4.9, 4.10 and 4.11 are examples of existing multi-lane facilities combining transceivers (ETC RX/TX), detection and classification units, and video capture.

Figure 4.9 **Singapore**

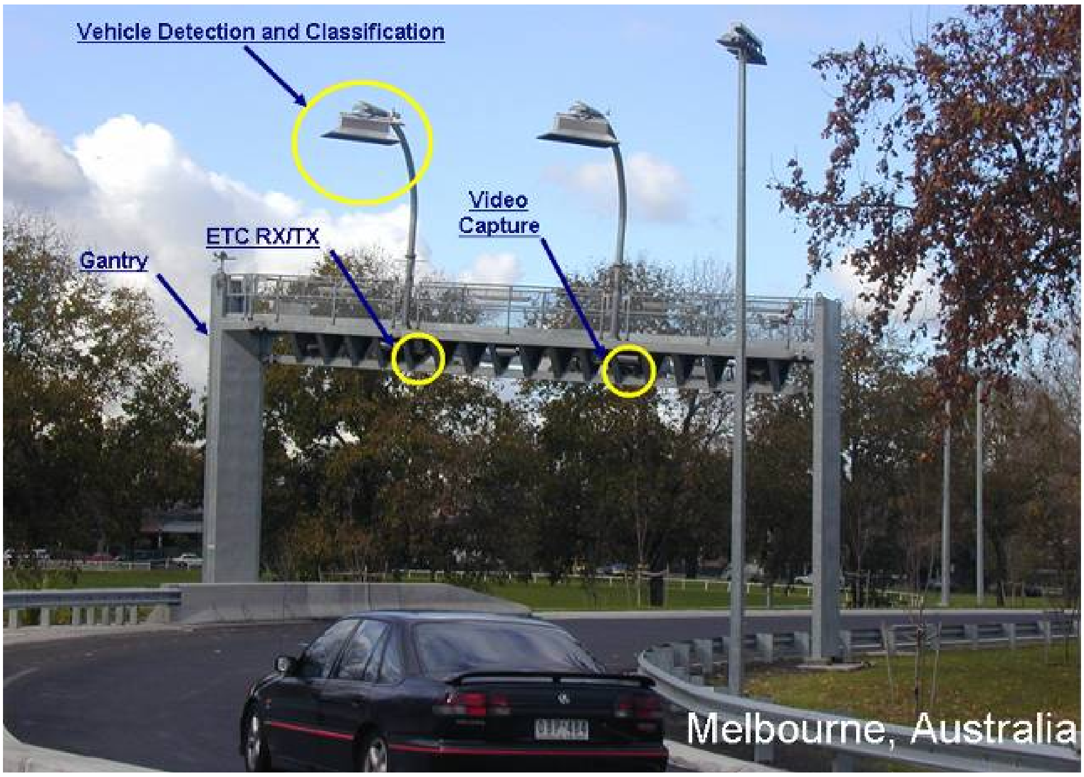


Figure 4.10 **Melbourne, Australia**

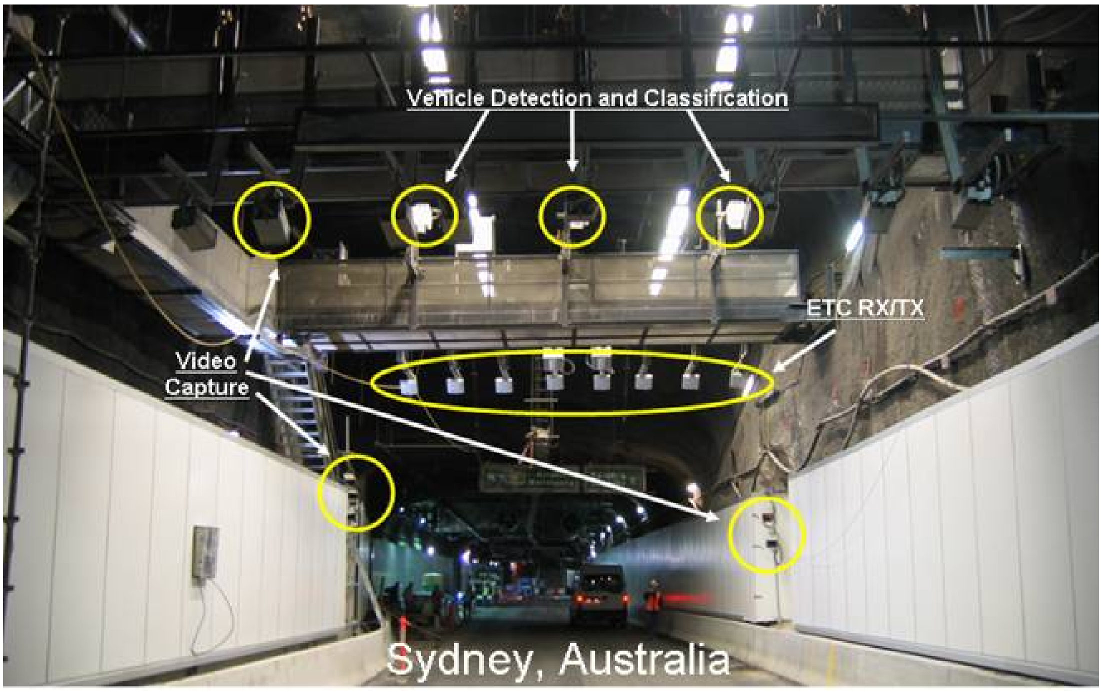


Figure 4.11 Sydney, Australia

Where multi-lane facilities are to be installed in two directions, the relative location of gantries also requires consideration, as a degree of separation is required between some equipment. Figure 4.11 illustrates a typical layout.

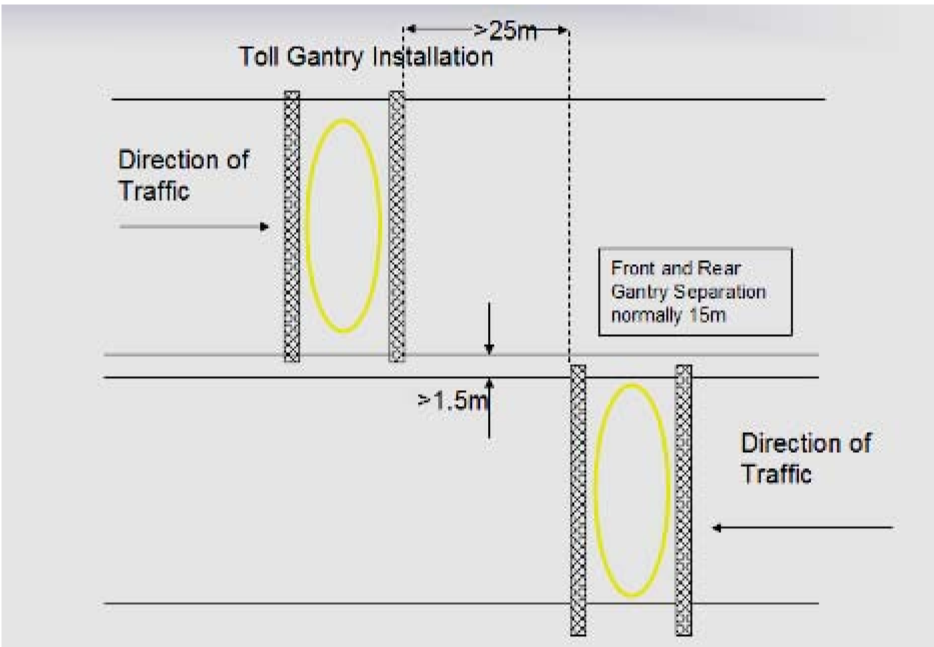


Figure 4.12 Twin gantry system

4.4.4.2 Examples

(i) Singapore congestion charge. Singapore operates a system based on 2.45 Ghz. as its primary technology. Groups (arrays) of transceivers mounted on entry point gantries communicate with units in each vehicle to locate the vehicle and record the transaction. In Singapore the on board units (OBUs) are also equipped with smart card payment facilities.

Figure 4.13 Singapore ERP system and vehicle on-board unit

(ii) Italy access control and toll systems. In Italy several major cities operate access control systems that use the TELEPASS toll system developed and operated on the Italian motorway network. This system is based on the use of 5.8GHz transceivers and OBUs. This system does not use the European CEN-278 standard and is designed for use in single lane toll gate situations, and as such multi-lane charge/check points are not used.

4.4.4.3 Summary comparison and functional requirements

Considering this type of system against the functional framework described in 4.1 provides a base level assessment of its key strengths and weaknesses, and those of the current technologies used.

1. **Informing** – providing adequate information to users and potential users (often defined by legislation). For this type of system signage is also the main method of informing drivers of the restrictions, with VMS likely to be used for situations where variable charges are applied. In most cases information would also be promoted through public media to improve public understanding and acceptance of the systems. Some OBUs also include the ability to provide information on charge levels and account balance through displays or audible signals to confirm transaction or for low account balance warning.
2. **Detection** – detecting, and in some cases measuring, each individual instance of use (e.g. vehicle entering a zone). Although most DSRC systems do provide an 'echo' based location function for multilane applications, in most cases the detection of a vehicle entering the zone is addressed using a separate system, using loops or lasers (Section 2.5 Sub System Technologies). This detection is then matched to the identification process for timing of the transaction, and linking to possible future enforcement evidence.
3. **Identification** – identification of the vehicle, user, or in some cases numbered account. The identification function is the primary role of the DSRC system, the OBU

having a unique number that is identified by the transceiver and its associated systems, and through the account structures to the vehicle or account holder. There are a range of scheme variations that use this type of technology, using the OBU to identify vehicles' movements to confirm access or process payments for use, matching and processing transactions by time location and distance. The correct operation of the system does depend to a degree on the users placing and treatment of the OBU. In most cases it is necessary to ensure that the OBU is placed in the correct orientation on the windscreen of the vehicle. This can lead to problems as some users fail to use the OBU correctly and this can lead to read failure and subsequently disputes or additional operational processes to correct.

4. **Classification** – measuring the vehicle to confirm its class, aligned with the classification framework for the scheme. The classification of vehicles under a DSRC system is generally addressed using a secondary technology based on some physical measures, such as lasers, digital loops or stereoscopic video (Section 4.6 Sub System Technologies). However The DSRC OBU will often include information on the class of the vehicle that will be cross-checked with these physical measures. In some cases the class information from the OBU is fixed, and in others it is selected by the user.
5. **Verification** – cross checking processes and secondary means of detection, to assist in confirming transactions, reducing processing costs and providing a backup for potential enforcement. With most DSRC systems a series of verification checks are carried out at each vehicle passing, including matching OBU information against account records and classification measures to confirm the validity of the transaction, and determining the need for retention of any enforcement records. A secondary verification system is also generally provided (for audit and monitoring purposes) to measure traffic and transaction rates, and matching these to revenue collection.
6. **Payment** – pre and post use collection of payment from users based on verified use. The collection of payments for DSRC based systems is addressed through a variety of means. In most cases payment is managed through pre or post pay accounts, the DSRC OBUs being used as remote identifiers of transactions against these accounts. Others, such as Singapore, offer the ability to make payment through smartcards directly linked to the OBU. The Italian Access Control facilities use DSRC units to simply check the validity of user's rights of access, payments for annual permits being handled completely separately. DSRC account based payments generally require account holders to provide a valid bank account or credit card from which top-ups are drawn, these being the primary payment options for users. However, other options are provided with some DSRC applications such as the purchase of prepaid OBUs from retail outlets that allow customers to pay using cash or other charge card alternatives. An issue to consider with this type of system is the cost and use of the OBU. In most systems the initial cost of the OBU is recovered from the user in the form of a deposit or minimum balance requirement, and any replacements required due to misuse are covered by this fee.
7. **Enforcement** – providing the means to prosecute violators, and/or pursue violators for payment of charges and/or fines. In most instances DSRC systems provide for unrestricted free-flow of traffic. This requires that some form of enforcement facility is provided to ensure that violators of the system (users without valid OBUs, those

with default accounts, or incorrect class etc). The most common form of enforcement used is based on a system of cameras and ANPR technology. These cameras capture images of the license plates of offending vehicles to provide evidence of the event and a means of pursuing violators through the motor vehicle registry. A common issue with DSRC systems (as referred to under 'Identification' above) is the misuse of OBUs that lead to 'false' infringement or casual user processing. These can result in significant additional work for back office staff and inconvenience to users, and reduce the operational and cost benefits of OBU based transactions.

8. **Exemptions** – providing the facility to manage a range of exemptions within the context of the scheme. DSRC based systems provide the facility to manage a wide range of exemptions. As each OBU can be programmed with an individual and unique identification number, these can be linked to special exemptions or conditions for almost any scenario. The Italian Access Control systems illustrate this with special exemption being provided by day and time for users of particular services within the designated zones. As with regular payments, the use of OBU based exemption systems requires the proper use of the OBU. The fraudulent use of exemption OBUs can be an issue, and this is generally dealt with by cross matching ANPR information.
9. **System Reliability & Accuracy** – providing all of the above through cost effective systems and technologies that can meet the required levels of reliability and accuracy, minimise revenue leakage and fraud. DSRC systems have been in use on toll routes and congestion charging schemes for many years, and as such the technology is now well developed and has evolved to a high level of accuracy. These systems have proved to provide a cost effective solution, the processing and management costs of the system being lower than most other alternatives. Key issues include, as mentioned above, the correct use of the OBU, regular monitoring and maintenance of systems and management of the OBU inventory to address battery life limitations.

4.4.5 Vehicle positioning systems (e.g. GPS)

Internationally, road authorities have been exploring and implementing Vehicle Positioning Systems (VPS) which do not require on-road infrastructure to assign a position to a vehicle. Instead, these systems use satellite location systems (generally GPS) to determine the vehicle's position and to measure its location and distance travelled for the purposes of charging and access control. These systems offer greater flexibility for authorities to vary charges in order to influence more aspects of travel and transport choice.

Although VPS technology is an effective means of tracking vehicle position, the information gathered and stored needs to be communicated to central systems on a regular basis, and as such VPS units are generally combined with other technologies (digital maps, wide area communications, and short range GPRS communications) to charge and enforce the system. Additional features required for this type of system include enforcement check points (fixed and mobile) and, depending on the focus of the system, these can be extensive.

The current cost of units has been a major factor in these systems only being used for major heavy vehicle application to date, but these are reducing and, once established, VPS based systems have the advantages of wide coverage and far fewer check points than other technologies. It is expected that on-board VPS units will become standard features in new vehicles within 10 years, and this migration is a specifically identified strategy for the European Union.

4.4.5.1 On-street equipment and environment

VPS based system require far less on-street equipment than other systems, with the primary function of the street based facilities being backup enforcement at selected check points. Fixed on street checkpoints are most likely to use similar DSRC and ANPR technologies described in the previous section, and require a series of pole or gantry mounted devices.

The check points will be similar to ANPR and DSRC facilities, with the functions depending on the structure of the system. Devices required may include DSRC transceivers, ANPR cameras and vehicle classifiers, with similar controller requirements to the systems already described.

These fixed enforcement stations will most likely be supported by mobile units that reduce the number of locations required. The location of these sites around the network would be relatively flexible, and the impact of the pole and/or gantry supports adapted to the local environment.

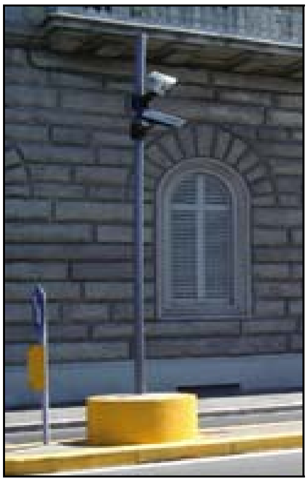


Figure 4.14 Typical camera installations.

4.4.5.2 Examples

VPS type technology is used in several wide area heavy vehicle road user charging facilities, including systems in Germany and Switzerland. Internationally, VPS-based systems have been introduced (e.g. Germany) or considered (United Kingdom) as technology solutions for the introduction of distance-based charging, primarily for heavy vehicles. The German model is now beginning to demonstrate that the technology is moving towards being ‘proven’ – but only for a distance-based charge. Nowhere in the world has VPS yet been used for a more contained urban congestion charging scheme – primarily because of difficulties in managing the urban environment (with its canyon effect) and because the higher costs of in-vehicle units is prohibitive in smaller areas. In an urban area the costs of the scheme would also be likely to rise dramatically due to the need for ‘repeater’ units to overcome the canyon effects and generally improve boundary accuracy.

4.4.5.3 Summary comparison and functional requirements

Considering this type of system against the functional framework described in 4.1 provides a base level assessment of its key strengths and weaknesses, and those of the current technologies used.

1. **Informing** – providing adequate information to users and potential users (often defined by legislation). For this type of system signage would again be the main method of informing drivers of the restrictions, with VMS likely to be used for situations where variable charges are applied. In most cases information would also be promoted through public media to improve public understanding and acceptance of the systems. The multi system VPS/DSRC OBUs would also include the ability to provide information on charge levels and account balance.
2. **Detection** – detecting, and in some cases measuring, each individual instance of use (e.g. vehicle entering a zone). As mentioned above, VPS devices alone cannot be used to address the detection function. In current operational systems the OBUs combine with either DSRC or cell phone technologies to communicate with ground based detection sites, and to transfer VPS data to roadside and back office systems. Other boundary trigger technologies can also be used to detect vehicles passing boundary or check points.
3. **Identification** – identification of the vehicle, user, or in some cases numbered account. The identification function is provided by the OBU having a unique number that is identified through the roadside communications and associated systems, and then though the account structures to the vehicle or account holder. A key aspect of VPS systems is the continual tracking of units to determine distance and location. Generally this is done within the OBU, data then being transferred on a regular basis through roadside communications. As it is the unit that records the movements of the vehicle, the identification is only necessary at these defined communication points.
4. **Classification** – measuring the vehicle to confirm its class, aligned with the classification framework for the scheme. The classification function of vehicles under a VPS system is generally addressed using a combination of programmed OBU class and some secondary technology based on physical measures, such as lasers, digital loops or stereoscopic video. (Section 4.6 Sub System Technologies). In some cases the class information from the OBU is able to be selected by the user, particularly heavy vehicle systems where the loading and unloading of trailer units can vary the class of a vehicle using the same OBU. This also increases the need for closer checking through enforcement systems.
5. **Verification** – cross checking processes and secondary means of detection, to assist in confirming transactions, reducing processing costs and providing a backup for potential enforcement. With most VPS systems a series of verification checks are carried out through roadside enforcement stations, including matching OBU information against account records and classification measures to confirm the validity of transactions, and determining the need for retention of any enforcement records. Classification checking is of particular relevance in the current heavy vehicle systems operating.
6. **Payment** – pre and post use collection of payment from users based on verified use. The collection of payment for VPS based systems is addressed through a variety of

means. In most cases payment is managed through pre or post pay accounts. The OBUs are used as remote identifiers of distance based transactions against these accounts. Some systems offer the ability to make payment through smartcards directly linked to the OBU. Account based payments generally require account holders to provide a valid bank account or credit card from which top-ups are drawn, these being the primary payment options for users. However, other options are provided such as the purchase of prepaid OBUs that allow customers to pay using cash or other charge card alternatives. An issue to consider with this type of system is the cost and use of the OBU. In most systems the initial cost (or at least part cost) of the OBU will is recovered from the user in the form of a deposit or minimum balance requirement, and any replacements required due to misuse are covered by this fee.

7. **Enforcement** – providing the means to identify and prosecute violators, and/or pursue violators for payment of charges and/or fines. VPS systems provide for unrestricted free-flow of traffic and the ability to charge by distance and location over a wide area. This requires that some form of enforcement facility is provided to ensure that violators of the system (users without valid OBUs, those with default accounts, or incorrect class etc). The most common form of enforcement used is based on a system of cameras and ANPR technology. These cameras capture images of the license plates of offending vehicles to provide evidence of the event and a means of pursuing violators through the motor vehicle registry. These enforcement points also need to check OBU data against class and account status, and all of these functions must also be provided within mobile enforcement units in order for and effective system to established.
8. **Exemptions** – providing the facility to manage a range of exemptions within the context of the scheme. VPS based systems provide the facility to manage a wide range of exemptions, as each OBU can be programmed with an individual and unique identification number, which can be linked to special exemptions or conditions. The fraudulent use of exception OBUs is not a major issue due to the complexity of the units, and this can be further reduced by cross matching ANPR information.
9. **System Reliability & Accuracy** – providing all of the above through cost effective systems and technologies that can meet the required levels of reliability and accuracy, minimise revenue leakage and fraud. VPS systems have only recently been implemented as the primary technology of a toll system, and these only for heavy vehicles. The main reason for such limited deployment at this stage is the cost of units. However the base VPS technology is well developed and, supplemented with widely used DSRC systems, the overall reliability and accuracy is good. There have been some documented problems with the early applications of the German system, but these have now been addressed and the system is working well. The key issue still to be addressed is the ability of this type of system to operate in a dense urban area and as a system that operates across the entire vehicle fleet.

4.4.6 Cellular telephone and pico-cell systems

A cellular network is basically a radio network made up of a number of radio ‘cells’ each served by a fixed transmitter, known as a cell site or base station. These cells are used to cover different areas in order to provide radio coverage over a wider area. Cellular networks use a set of fixed main transceivers, each serving a cell and a set of distributed transceivers which provide services to the network's users.

Pico-cell technology is (in simple terms) a more concentrated cell network using smaller transceivers and so developing a cell network that provides a greater ability to locate mobile devices within the network. Using this type of network it is possible to locate properly equipped vehicles with a high degree of accuracy, thus providing the potential to introduce distance based charging using a ground based technology. The sensor networks being developed for this type of application consist of large number of devices (commonly known as motes) connected using wireless technology.

Recent trials have involved a static network of motes connected to bus stops, and mobile motes placed on buses which become transient members of the static network as they approach a bus stop. The system trials have been used to provide position information collected from the buses. Future intelligent infrastructure pico-cell systems are based on the concept of a dense network of low cost short range transceivers located within vehicles and at roadside.

Trials of this type of technology have recently been undertaken in the UK (Newcastle and London) to test the feasibility of this technology for road pricing. The results of these trials have indicated that this type of technology does have the potential to provide a viable alternative to other location based systems such as VPS.

4.4.6.1 On-street equipment and environment

The street based equipment required for this type of system would include an extensive network of short range communications devices making up an integrated web of communications. These devices would be located in vehicles and as part of a range of roadside infrastructure having minimal impact in terms of space or visual intrusion.

As with VPS based systems, this type of system would require some on street enforcement, although far less than other systems, with the primary function of the street based facilities being backup enforcement at selected check points. Fixed on street checkpoints are most likely to use similar DSRC and ANPR technologies described in the previous section, and require a series of pole or gantry mounted devices.

The check points will be similar to ANPR and DSRC facilities, with the functions depending on the structure of the system. Devices required may include DSRC transceivers, ANPR cameras and vehicle classifiers, with similar controller requirements to the systems already described.

These fixed enforcement stations will most likely be supported by mobile units that will reduce the number of locations required. The location of these sites around the network would be relatively flexible, and the impact of the pole and/or gantry supports adapted to the local environment.

4.4.6.2 Summary comparison and functional requirements

Considering this type of system against the functional framework described in 4.1 provides a base level assessment of its key strengths and weaknesses, and those of the current technologies used.

1. **Informing** – providing adequate information to users and potential users (often defined by legislation). For this type of system signage would be the main method of informing drivers of the restrictions, with VMS likely to be used for situations where variable charges are applied. In most cases information would also be promoted through public media to improve public understanding and acceptance of the systems. Some OBUs also include the ability to provide information on charge levels and account balance.
2. **Detection** – detecting, and in some cases measuring, each individual instance of use (e.g. vehicle entering a zone). With a cell network based system the vehicles OBU can be used to address the detection function. Being part of a ground based communications system, the OBUs would have the ability to transfer location and distance data continually to roadside and back office systems. Other boundary trigger technologies would also be used to detect vehicles passing boundary or check points, particularly for enforcement purposes.
3. **Identification** – identification of the vehicle, user, or in some cases numbered account. The identification function is provided by the OBU having a unique number that is identified through the roadside communications and associated systems, and then though the account structures to the vehicle or account holder.
4. **Classification** – measuring the vehicle to confirm its class, aligned with the classification framework for the scheme. The classification function of vehicles under a cell network system would be addressed using a combination of programmed OBU class and some secondary technology based on physical measures, such as lasers, digital loops or stereoscopic video. In some cases the class information from the OBU may be selected by the user and this increases the need for closer checking through enforcement systems.
5. **Verification** – cross checking processes and secondary means of detection, to assist in confirming transactions, reducing processing costs and providing a backup for potential enforcement. As with other distance based options, a series of verification checks would be carried out through roadside enforcement stations, including matching OBU information against account records and classification measures to confirm the validity of transactions, and determining the need for retention of any enforcement records.
6. **Payment** – pre and post use collection of payment from users based on verified use. The collection of payment for Cell Network based systems would be addressed through a variety of means. In most cases payment would be managed through pre or post pay accounts. The OBUs being used as remote identifiers of distance based transactions against these accounts. As with other OBU based systems, account based payments would generally require account holders to provide a valid bank account or credit card from which top-ups are drawn, these being the primary payment options for users. However, other options may be provided such as the purchase of prepaid OBUs that allow customers to pay using cash or other charge card alternatives.

7. **Enforcement** – providing the means to identify and prosecute violators, and/or pursue violators for payment of charges and/or fines. Cell Network systems would provide for unrestricted free-flow of traffic and the ability to charge by distance and location over a wide area. This requires that some form of enforcement facility be provided to ensure that violators of the system (users without valid OBUs, those with default accounts, or incorrect class etc). The most likely form of enforcement would be a system of cameras and ANPR technology. The cameras capturing images of the license plates of offending vehicles to provide evidence of the event and a means of pursuing violators through the motor vehicle registry.
8. **Exemptions** – providing the facility to manage a range of exemptions within the context of the scheme cell network based systems would provide the facility to manage a wide range of exemptions. As each OBU could be programmed with an individual and unique identification number, these can then be linked to special exemptions or conditions.
9. **System Reliability & Accuracy** – providing all of the above through cost effective systems and technologies that can meet the required levels of reliability and accuracy, minimise revenue leakage and fraud. Cell network systems are currently only at the technology trial stage, as a primary charging technology, however the trials that have been carried out indicate a degree of success and may be a feasible option within the next 10 years.

4.4.7 Combination systems

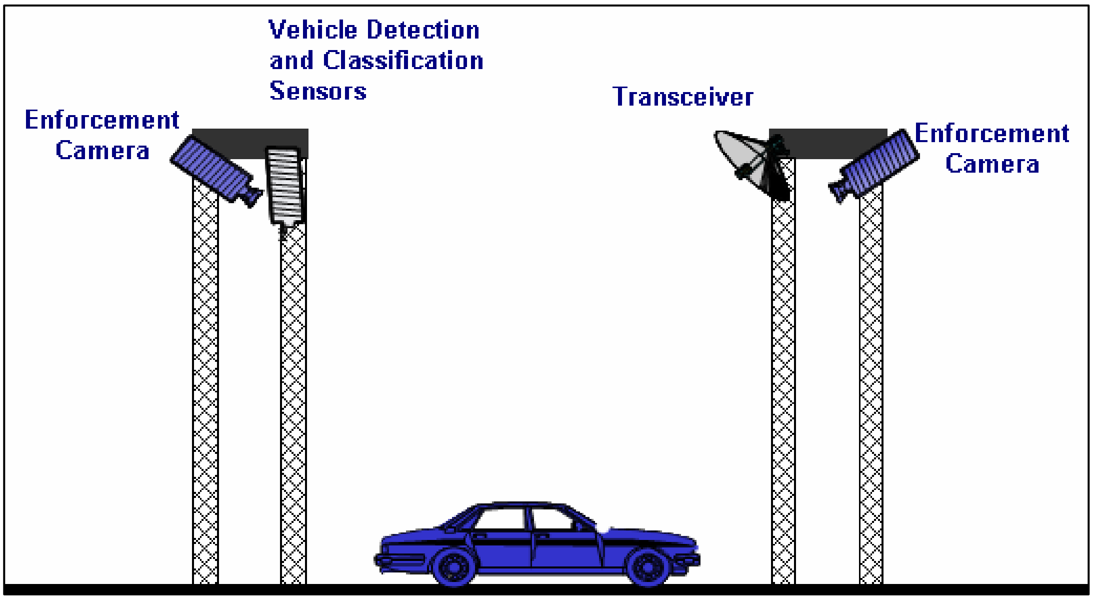


Figure 4.15 Typical combined system.

The majority of current road charging systems, including toll roads and urban charging and access schemes, use a combination of technologies to manage the collection and enforcement process.

By doing so these systems are able to apply the most suitable technology to specific tasks and achieve an optimum system overall.

One of the most common combinations is the use of DSRC OBUs as the primary payment and identification technology, and ANPR technology for enforcement and casual user transactions. This combination allows operators to benefit from the higher accuracy and lower operating costs of DSRC, while overcoming the DSRC limitations of casual user management and enforcement with ANPR. This package also limits the use of the less accurate and more operations cost hungry ANPR technology to a reduced number of transactions.

Example combinations include the main current deployments of VPS on the German and Swiss Truck Toll systems, which use VPS to address the distance and location based elements, DSRC to provide the necessary local roadside communication, and ANPR as a the base enforcement technology.

4.5 Summary of primary system technologies

Table 4.1 Summary of primary system technologies.

Functional Requirement	Primary System					
	Paper-based system	**Manual toll plazas**	**ANPR**	**DSRC**	**Vehicle Positioning GNSS systems (GPS, Galileo)**	**Cellular telephone & pico-cell systems**
Informing	Combination of fixed signage, public media and VMS where variable charging is used.			Combination of fixed signage, public media and VMS where variable charging is used. Ability to also provide information through OBUs on charge levels and account balances.		
Detection	Manual	Manual and detection devices for semi automated lanes.	Through detection device (laser, loop, video).		Short range communications and/or detection device (laser, loop, video).	Cell communications and/or detection device (laser, loop, video).
Identification	Manual	Manual	Vehicle plate	OBU	OBU	OBU
Classification	Manual	Manual and detection devices for semi automated lanes.	Through detection device (laser, loop, video).	Through OBU and detection device (laser, loop, video).	Through OBU and detection device (laser, loop, video).	Through OBU and detection device (laser, loop, video).
Verification	Manual	Manual and some cross checks with detection devices for semi automated lanes.	Plate number against account records and classification measures.	OBU against account records and classification measures.		
Payment	Retail outlets and vending machines using cash or card payment.	At booth cash or card payments (some pre-purchased voucher options).	Pre or post pay accounts or licences based on plate number.	Pre or post pay accounts based on OBU. Some with smartcards directly linked to the OBU.		
Enforcement	Manual		License plate through the motor vehicle registry.			
Exemptions	Manual (paper based)		Linked to registration.	Linked to OBU.		
Reliability & accuracy	High manual content component leads to high cost.	Traffic delays and high manual content component leads to high cost.	ANPR read rate 85 %. Increased costs from manual checking and data handling.	DSRC read rate 98 %. Reduced cost of processing and data handling.	Proven heavy vehicle systems but units still expensive.	No existing systems in operation. Still at technology trial stage.

4.6 Sub-system technologies

As described above, in addition to the primary charging system technologies there are several related sub systems for which a range of technology options exist, these include:

1. Vehicle classification systems (e.g. laser, video, digital loop, axle detection treadles).
2. Telecommunications, Roadside and Centralised Control Facilities (e.g. in unit, controller based processing).
3. Automation of Operations (e.g. payment and enforcement processing, account setup and management).
4. Secondary enforcement systems (e.g. scene image capture, mobile and portable enforcement).
5. Payment systems.
6. DSRC Systems.
7. OBU distribution facilities.
8. ITS Integration.

The basic operation and issues related to each of these are summarised below.

4.6.1 Vehicle classification

The task of vehicle classification for road charging varies with the type of scheme and primary technology used. For manual or semi-automated toll lanes, where vehicles are confined to a single lane at reduced speed, classification can be measured by size, weight or number of axles. In these situations devices such as Weigh in Motion (WIM) detectors, treadles or lasers can be used with relative accuracy.

Once a free-flow environment is introduced, where vehicles are required to be classified at full speed, and in a multi-lane environment, the ability to classify using technology is reduced, along with the range of technologies available.

Current axle treadles and WIM technology do not provide sufficient accuracy to classify vehicles in this type of environment, and a size based classification system is therefore required.

There are currently two sufficiently reliable methods available to classify vehicles by size in a multi-lane free-flow environment; scanning laser technology and stereoscopic video technology. Digital loops also provide an option, but are affected by lane change movements and do not provide the range of classification available with Laser and Video.

The selection of an appropriate classification system within the overall charging scheme, and a suitable technology to address this task is an important element in the successful implementation of any road charging application.

4.6.2 Telecommunications: roadside and centralised control equipment

All road charging systems require the continuous processing of large volumes of transactions. Depending on the charging scheme and primary charging technology used, the complexities and volumes of these transactions can be managed in different ways to achieve a suitable balance between system reliability and operational cost.
One major area of consideration is the balance between roadside and centralised processing and the communications architecture developed to support these processes.

Decisions will be based on several factors:

- The volumes of data that need to be moved around the system
- The availability, reliability and cost of communications
- The number, security and accessibility of roadside installations

Congestion Charging schemes rely on large volumes of transaction data passing between a network of roadside facilities and the back office systems. Depending on the type and structure of the system used this data may be relatively low volume character based files, or much larger (for ANPR) digital image files. These system requirements will have a significant influence on the architecture of the system and in particular the communications networks. For example, carrying out ANPR processing at the roadside may significantly reduce communications and storage costs if the system provides for this type of operation; however, this requires a greater level of functionality within roadside equipment that may prove to costly to provide at a large number of locations.

These decisions and the resulting system architecture can have a major influence on the cost effectiveness of the entire system. For example, the London Congestion Charge is based on a high level of centralised processing with large volumes of data being transferred daily from many roadside facilities. This leads to higher costs, with recent technology reviews and trials highlighting the potential savings that could be made through more a more efficient architecture.

Recent trends in the development of the primary DSRC and ANPR equipment have led to the consolidation of some processing within these units, so reducing the functions of roadside control units and further improving cost efficiency.

The selection of an appropriate system architecture designed for the overall charging scheme and of suitable technologies to manage the underlying systems are an important element in the successful implementation of any road charging application.

The consideration of the most appropriate system architecture is an issue for all of the technologies being considered and, in all cases, is best addressed at the detailed scheme design stage when the functionality of the full system has been further developed. However, with the high systems demands created by ANPR, those systems that are based on a higher use of this technology would be most critical.

This being the case, ANPR based systems have most to gain from improved architecture design, having the highest potential data requirements; DSRC systems that use an ANPR enforcement component would be the next highest user, with VPS and Cell systems most likely to have the lowest demand.

In terms of on-street equipment the key differences would be within the functionality of the control equipment, and the level of the supporting communications networks.

4.6.3 Automation

The major operational costs of road charging systems result from the continuous processing of large volumes of transactions. Depending on the charging scheme and primary charging technology used, these transactions and processes can be automated to reduce cost and improve the overall efficiency of the system. A key objective is to minimise manual processing, particularly where there is no direct customer contact.

At present, the use of OBUs is a major contributor to reducing operational cost across most free-flow facilities. As the most reliable means of automating vehicle (or account holder) identification, this technology reduces the level of manual processing required and so minimises cost.

Other areas of automation include account setup and management processes, through IVR and Internet, ordering of statements and account top-up facilities.

The selection of appropriate systems to automate back office functions is critical to developing a cost effective road charging system. Electronic toll (or congestion charge) collection is a business based on high transaction volumes and relatively low transaction values. This leads to a necessary focus on small costs to ensure a cost efficient system.

Electronic Toll Collection				
High transaction volumes	+	Low transaction values	=	**Small costs are important!**

4.6.4 Secondary enforcement

The main technology used in most tolling and road charging situations is ANPR. This technology is effectively the foundation of all electronic free flow charging as it is the only common point of reference for all vehicles passing through a toll check point or zone boundary.

In most free-flow tolling applications ANPR is used only as an enforcement tool, with the majority of users being charged and verified through an OBU. Even in this situation, where the levels of ANPR based transactions are lower, secondary enforcement systems such as colour scene images are recorded for evidence, and to back up the basic ANPR records.

However, in situations where ANPR is the primary technology, or where there is a need for further enforcement backup, other backup systems and technologies can be used, such as front and read ANPR systems, or digital video recording of traffic that can be accessed later to assist in identifying offending vehicles. These systems can be located to provide an alternative view of traffic form the primary ANPR systems, to overcome adverse environmental conditions such as sunlight or shadow effects.

4.6.5 Payments

There are many payment options available for road charging schemes, and the selection of an appropriate package of options needs to be developed to address the specific needs of each scheme. A key issue in this selection is the balance between providing security of payment at reasonable cost, against providing convenience for the user.

Where manual or machine based payment options are available, the use of cash and standard card payment options are feasible, and while the management of cash payments involves some cost to the operator, the convenience and anonymity of cash addresses a key concern of some users.

For most electronic tolling and road charging systems the primary and preferred payment mechanism is through customer accounts. These provide greater security of payment for the operator (as users are generally required to prepay and provide bank account or credit card details) and also reduce the cost of operation. Accounts are also more convenient for most users, as they are not required to make individual payments for each transaction. Account based payments can be used with any OBU or ANPR based system, and are the most common form of payment for free-flow toll facilities.

A further option is the use of smartcards, as used in the Singapore ERP system. These cards are used with the vehicles OBU and payment is debited from the card balance for each payment. This type of facility provides a further level of convenience that is preferred by some customers, and as the balance on the card is prepaid, there is a degree of security of the operator. The main disadvantage of this facility is the increased complexity and cost of the OBU, and the need to provide real time roadside processing of payments.

4.6.6 DSRC systems

Charging systems using vehicle based OBUs are used widely across the world for a range of tolling and road charging applications. In the current market these systems generally use a microwave signal at or around 5.8 GHz to provide the critical vehicle to roadside communication function, the most widely used standard for this frequency range being the European CEN-278 standard. Others standards are also used in the 5.8 GHz range, most notably the TELEPASS system used across the Italian motorway and access control networks.

As the planned role for vehicle to roadside and vehicle to vehicle communications becomes more widespread, moving into dedicated safety systems, traveller information and other ITS applications, the 5.8 GHz standard is being superseded by a standard in the range 5.850 - 5.925 GHz. This developing standard known as WAVE, has greater range (up to 1000 m) and has a greater multi channel capability. Although there are no current road charging applications in operation, it is likely that this standard will replace and enhance current systems over the next 10 years or so.

Other lower frequency systems are also used in some areas to provide toll-lane based payment facilities. Such a system is currently used for some toll roads and tunnels. These low frequency systems have very limited application outside confined and barrier operated toll lanes, due to their short range and vulnerability to interference.

4.6.7 OBU distribution

The distribution and management of OBUs for DSRC and VPS based systems incorporates a range of technologies and systems designed to address the specific requirements of particular schemes.

The majority of OBUs for these types of systems would be distributed from a central facility by mail, customer collection or through agent networks. However, in some cases the use of vending machines has helped to improve distribution and availability, the most recent example being the Austrian Motorway toll system.

4.6.8 ITS integration

The level and type of ITS integration will depend on the type of charging system adopted and the payment structures and technologies used, but opportunities exist to integrate at many levels.

Another major area of ITS integration is the use of road charging system data to provide travel time and congestion information. One of the best developed systems in this area is the Italian TELEPASS system that has been in operation on the motorway network form many years.

The large numbers of OBUs continually moving across the motorway network are tracked by purpose designed stations to provide real time travel time information, linked into traveller information systems.

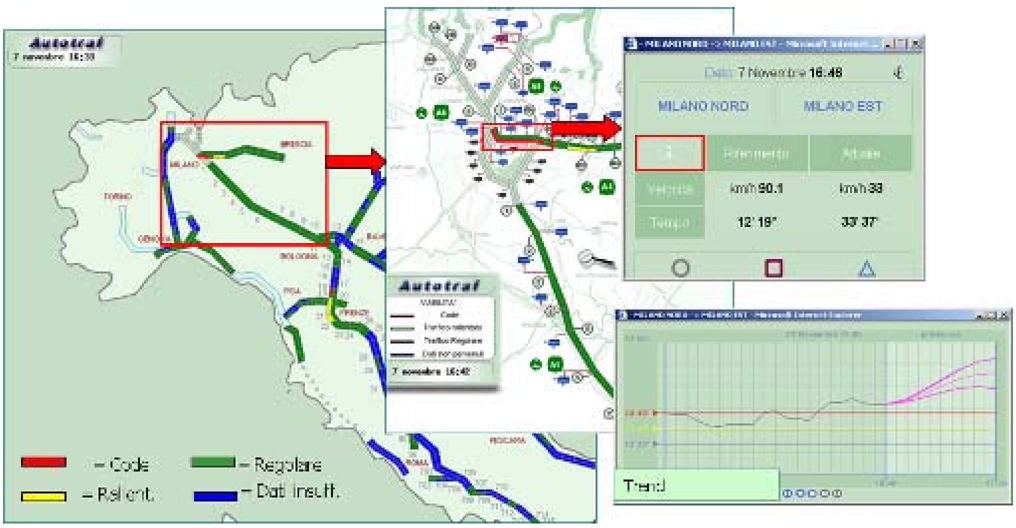


Figure 4.16 TELEPASS system.

4.6.9 Summary – Table 4.2

The following table sets out a summary of sub-system technologies, considering the suitability of each for an Urban Congestion Charging application. Note that 'ITS integration' refers to the relationship between the different technologies, see Section 4.6.8.

Table 4.2 Suitability of sub-system technologies.

1. Vehicle Classification				
	Axle Treadles	**Digital Loops**	**Scanning Laser**	**Stereoscopic Video**
Lane Based	Feasible, but heavy maintenance requirements. Limited to axle number classifications.	Robust but some pavement maintenance issues.	Highly effective for size and shape based classification systems.	Highly effective for size and shape based classification systems.
Multi Lane Free Flow	Not feasible	Feasible for length based systems, but some limitations in multi-lane environment.	Highly effective for size and shape based classification systems.	Highly effective for size and shape based classification systems.
2. Telecommunications; Roadside and Centralised Control Facilities				
	High level of Roadside processing	**High level of centralized processing**	**Dedicated fibre communications**	**Wireless sub communications systems**
Urban Congestion Charging	Reduced data volumes; but increased cost with higher numbers of roadside units. Can be improved with zone based processing.	Reduces on street equipment cost. Best suited to low data volume systems (e.g. OBU based). Can increase reliance and risks linked to communications infrastructure.	Improved capacity and security; but can be expensive in urban locations where there are no existing systems, or where wide dispersed networks are required.	Not viable as a primary communications technology due to vulnerability; but useful for reducing cost of dispersed networks through local consolidation to hubs.
3. Automation of Operations				
	OBU Transactions	**Account Setup and Management**	**ANPR processing**	**Non-Standard Transaction Processing**
Urban Congestion Charging	Provide a major source of automation of a high volume process.	Although a major customer interface, automation through well designed IVR and on line systems can be achieved.	Incomplete ANPR reads can be filtered and managed through systems that minimise manual input. (identifying individual problem characters).	Well designed automated cross checking functions can reduce non standard transactions that require manual processing.

Table 4.2 (continued) Suitability of sub-system technologies.

4. Secondary Enforcement Systems		
	Front and Rear ANPR	**Backup Video Recording**
Urban Congestion Charging	This is a common facility on many free-flow systems; providing the ability to capture and process both front and rear plates; leading to higher levels on ANPR reliability, and increased evidence in the event of infringement.	In some systems an additional digital video recording system is used (often located away from the main charge points). This is used to provide a second source of information and evidence to identify violators.

5. Payment Systems				
	Account Based	**Charge Cards**	**SmartCards**	**Cash and Alternatives**
Urban Congestion Charging	Provides operators with greater security and reduced processing cost; and users with greater convenience.	Secure and reliable payment method that can be used in conjunction with accounts; but also for individual post and pre payment. Merchant fees can increase costs to users and operators.	Provides operators with greater security, advantages of pre-payment and reduce processing cost; and users with greater convenience. But increases cost and complexity of OBUs.	This option is not easily provided for free-flow systems as requires agent networks and manual interfaces. Also cash is expensive to handle and prone to leakage.

6. DSRC Systems				
	5.8 GHz CEN-278	**5.8 GHz Other**	**5.9 GHz WAVE**	**Sub 3 Ghz Toll Lane system**
Urban Congestion Charging	This standard, and close copies (e.g. Australia), is the most widely used system for free-flow toll collection internationally.	The most widely used alternative is the Italian TELEPASS system. Not currently used in any true free-flow situations, but combined CEN / TELEPASS OBUs provided for the Austrian motorway system.	Currently being developed, this standard is targeted at providing DSRC for a wide range of ITS applications. Provides longer range and multi channel capability, and planned as future standard installation for all new vehicles.	Legacy systems with limited application outside confined barrier controlled toll lanes.

7. OBU Distribution Facilities		
	Centralised	**Vending**
Urban Congestion Charging	Technologies include automated dispatch and account matching, tracking and monitoring, and programmed replacement.	Currently limited to DSRC OBUs due to relative cost of VPS units. Size and shape of units fix some machine parameters. Can be provided with account setup instructions or as a true prepay anonymous unit.

5. Road Pricing Mechanisms

5.1 Introduction

This section reviews the range of potential Congestion Charging and Road Pricing scheme types (e.g. Cordon Charge, Area Charge etc) that may be adopted depending on specific conditions.
The types of schemes described in the following pages are:

1. Cordon charging,
2. Multi-cordon and zone-based charging
3. Area licensing
4. Distance-based charging
5. Parking levies
6. Access control

5.2 Current experience with road pricing mechanisms

Practical experience with road pricing has been increasing worldwide. Recent developments have come a long way (both in numbers and technical efficiency) from the leading Singaporean experience with a pricing scheme in the 1970s to address traffic congestion[1]. The crucial meaning in all of these road-pricing initiatives relates to the degree of success with which the theoretical advantages of pricing are converted into practical and politically acceptable policies. Some of the basic principles governing the choices related to the road pricing mechanisms include the following:

- The concept of marginal social cost pricing (theory and measurement issues).
- A road pricing scheme should be based on sound economic theory, but needs to be technically, financially and politically practical.
- An understanding of the role and significance of congestion costs.
- The consideration of other external costs.
- Traffic considerations (e.g. commercial traffic is expected to respond more 'rationally' to road pricing than traffic associated with personal travel).
- Importance of a clear policy of adopting and using these principles.
- How to make these principles work in practice. (It is important that people understand how the pricing works. For example, people will only act in a certain way if they have a clear understanding of the need and consequences.)
    - A good example of focusing 'too much' on making a scheme theoretically appealing and 'too little' on making it practical is the Dutch 'kilometerheffing' project, which had as an aim to change current vehicle taxation to a full road pricing taxation system in the Netherlands. It was planned to charge per kilometre driven on any road, with three road types differentiated, plus three times of day (nine different

[1] The Area Licensing Scheme or ALS later converted into an Electronic Road Pricing or ERP.

tariffs). It appears that its complexity has been one of the key factors in its lack of success.

    - In contrast, the Singapore ALS/ERP experience seems to have worked better. Charge rates are clearly indicated and the scheme is simple and easy to understand. Users know quickly how to plan and decide about their trips.
    - Similar simplicity appears to have helped the application of the London scheme. A simple pricing rule has been used for congested and un-congested periods.

- The chances of a road pricing scheme being successful (better accepted) are increased the simpler, more transparent and easily understood it is by the user.
    - Not too many different tariffs (keep it simple, base it on a simple message, e.g. simple per kilometre charge, peak versus non-peak period charge, driving empty charge, etc).
    - User acceptance of the need for pricing.
    - Not excessive variability of tariffs over time.
    - Predictability of tariffs over prescribed time horizons.
    - Consistency of tariffs over different road types or areas of the network.

5.3 Road pricing mechanisms used in urban areas

The three most common objectives driving the consideration and application of road pricing schemes in urban areas relate to the need for (i) congestion reduction, (ii) minimising the environmental impacts of transport, and (iii) revenue raising by governments. A fourth objective could be to use road-pricing mechanisms to differentiate between vehicle types (and road types) to give priority to ‘high value’ modes such as freight and public transport vehicles.

These objectives are either pursued independently or increasingly in combination. There are a number of approaches that can be used to characterise the pricing mechanisms employed to achieve these objectives. Small and Gomez-Ibanez (1997) divide road pricing mechanisms/schemes into four broad categories as follows[2]:

- Congestion pricing applied to a city centre (notable examples are Singapore’s Area License Scheme and Hong Kong’s Electronic Road Pricing Trial).
- City centre toll-rings designed primarily to raise revenue (notable examples are the Scandinavian toll rings of Bergen, Oslo and Trondheim in Norway and Stockholm in Sweden).
- Congestion pricing of a single facility (notable examples are Autoroute A1 in Northern France, California’s Private Toll Lanes and the I-15 Express Lanes in San Diego).
- Comprehensive area-wide congestion pricing (notable examples are the Netherlands’ Randstad Region scheme and the London Congestion Charging scheme).

[2] Some of these schemes and their characteristics are described in more detail in Section 4.

Urban road pricing provides an efficient mechanism for charging for the use of roads over a certain area and/or during a particular time period. Depending on the local conditions and the purpose of the respective road pricing, different systems of charging can be applied. From this perspective, road-pricing schemes can be categorised into two broad forms using trip length and trip duration as key attributes in the user's decisions to travel. These two forms can be described as follows:

- Travel dependent area pricing which is based on the amount of kilometres driven within a certain perimeter/cordoned area (e.g. the Switzerland scheme), or on a network of interdependent motorways (e.g. schemes used in France, Spain, Italy, Portugal and Germany or CityLink in Melbourne), or based on a zone principle (similar to the zones in a public transport fare collection system). In this form, trips can be charged according to the time of the day they are made, road category used, peak traffic lanes, and vehicle category.
- Time dependent area pricing that requires a driving permit/licence to travel within a certain perimeter for a limited time period (Germany before Toll Collect project, Benelux, Denmark).

However, a finer specification of pricing mechanisms fitting the two broad principles of travel demand decisions (i.e. trip length and trip duration) is likely to be required in order to aid the practicality and applicability of the pricing regime. These are discussed in more detail below and are based on the notion of cordon pricing, where each trip into and/or out of the priced area is charged in distinct step charges rather than by increments (e.g. congestion pricing flat fee in London or pricing in peak hours such as the Stockholm ERP trial); and the notion of distance or zonal related pricing, where vehicles are charged in increments according to the travelled distance within a defined area or to zones which are crossed during the trip. In addition, there can be pricing for the use of specific parts of infrastructure such as freeways/highways, tunnels, bridges etc. and value pricing, where charging is applied for the use of dedicated lanes (e.g. HOT (high occupancy toll) lanes in the USA).

A more recent account of basic pricing mechanisms/schemes that can potentially be used for urban road pricing is presented in Europe's Progress Project (2004) or in the Auckland Road Pricing Evaluation Study (2006). The main options listed in this report are described in the following sections.

5.3.1 Area licensing schemes

These types of schemes apply to trips made within a defined area during a defined time period. Users who wish to use (or keep) their vehicles within a defined area during a defined time period need to purchase and display a special permit, or to register the vehicle in a computer database (e.g. the London congestion charging scheme). A variant of this scheme requires a permit for users (vehicles) who wish to enter a defined area (the restricted zone). In this case, users are charged when entering a defined area at designated entry points on a defined boundary (e.g. Singapore's Area Licensing Scheme that operated from 1975 until 1998). Area licensing and entry permit schemes are set up and operate by applying charges to either moving vehicles or to moving and parked vehicles.

A key advantage for these types of pricing mechanisms is that for a small, simple scheme it can be relatively easy for the public to understand and relatively straightforward to implement. However, a significant disadvantage is that charges are applied on a daily basis for access to the defined area (a relatively blunt instrument), rather than on a per trip basis. Trip making decisions are therefore correspondingly taken on a daily basis, and there is no incentive to restrict the number of daily trips made once the daily licence has been purchased. These schemes are also not very flexible. There are practical limits on the number of combinations of licence variants (e.g. charging zones, time periods, vehicle types) that could be accommodated within a scheme, before the range of licence types required becomes complicated and confusing to the user.

Area schemes are designed to impose a charge on all vehicle trips made within a defined zone or 'area' usually during a defined time period, users being required to pay a charge if they wish to use (or keep) their vehicle within this defined zone.

Area schemes (similar to cordon schemes) generally involve identifying an area of major congestion such as the centre of a large city, drawing a line around that area and charging vehicles that cross that line, with the aim of reducing congestion on routes leading into and through the defined network.

The key difference with an area charge is that drivers who travel entirely within the boundary are also charged, not just those that cross the defined boundary line, the aim being to further lower congestion levels, or to specifically target areas where circulating traffic is a problem.

As with cordon schemes, charges can be fixed at a single flat rate for any travel within the area (for any given vehicle type), or varied by time of day.

The best known Area scheme is the London Congestion Charging scheme, which commenced operation in early 2003. This scheme has around 260 detection points and is based 100% on automated number plate recognition technology (ANPR).

The characteristics of area schemes generally include:

- significant congestion problems with the defined area,
- a major destination for large numbers of vehicles, and
- high levels of circulating traffic.

5.3.1.1 Summary of key issues for area licensing schemes

Key issues associated with 'area' schemes that have relevance to decisions on technology and operations include:

- The need to monitor vehicle movements within the zone in addition to the defined boundary leads to a greater number of charge/check points.
- Multiple internal check points leads to multiple processing of the same vehicles, and so to a need for cross matching and rationalisation.

- Higher transactions volumes lead to increased communications and processing, and the need for efficient purpose designed architecture.
- Area schemes are relatively easy for the public to understand in comparison to some more complex alternatives.
- Effective area schemes also include mobile enforcement facilities.

5.3.2 Cordon charging schemes

Cordon type pricing mechanisms are perhaps the most commonly proposed form of electronic road pricing (e.g. Singapore ERP scheme). These involve setting up a cordon of road pricing points around a defined area of a city. Road users are then charged (usually electronically) each time they cross the cordon. A key improvement of cordon pricing in comparison with licensing and permit schemes mentioned above, is that each individual trip made into the defined area during the time of operation is subject to a road user charge. Each trip is therefore the subject of a choice decision influenced by the level of the applied charge. Pricing of individual trips can also be relatively sophisticated with variations by time-of-day and a range of vehicle types.

Simple cordon charging schemes are, however, likely to have boundary effects. These may include increased parking just outside the boundary, local difficulties related to trip origins or destinations located just inside or outside the cordon, and trip diversion on to roads outside the cordon.

Cordon schemes generally involve identifying an area, or areas, of major congestion such as the centre of a large city, drawing a line around that area, and charging vehicles that cross that line, with the aim of reducing congestion on routes leading into and through the cordoned area.

Charges can be fixed at a single known rate (for any given vehicle type) with only one payment required per day, or could be varied either across time, e.g. on a daily basis according to the actual or expected level of congestion, or across toll points so that it would cost more to cross the cordon at toll points where congestion is higher.

By their nature, cordon schemes influence only traffic which passes across the cordon and not traffic circulating inside the cordon. This means that congestion reductions across the network rely largely on changes in the behaviour of commuters who are travelling in from areas outside the cordon, to locations within it.

This effectively provides a free ‘benefit’ to those vehicles travelling within the cordoned area that benefit from the reduced congestion inside the cordon but are not required to pay the charge unless they cross the cordon, and indeed it is likely that increased use of vehicles may occur in this environment. On the other hand it rewards those who choose to live closer to their destination with an improved level of service.

Cordons are best targeted at managing the total amount of road traffic entering and/or exiting a central congested zone. Cordons are simple to understand and implement, but remain a relatively blunt form of road pricing. Nevertheless, it is possible to operate cordons with charges that vary by entry point and time of day to improve the effectiveness of a scheme.

The actual cordon boundary selected depends on consideration of a number of factors:

- It should encircle an area which both suffers from serious congestion (to maximise benefits in terms of alleviating congestion within the cordon) and is also a major destination for large numbers of vehicles across the network (to maximise benefits in terms of alleviating congestion on routes outside the cordon);
- The ease with which 'toll points' could practically be implemented to cover all cordon crossing points (the fewer the better);
- The likely diversion impact onto other routes outside the cordon area, this impact will depend on whether trips can be modified to avoid crossing the cordon; and
- The total overall number of trips likely to be impacted by the scheme.

5.3.3 Multi-cordon and zone-based schemes

Potential variations to a simple single cordon scheme include multiple cordon rings (or Zones), or as mentioned above, a cordon with variable tolls payable according to time of day, the point at which the vehicle crosses the cordon, or extent of congestion. It should be noted, however, that the more complex a scheme, the greater the potential for low public acceptability and understanding.

Variations on cordon schemes operate in Singapore where charges vary by time (linked to congestion level) and Stockholm where charges are also varied by time, and exemptions provided for 'through' traffic.

These types of pricing mechanisms are conceptually similar to simple cordon charging, as road users are charged each time they cross defined boundaries. Multi-cordon charging schemes typically have two or more concentric cordons, while zone-based schemes levy charges for travelling across defined zone boundaries that may intercept orbital movements as well as radial ones. (e.g. Trondheim expansion scheme).

Use of multiple cordons or zone-based charges can give a finer level of influence over travel patterns since the charging points can more closely reflect the problem traffic movements that the scheme is seeking to address. Boundary problems can also be reduced if lower charges are levied at more points, rather than concentrating the road user charge at a single cordon. However, multi-cordon and zone-based charging schemes are more expensive to implement and more complex for the public to understand than simple cordon charging.

5.3.3.1 Summary of key issues for cordon and multiple cordon schemes

Key issues associated with cordon schemes that have relevance to decisions on technology and operations include:

- Numbers of charge and check points are limited to the boundaries of the cordons, so less than some other systems.

- Likely to require charge/check points on multi-lane highways and on urban streets, leading to a variety of designs but liked to the same systems.
- Varying charges by time requires accurate synchronisation and potentially also VMS information displays.
- Potential need to address variations by direction.
- Potential need to manage ‘through’ traffic exemptions or discounts.

5.3.4 Distance-based charging schemes

Charges under these schemes are applied directly on the basis of distance travelled. Such schemes can be used on toll roads (where distance travelled between toll plazas is simple to calculate) but have not yet been implemented in urban areas. A distance-based charging scheme was proposed for heavy goods vehicles in the UK from 2007-08 (an initiative that is now diverted into a wider process for a more comprehensive road pricing regime design for UK cities/regions). Another notable example is the Swiss heavy vehicle, distance-based, charging system (LSVA).

Distance–based charging is attractive in that it charges directly for travel in the problem areas. It is therefore the logical end-point in a process of creating denser and denser networks of charging zones, and correspondingly should theoretically be even better at influencing demand than multi-cordon or zone-based charging schemes. However, the technology required is more complex and costly to implement.

Distance–based charging is even more efficient than cordon charging because it is specifically targeted to the demand/use of the road (distance travelled) rather than just for access to a part of the network such as a CBD. It is well suited to urban travel where only trips actually embarked upon are charged for. Congestion would therefore be reduced, depending on what trip choices and lengths are charged.

5.3.4.1 Summary of key issues for distance-based charging schemes

Key issues associated with distance based charging schemes that have relevance to decisions on technology and operations include:

- The need to track and record distance travelled within a defined area requires all vehicles to be equipped with suitable technology.
- Enforcement facilities are still required, potentially across a wide area.
- Cost of OBUs is high and so difficult to deploy across the entire fleet.
- VPS require land based backup in dense urban environments.

5.3.5 Access control schemes

In Italy where they are currently found, access control schemes are also known as ‘Electronic Gateways’. These schemes differ from other charging schemes in that the local businesses and residents (organic traffic) are allowed free access, but charges are applied to all other traffic (non-organic traffic) wanting to enter the designated areas. Charges under these schemes are applied directly on the basis of daily access into the designated areas of the urban centre. In larger cities, your access is only free into your designated area whilst access into other areas of the city are denied or charged. In Florence and Bologna, for example, there are several areas designated and each has its own entry and exit routes without crossing into adjacent areas. Vehicles not organic to the area are charged an entry fee on a daily basis for up to a maximum of a three-day limit. These charges and fines generate revenues from non-organic vehicles and violators respectively. The only exceptions are free day passes for authorised customers of doctors, hospitals and specified businesses such as automotive diagnostic centres. These agents can register their clients on an Internet portal into the system's administrative database. Audits are performed by the local Police for any abuse of the 'privilege' to be a designated agent and any repeat instances of abuse by an agent could result in the loss of the privileged agent's status.

Access control schemes are currently deployed in eight cities in Italy, the most notable being Rome, Florence, Bologna and Sienna. The system is a combination of DSRC electronic read of wind screen mounted transponders and electronic image capture of number plates. The DSRC transponder is identical to the DSRC transponder used on the Italian Autostrade with a special access coding for the driver's home city area. The scheme's technology provides added value for the user to have only one transponder and one billing account to pay motorway tolls, while also providing electronic gateway access into his own city centre or payment of fees into other city centres.

Access control schemes are attractive in providing more user acceptance in the local urban centre. Unlike the blunt area schemes such as London, these access control schemes provide flexibility for occasional users who are forced into the designated area for appointments beyond their control. The electronic gateway scheme also provides, in its design, the necessary by-passes to allow non-organic vehicles to circumnavigate the designated access areas. In effectiveness, the Florence scheme and the Bologna scheme provide a suppression of 20% and 24% respectively. This compares favourably with London's 18% suppression of trips.

Zonal/Access control schemes differ from other charging schemes in that the local businesses and residents (for example) are allowed free (or controlled) access, but charges are applied to all other traffic wanting to enter the designated areas. Charges for some categories of user are applied either directly, or through annual permit fees.

This is essentially a variation of multi-cordon or area schemes to allow different levels of access to a central zone. While the Italian system does not charge directly for access at this stage (mainly as a result of legislative constraints), the move to a direct charge per entry is being considered. Options include charging more or less or not at all for different motorists accessing different zones. For example, residents in zone A may be charged nothing for driving in zone A, €1 for zone B and €3 for zone C, whereas a resident from zone B may be charged nothing for zone B, or a non-resident charged €3 for all three zones.

In larger cities free access may only be available in designated areas whilst access into other areas of the city may be restricted or charged. In Florence and Bologna (Italy), for example, there are several areas designated and each has its own entry and exit routes without crossing into adjacent areas.

5.3.5.1 Summary of key issues for access control schemes

Key issues associated with access control schemes that have relevance to decisions on technology and operations include:

- The need to provide systems to manage access rights and short term exemptions.
- Ability to provide agent access to permit systems.
- Need to monitor OBU equipped vehicles and casual or infrequent users.

5.3.6 Parking levy schemes

Parking Levy schemes aimed at addressing congestion are generally applied to areas with high concentrations of businesses where large numbers of employees travel to work each day in private vehicles. This is because commuter traffic (home-work trips) tends to be the greatest contributor to congestion, as these trips generally occur within the morning peak. In theory all private vehicles parking in a designated area should be levied an additional charge over and above any existing cost of parking to achieve the greatest level of impact on travel demand and to mitigate against avoidance measures.

Charges may be fixed at a single known flat rate for any vehicle parked within the area for any period of time with only one payment required per day, or alternative variations may be developed. The actual car parks to which such a scheme might apply will depend on consideration of the following factors:

- There should be a sufficient number of car parks included within the scheme to influence the behaviour of a meaningful number of road users, and these car parks should be in areas which are major destinations and/or suffer from serious congestion; and
- The area covered must include all car parks which are within a reasonable walking distance of key employment locations, or alternatively 'Residents Parking Schemes' must be implemented simultaneously to avoid heavy competition for car parks immediately outside the charging zones.

5.3.6.1 Summary of key issues for parking levy schemes

Key issues associated with parking schemes that have relevance to decisions on technology and operations include:

- The need to provide systems to manage all parking situations.
- Ability to monitor and enforce all parking areas.

The following table sets out a summary comparison of the primary technology options against the main scheme types. It provides high level comments on the key feasibility issues in each case.

Table 5.1 Summary of comparison of primary technologies against scheme type.

Scheme Type	Primary Technology					
	Paper-based system	**Manual Toll Plazas**	**ANPR**	**DSRC**	**Vehicle Positioning Systems (GPS, Galileo)**	**Cellular Telephone & Pico-Cell Systems**
Cordon	Not recommended. Enforcement is restrictive and provides little opportunity to differentiate by time of day/level of congestion.	Not recommended. Location and delays from charging points, traffic and safety issues would outweigh any benefits.	Not recommended. Difficult to match images across boundaries and to apply variable charges.	Best current option. Similar to the model adopted by Singapore. Infrequent user issues would need to be resolved.	Technically possible, but not cost-effective currently. Issue of infrequent users would need to be addressed. Costs would need to be balanced with greater ability to differentiate charges by time/location.	Technically possible, but still at trial stage. Infrequent users would need to be addressed and costs balanced with greater ability to differentiate charges by time/location.
Multi-Cordon	Not recommended. Enforcement poses some issues, very difficult to differentiate by time of day/level of congestion.	Not recommended. Location and delays from charging points, traffic and safety issues would outweigh any benefits.	Not recommended. Difficult to match images across boundaries and to apply variable charges.	Best current option. Similar to the model adopted by Singapore. Infrequent user issues would need to be resolved.	Technically possible, but not cost-effective currently. Issue of infrequent users would need to be addressed. Costs would need to be balanced with greater ability to differentiate charges by time/location.	Technically possible, but still at trial stage. Infrequent users would need to be addressed and costs balanced with greater ability to differentiate charges by time/location.
Area	Not recommended. Although a possible option, enforcement difficult with a number of different areas to be charged. Difficult to vary charge by time of day/level of congestion.	Not applicable. Traffic management issues and disruption of traffic on existing roadways make this option unrealistic.	Realistic option. For a single zone area charge, but system complexity increases with multiple zones. Higher operating costs reduce net revenue.	Good option. Infrequent user issues would need to be resolved and would require internal checkpoint facilities.	Technically possible, but not cost-effective currently. Issue of infrequent users would need to be addressed by ANPR type product and ‘area pass’. Costs would need to be balanced with greater ability to differentiate charges by time/location.	Technically possible, but still at trial stage. Issue of infrequent users would need to be addressed by ANPR type product and ‘area pass’. Costs balanced with greater ability to differentiate charges by time/location.

Table 5.1 (continued) Summary of comparison of primary technologies against scheme type.

Scheme Type	Primary Technology					
	Paper-based system	Manual Toll Plazas	ANPR	DSRC	Vehicle Positioning Systems (GPS, Galileo)	Cellular Telephone & Pico-Cell Systems
Distance Based	Not recommended. Enforcement difficult without ANPR, or similar. Technically feasible option but only for charging by distance on defined routes.	Not recommended. Enforcement difficult without ANPR, or similar. Technically feasible option but only for charging by distance on defined routes.	Not recommended. Technically feasible option but only for charging by distance on defined routes.	Not recommended. Technically feasible option but only for charging by distance on defined routes.	Best option for distanced based charging. Issue of infrequent users would need to be addressed. Costs of IVUs would need to be balanced with greater ability to differentiate charges by time/location.	Feasible option for distanced based charging. Issue of infrequent users would need to be addressed. by Costs of IVUs would need to be balanced with greater ability to differentiate charges by time/location.
Access Control	Not recommended. A feasible option, but high manual enforcement costs.	Not recommended. High manual enforcement costs and delays to traffic.	Realistic option. System complexity increases with multiple zones. Higher operating costs reduce net revenue.	Good option. Infrequent user issues would need to be resolved and would require internal checkpoint facilities.	Technically possible, but not cost-effective currently. Issue of infrequent users would need to be addressed. Added benefits of differentiating charges by time/location may not be beneficial.	Technically possible, but currently at trial stage. Issue of infrequent users would need to be addressed. Added benefits of differentiating charges by time/location may not be beneficial.
Parking	Feasible option, potentially best suited to parking environment in spite of high manual enforcement costs.	Feasible option for designated parking lots, but likely increased cost over automated paper systems.	Not recommended. Technically feasible option but not cost effective for large numbers of on-street parks.	Not recommended. Technically feasible option but not cost effective for large numbers of on-street parks.	Not applicable. Not cost effective for large numbers of on-street parks.	Not applicable. Not cost effective for large numbers of on-street parks.

Table legend

Not recommended	Not recommended (rejected)	Technically possible	Possible future candidate option
Feasible option	Feasible but not recommended (rejected)	Good option	Feasible candidate option

5.4 Road pricing mechanisms – some implications

Road pricing solutions are likely to become more acceptable to users and communities as the benefits and efficiencies of real-world pricing applications are better understood. However, public acceptance will continue to depend on a number of key factors, including:

- A clear need for their consideration (e.g. severe congestion problems).
- A clear understanding of their effectiveness as proposed solutions over alternative approaches (e.g. paying for the true cost of each trip rather than via non-transparent lumpy payments such as registration, insurance and petrol taxes).
- Transparent and uncomplicated solutions which are easily understood and not perceived as additional charges by the public (i.e. pricing not perceived as primarily an additional revenue source).
- Perceived equity of application.
- Favourable economic climate (e.g. no major economic shocks such as high unemployment, high petrol prices and the like)[3].

Table 5.1 A summary of travel impacts due to pricing/tolling.

Travel impact	Toll road funding	Congestion Pricing	Comments
Reduces total traffic	1	2	Impacts on total travel depend on the price structure and the quality of alternatives.
Reduces peak period traffic	2	3	Fixed tolls cause moderate peak reductions.
Shifts peak traffic to off-peak periods	0	3	Fixed tolls provide no incentive to shift.
Shifts car travel to alternative modes	2	3	Congestion pricing supports use of travel alternatives, toll roads do not.
Improves access, reduces the need for travel	-1	0	Additional roadway capacity can encourage low-density urban expansion.
Increased ride sharing	2	3	Encourages ridesharing and may fund rideshare programs.
Increased public transport	2	3	Encourages transit use and may fund transit improvements.
Increased cycling	1	2	Encourages cycling and may fund cycling improvements.
Increased walking	1	2	Encourages walking and may fund pedestrian improvements.
Increased telework	1	2	Encourages telework.
Reduced freight traffic	1	1	May have some effect.

Note: Rating from 3 (very beneficial) to –3 (very harmful). A 0 indicates no impact or mixed impacts

Source: TDM Encyclopaedia - http://www.vtpi.org/tdm/tdm35.htm

[3] This is often the case as no matter how elegant pricing mechanisms can be, experience in many countries shows that political/public resistance has always been a major impediment to implementation. For example, attempting the introduction of road pricing when economic conditions are not favourable or fuel prices are high is likely to increase public resistance, as perceptions of increased transport costs also increase opposition to additional charges. However, high petrol prices and as a result pressure on governments not to increase fuel taxes may lead to a search for alternatives such as use of more direct pricing mechanisms.

6. Example Systems

This section looks at the systems in the example cities studied and breaks down the analysis into a number of categories.

The structure of these categories is outlined below

- Scheme type
- Technology
- Pricing structure
- Key management system issues
- Urban Formf
- Other characteristics
- Level of success

6.1 Italy

6.1.1 Scheme type

Italy has implemented a series of ‘Electronic Gateways’ in eight of its major cities and more are likely to follow the trend set by the Autostrade Group. The Autostrade Group currently operates over 3,408 (approximately 61%) of Italy’s 5,590 kilometres of tolled motorway. It is the largest of the 15 private Italian Concession companies.

The ‘Electronic Gateway’ is a form of congestion charging by regulation. It allows residents and key businesses and services free access to the city centre, while requiring all other vehicles to either register for access or bypass the designated area. It is strictly an access control system which employs bypasses and park-and-ride together with bus services and public transport from the edges of the zone to support access into the historic centres of the cities.

The scheme design of all the Italian Cities is a zone design. Small zones are used to match local divisions of the city for easy recognition and provide greater identity of the ‘home’ zone for free access. The small zone designs also provide good suppression of recycling of traffic in the overall city boundary.

The registration for access to the city centres is not free but acquired through the scheme administration for a yearly fee. Registered vehicles are provided a specially coded DSRC transponder to be mounted at all times in the vehicles windscreen and this transponder is linked to the vehicle number plate.

Temporary access (one to three days) can also be purchased from the city scheme authority for a fee. Any vehicle captured by video image not registered or violating the access restrictions is fined by the local police. Another form of temporary access is provided free to specific patrons or patients of medical facilities and businesses. In this case, the medical facility can register the patient's vehicle specifics and number plates from a computer terminal through an Internet portal with password and security. This allows, for example, patients who are referred to a medical facility in the CBD to be exempt for the day of their appointment. Police audit the records and patient records periodically to prevent abuse and fraud.

Electronic Gateways are currently employed in Rome, Florence, Bologna, Sienna, Pisa, Peruglia. Torino and Padua are currently in the process of installing schemes. Cities such as Rome, Florence, Bologna and Torino are divided into sub-access zones and access is provided to one or multiple zones depending on the location of the business in the access control area.

6.1.2 Technology

6.1.2.1 Evaluation of the scheme

The electronic gateway schemes in Italy are different from other electronic road pricing schemes, yet similar. The use of DSRC transponders for the registered users means that after registration, the authorised user has little to no interface with the scheme unless his DSRC transponder malfunctions or the registered user needs to change his status. Unlike London, but similar to Stockholm, discounts and financial burdens are not imposed on the local residents. This makes the application for the user valued and sought after in the mind of the public. It also helps acceptability of the scheme to the public.

The flexibility of the electronic gateway scheme is very interesting. It is customised in each Italian City to fit the character, culture and geographic layout of each city. It recognizes the natural boundaries of various districts and access routes into and out of each zone. The system can even handle the strategic network routes through or across the CBD while still reducing cross traffic from other zones. Access is only granted to the route and area that the vehicle must pass through to get to the residence or place of business. Other intra-city trips are suppressed which results in an overall suppression of trips that is suggested to be approximately 20%.

The electronic gateway scheme also recognises the need for special treatment or needs of medical or business related trips. It is the only scheme that does incorporate this feature. Patients referred to medical facilities in the access area can attend their appointment without being charged. Likewise special business considerations are given for CBD businesses such as automotive diagnostic centres where their dealers refer vehicles to specially equipped facilities diagnose special problems. In Florence, a special consideration is given to furniture dealers for customer pickup of items purchased. This practice in Florence has a historical and cultural context and to charge an additional fee on this practice would be unacceptable to the local population. In another case, Pisa, the same is true for registered tourist agents visiting the historic CBD around the leaning tower. This practice helps regulate the authorised travel agencies and reduces the number of unauthorised agents.

The electronic gateway technology is based on proven technology and uses the DSRC transponder for the majority of its transactions so there is little to no overhead in operating the controlled access vehicles. The transponder-based vehicles are recognised and identified automatically and no manual intervention is necessary. This makes the system more economic than an ANPR system such as London.

The DSRC transponder is the standard Italian 'Telepass' transponder used on the Italian motorways. In 2005, there were over four million transponders in use in Italy with numbers projected to exceed five million in 2006. The transponder can be programmed to be used for the specific access control zone of the specific local authority; or, it can be programmed for only the Autostrade motorways. Additionally, the transponder can be programmed for both and add value to the user to make payment of his motorway tolls as well as access into his urban access zone. The user has this option at the time of registration. If the user later wishes to change his status to just access control or just a motorway account, the user can do so. Any change in status to add access control can only be authorised onto an existing transponder by the local authority. If the user wishes to purchase a temporary day-pass in another access control area or local authority access zone, he can use the transponder account of the motorway to pay the local authority for his access fee.

Accuracy of the Telepass DSRC transponder is in excess of 99.95%. The biggest technical issue with the transponder is the battery power. The life of the battery is approximately five to eight years of normal usage.

The DSRC transponder is respectful of privacy. The registered owner has the convenience of non-stop access without being stopped or held-up by access control gates or other such restraints. The access control is flexible and low administration. Since the majority of the vehicles are authorised and registered vehicles, time is spent on the temporary and unauthorised vehicles. This is a reversal of the London scheme where video images of paid Congestion Charging vehicles may be misread 30% to 40% of the time and require some level of screening through a manual process.

The video capture camera and illuminator are also standard and mature equipment. Number plate capture is necessary for those vehicles unequipped (non-organic vehicles to the scheme), temporary registrations and violations of the access control zone. In some cases, unauthorised access is associated with a DSRC transponder because the registered vehicle is not authorised access into the specific zone.

The performance of the video capture in Italy is between 70% and 84%. This is approximately the same or better than London's Congestion Charging performance.

The technology used for the Electronic Gateway is a combination of DSRC transponders and ANPR technology. A typical station is set up for a single, double or triple lane facility. A DSRC beacon is set up to read the transponder in the designated lane and works in conjunction with an infrared vehicle detector and classification sensor. This sensor continually sweeps the lane in the immediate area of the transponder beacon and detects vehicles passing through the access screen line. Working with this equipment is a digital camera and illuminator that captures and reads the number plate of every vehicle. If the vehicle is registered, the number plate read is compared to the number plate of the vehicle registered for access into the CBD or CBD zone depending on the size of the city. If the transponder is registered but the number plate is different from the vehicle registered, the transaction is flagged for review. If the captured image matches an authorised access vehicle but the transponder signal is missing, the transaction is also checked to ensure that the transponder is not malfunctioning. Figure 6.1 below illustrates the electronic gateway system.

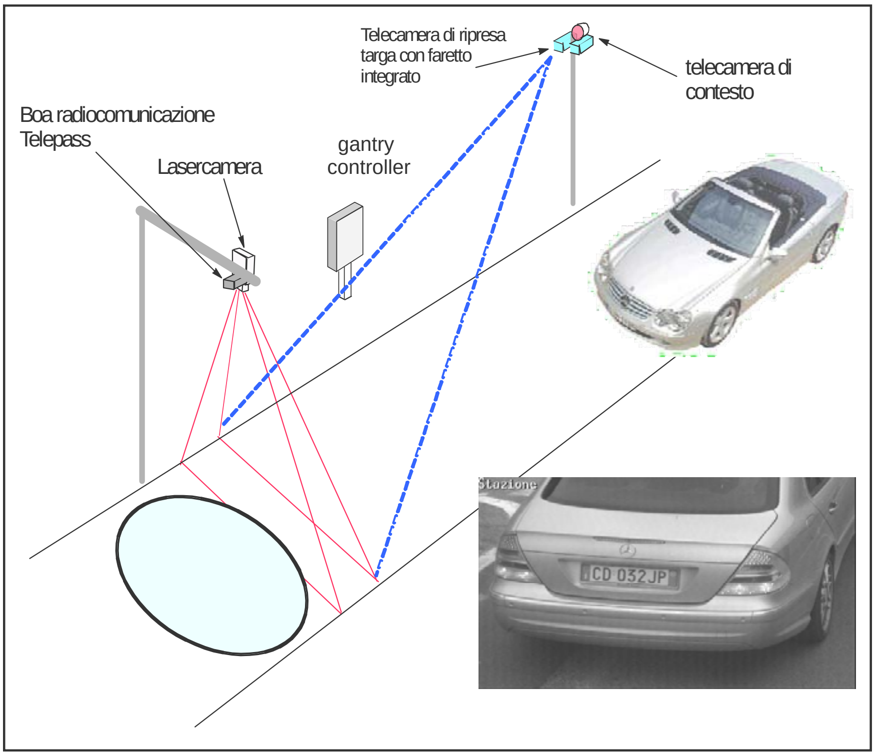


Figure 6.1 Electronic gateway.

Each access control system is managed and controlled by the local authority that is sponsoring the access control scheme. The operations and management in four of the six installed electronic gateways is contracted to Autostrade. Each local authority manages its own list of registered access vehicles that in other congestion charging or ERP systems are referred to as 'exemptions'. In the electronic gateway, the 'exemptions' are merely authorised vehicles whose registration is free based on each local authority's rules and statutes.

Key to the success of the electronic gateway is the bypass routes around or through the CBD. Whilst it is easy to consider the access control area as a cordon, it can be two areas on either side of a major road that bisects the city centre. In this case, the access road is open and not controlled, whilst the city areas on either side are designated access zones and restricted to vehicles that are registered for that specific zone. In this way, the electronic gateway scheme reduces cross flows of traffic across and between zones without the need to build a ring road around the CBD.

The flow of the transaction data is shown in Figure 6.2. The system is highly automated and is lightly manned since many functions for the managing of the vehicle registration and police control overlap with existing local authority functions.

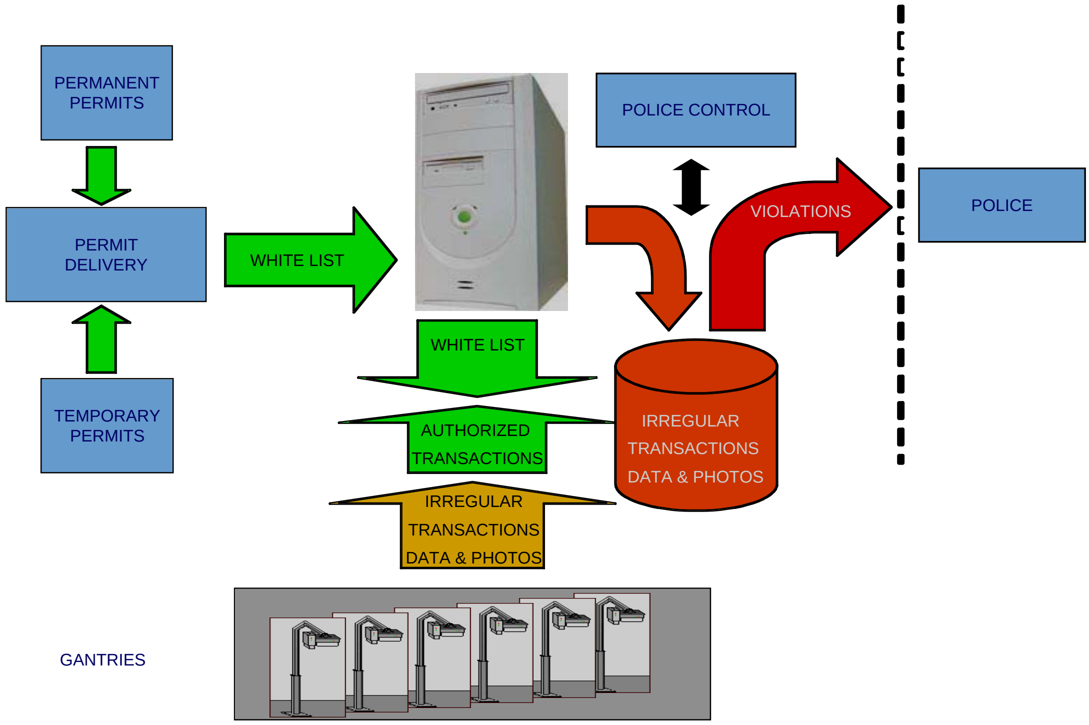


Figure 6.2 Flow of transaction data.

6.1.3 Pricing structure

The registration for access to the city centres is not free but acquired through the scheme administration for a yearly fee. Registered vehicles are provided a specially coded DSRC transponder to be mounted at all times in the vehicles windscreen and this transponder is linked to the vehicle number plate.

Temporary access (one to three days) can also be purchased from the city scheme authority for a fee. Any vehicle captured by video image not registered or violating the access restrictions is fined by the local police. Another form of temporary access is provided free to specific patrons or patients of medical facilities and businesses. In this case, the medical facility can register the patient's vehicle specifics and number plates from a computer terminal through an Internet portal with password and security. This allows, for example, patients who are referred to a medical facility in the CBD to be exempt for the day of their appointment. Police audit the records and patient records periodically to prevent abuse and fraud.

6.1.3.1 Costs

Cost varies on each installation. The costs of the Florence system were approximately € 52 million. Since each is a regulatory type of system, O & M costs are low because they are absorbed by existing Government Departments and not identifiable for accounting purposes. They are estimated to be in the range of 6%.

6.1.4 Key management system issues

6.1.4.1 Implementing authority

The implementing authority by law in Italy is the local urban authority. The functions and business process for managing the scheme map with most cities' administrative functions. The unique operational and maintenance aspects are contracted out by the local authority.

6.1.4.2 Business impacts

The flexibility of the Italian access control schemes is particularly interesting in how it is applied to the business sectors of the various cities. The electronic gateway scheme recognises the needs of business related trips. It is the only scheme that incorporates this feature. Overall, sensitivity for businesses to be able to 'book' vehicles of customers for specific trips, avoids the deterrence of a blanket charging scheme on businesses. When combined with the overall reduction in traffic and reduced costs of transport that result, the schemes are likely to have a positive economic impact on businesses within the zone.

6.1.4.3 Environmental impacts

Reductions in traffic have had a positive environmental impact on emissions in the central areas. The use of pole based DSRC technology has minimised the visual impact of the scheme on the historic cities.

6.1.4.4 Social impacts

Due to the implementation schemes, there is little social impact. In fact the accessibility of the zones and the ability of providing exemptions match the social fabric of each city and there are no social impacts in the scheme designs.

6.1.5 Urban form

The urban form has been a key factor in the design of all the Italian city schemes. The electronic gateway controlled zones throughout each city have been designed to match the natural local divisions of the cities. This has made it easy for the local residents to recognise the charging zones and their free 'home' zone.

The schemes were designed around using increased public transport services into the central zones to reduce the effect of the traffic pollution on the historic buildings and improve the air quality in the central areas.

The gateways are customised in each Italian city to fit the character, culture and geographic layout of each city. They recognise the natural boundaries of various districts and access routes into and out of each zone.

6.1.5.1 Land use/transportation integration

The Italian systems have been closely designed to reflect the individual conditions of each city, including the medical and business operations within the access controlled zones. This demonstrates a highly integrated consideration of the effects of the system on land use.

6.1.6 Other characteristics

6.1.6.1 Implementation

The system was easy to implement and has a high degree of reliability (over 99.95%). ANPR is necessary for those vehicles unequipped (non-organic vehicles to the scheme), temporary registrations and violations of the access control zone. In some cases, unauthorized access is associated with a DSRC transponder because the registered vehicle is not authorized to access the specific zone. The performance of ANPR in Italy is between 70% and 84%. This is approximately the same or better than London's Congestion Charging performance. Exemptions are monitored by the police and records checked to ensure no misuse of the privileged to provide exemptions by the various special interest agents.

6.1.6.2 Privacy

As this is not a charging system primarily, the DSRC transponder is respectful of privacy. The registered owner has the convenience of non-stop access without being stopped or held-up by access control gates or other such restraints. Residents with the transponder simply have their vehicle identified and no record need be kept, as their entry is authorised. Only those who are not authorised as residents or with day passes have their details identified in order that they be fined. Due to the residents having full rights of access, privacy concerns have been negated.

6.1.6.3 Financial

No information about costs or revenues has been sourced, but it is believed that the system at least recovers its costs of operations. As it is primarily a regulatory tool, and not a revenue based system, this is not unreasonable.

6.1.6.4 Institutional

The implementing authority by law in Italy is the local urban authority. The functions and business process for managing the scheme correlate with most cities' administrative functions. The unique operational and maintenance aspects are contracted out by the local authority. With one entity responsible for choosing to introduce the system, as well as building as administering it, governance is not a significant issue.

6.1.7 Level of success

6.1.7.1 Key findings

The electronic gateway schemes provide an interesting alternative to the other congestion charging schemes. The effectiveness is in the electronic gateway schemes to suppress through traffic or recirculation trips in the area of access restraint. It also provides a level of design flexibility to adapt to the specific cultural and geographic requirements of each site.

The electronic gateway schemes provide a measure of acceptability by eliminating the administrative load and overheads of other schemes whereby the registered users are provided DSRC transponders for automating the process of their access control. In this fashion, the overhead and costs associated with video images is greatly reduced. This makes the operational costs of the scheme more acceptable but the capital costs of the transponders a consideration. In the Italian cities, this cost is passed onto the registered user in his registration fee but the local authority retains ownership of the transponder.

The electronic gateway provides design flexibility to establish the necessary access zones to match the natural geographic restrictions and the strategic road network servicing the local authority area.

The use of the transponder being interoperable with the road tolling authorities is another important aspect of the electronic gateway. Not only is the user provided a convenient means to access and limit his approach to an area, it also provide the user with the added value of managing his toll transactions on the other toll facilities.

Success has been measured in all cities with statistics indicating that Florence and Bologna have benefited from a 20% and 24% reduction in daily trips into their urban centres. This matches well with London (33% for cars and 18% overall trip reduction) and Stockholm (25% trip reduction) and deserves attention as a plausible and acceptable measure to manage demand and reduce congestion.

6.1.7.2 Traffic impacts

Success has been measured in all cities with statistics indicating that Florence and Bologna have benefited from a 20% and 24% reduction in daily trips into their urban centres. This clearly has a positive effect on congestion within the central cities.

6.1.7.3 Operational performance

There is little evidence about change in mode, although the scheme encourages the use of public transport for non-residents entering the central cities. It is likely that the schemes have at least a modest positive impact on public transport, cycling and walking modes.

6.1.7.4 Network utilisation

As residents are exempt from the access schemes, their mobility is not affected negatively. In fact, they benefit from the reduced levels of traffic and congestion, and less demand for parking. Non-residents needing medical services are able to be granted day passes by the medical facility where they have their appointment.

6.1.7.5 Public acceptability

The Italian schemes have a high degree of public acceptability largely because residents are exempt and their exemption is guaranteed through the DSRC transponders, while residents benefit from the reduced traffic flow.

6.1.7.6 Summary

The experience in Italy reveals the following points with respect to scheme design:

- DSRC technology proven in narrow street environments.
- Design of system not intrusive in historic cities.
- Potential for zone based systems with free through routes.
- Potential for ‘home’ zone treatment for residents.
- Large number of exemptions probably labour intensive.

6.2 Singapore

6.2.1 Scheme type

Singapore's scheme has been specifically designed to manage congestion, with revenue generation almost incidental to the implementation of the charge.

Singapore has had long standing comprehensive policies to manage congestion. In 1972, the import duty on motor vehicles was raised from 30 to 45 percent. Also, a separate registration fee equal to 25 percent of a vehicle's market value was introduced. However, these measures had little impact on average traffic speeds (The Economist, 3 September 1998).

In 1975 the special registration fee was increased to 55% of a vehicle's market value, with the owner being eligible for a discount if an old vehicle was being scrapped. A working group inside the Public Works Agency, now subsumed under the Land Transport Authority, was asked by Prime Minister Lee Kwan Yew to come up with additional proposals. The government ultimately introduced the Area Licensing Scheme (ALS) requiring cars entering the central business district (CBD) during the morning rush hours to pay three Singapore dollars (S$3) per day, more than double the bus fare for those commuting in from outside. (Today, one Singapore dollar is approximately equivalent to a New Zealand Dollar). A driver was originally exempted from the charge if there were at least four people in the vehicle as it entered the CBD.

The traffic volume was cut by more than 50% when ALS was introduced. Average traffic speeds in the CBD doubled to 36 km per hour (The Economist, 3 September 1998). A vehicle owner had to purchase a sticker and place it on the inside of his front windshield if he wanted to drive into the central business district during the priced hours. Enforcement officials sat in booths at checkpoints to see if a vehicle had the required sticker for the day in question.

In 1988 pricing was applied to the late afternoon rush hours as well. At about the same time, a state-of-the art subway system came online, with lines running north, south, east, and west.

As previously mentioned, in 1990 the government announced a limit on the total number of vehicles to be allowed in Singapore. There were also ongoing discussions about adopting a method for charging vehicles electronically for their use of roadways.

Under manual road pricing with stickers (or what Singaporeans call paper licenses), a motorist could travel in and out of a priced area several times in a day without having to pay multiple charges. With electronic pricing, it was decided that every trip into a priced area results in an immediate deduction from the balance on a prepaid smart card, and the driver sees the amount subtracted flash in front of him (every time). Drivers must also regularly top up their smart cards with cash in order to finance their next set of journeys and must habitually check to see if their smart cards are inserted into an in-vehicle unit (the 'transponder'). They will have to pay extra if they pass a control point without having inserted their smart card in the in-vehicle unit. This is the system that was introduced in 1998 to replace the ALS.

6.2.2 Technology

Singapore pioneered multi-lane, free-flow dedicated short range communications technology (DSRC). It was the first in the world followed by Melbourne and Toronto 407 respectively. The 2.45 GHz technology still operates well today and the components are still operationally valid. The DSRC technology in Europe has moved on with the 5.8 GHz technology that is more robust and provides greater tracking ability whilst the vehicle is in the read zone of the beacons. The Austrian MAUT or Road User Charging System uses a more advanced DSRC transponder with a larger, circular memory to record the last 30 transactions. Sensitivities are also greater as it uses a circular polarization antenna whilst the Singaporean transponders provide a planar antenna.

The vehicle detection and classification equipment has also advanced from the late 1990’s technology found in Singapore. The Infrared detectors and video reading capabilities found in German MAUT Road User Charging system in Germany are more accurate and provide greater vehicle detail than the infra-red scanners found in Singapore. Video imagery is now using a DVD camera with wide aperture for producing over two mega-pixels as opposed to the Singaporean one mega-pixel cameras. The doubling of pixels means the images are crisper and the automatic number plate reading has more definition for higher accuracy.

The Singaporean system is the only DSRC system today that uses fast smartcard technology. The ability of the transponder to debit off a bank issued smart card to protect privacy is still ahead of any other system in the world. This is a four-fold benefit. The first benefit is the ability of the unit to debit the electronic purse of the smart card during the transaction period. This ensures the collection of the fee or the capture of the number plate data while the vehicle is in the charging zone. The second benefit is the card is issued and maintained by the banking system in Singapore. This provides a wide distribution chain and customer service and enquiries are fixed to the banking establishment where this operational cost is a marginal cost. The wide distribution chain also provides superior access to motorists who need to replenish their card. Thirdly, the card provides the individual with a debit card and the added value of being able to use the card for normal transactions in car parks, grocery stores, or merchant facilities. This convenience also lowers the transaction processing costs for the overall system albeit that these costs are outside the LTA’s budgetary responsibility. Lastly, it ensures protection for the individual since his account is financially secured by the national banking laws and fiduciary guarantees provided by the banking statutes in Singapore. The card is not backed up by a private operator with large overheads due to small transaction volumes or risks that he can declare bankruptcy and the individual’s account balance may not be recoverable.

6.2.2.1 Scheme design

The Singapore Scheme design is a cordon design. It changed from being an area charging scheme to a cordon scheme in 1999 with the introduction of ERP. The traveller is charged for every crossing of the cordon.

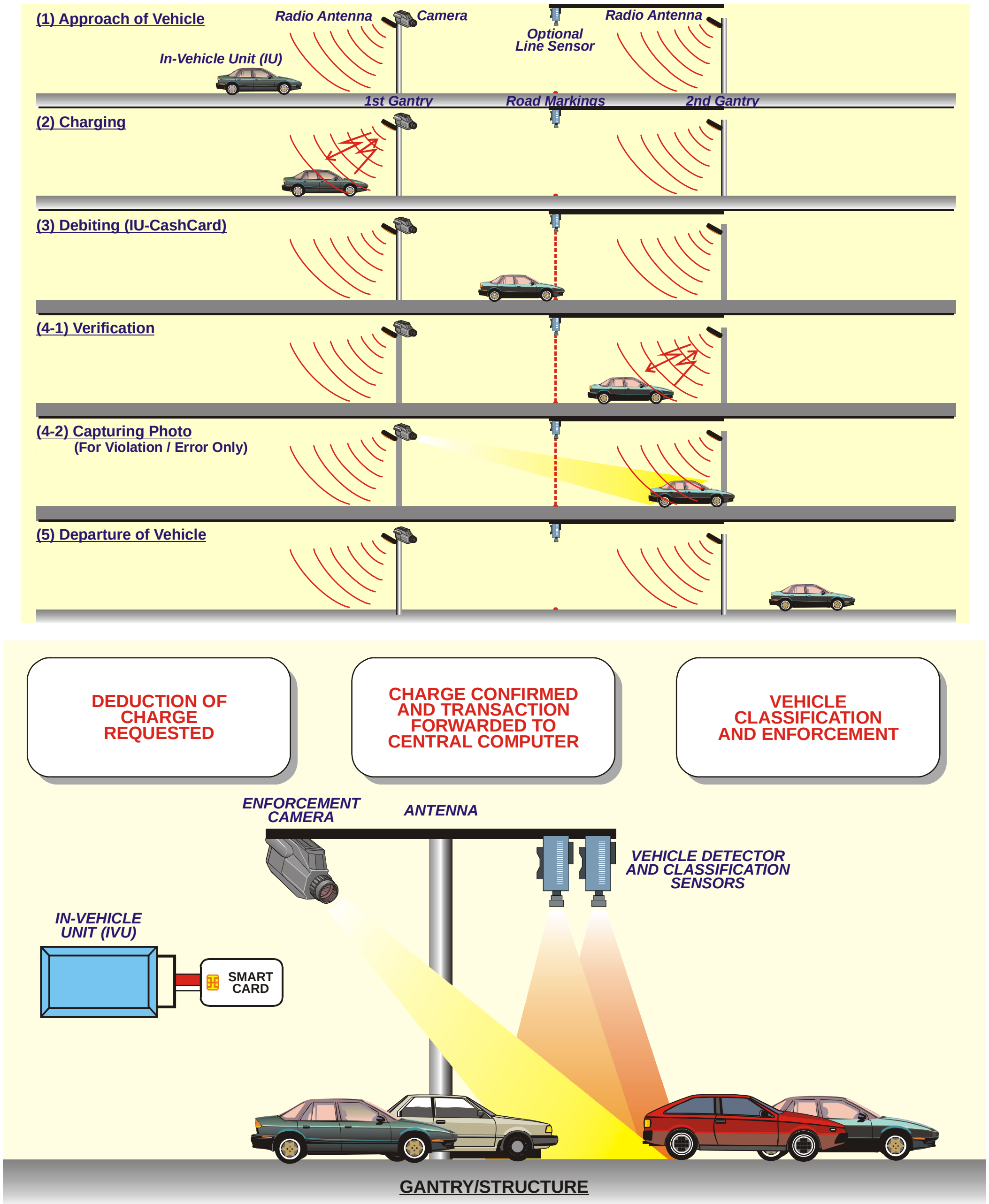


Figure 6.3 Singapore DSRC-based ERP system.

6.2.2.2 Implementation

The implementation of the scheme has evolved over time. A level of service criteria was placed on the measurement of congestion after the LTA learned of the proposed Hong Kong ERP system design. In the Singaporean implementation, each individual route was subject to a level of service or average speed to measure the level of traffic flow as a surrogate for congestion. If flows were too high, there was assumed to be too much suppression of traffic and the ERP charge was lowered. If the speeds were lower than the targets, there was too much congestion and the ERP charge on that artery was increased. As a result, the ERP charges vary on each leg of the strategic road network.

6.2.3 Pricing structure

Competing consortia vied for the job of implementing electronic road pricing in Singapore. Ten consortia were originally involved, with three of the 10 then invited to participate in a more extensive competition. The authorities decided that it was not sufficient for the government just to buy technology off the shelf and devise a more elaborate road pricing system. Instead, each remaining consortium was asked to come up with a detailed, customised proposal for Singapore's central business district and expressways. The Singapore government paid the consortia to conduct extensive field tests at Tuas, in the far west of Singapore, and consortia submitted bids for carrying out the customised proposals. In the end, the proposal of a consortium led by Mitsubishi and Philips Electronics was accepted. The proposal involved the charging of vehicles as they pass under the now-familiar gantries.

There was still much work to be done in constructing the gantries and determining the precise places to install them. The public had to be educated about what was to come. Signboards had to be made to inform drivers of the relevant charges before they entered the CBD or priced expressways.

A vehicle owner who wanted to use priced roadways would have to get a transponder to be mounted on the inside of his windscreen. Cost: S$80 (approximately NZ$80 also). A smart card ('CashCard') would have to be inserted into the transponder. The CashCard was issued by the banking institutions in Singapore and was introduced as a special debit card payment system for all goods, not just the payment of road pricing. As the vehicle passes under a gantry, the motorist hears one beep to inform him that he has just been charged. Several beeps are heard if the balance on the smart card is then below S$5.00. The beeps warn the motorist that his balance is low and that he should consider topping it up. The balance on a card can be topped up at an ATM machine by downloading funds from the driver's bank account.

A driver who has no transponder, fails to insert his CashCard into the transponder, or fails to maintain a cash balance sufficient to pay a particular charge, automatically has the rear of his vehicle photographed as he passes under a gantry. Such drivers were originally issued a court summons and had to pay a fine of S$70. Now, however, they are only charged S$10. Hundreds of thousands of vehicles had to be outfitted with transponders before widespread electronic road pricing could begin. In 1998 a pilot program was launched under which electronic road pricing was introduced on the inbound lanes of the East Coast Parkway. Full-scale electronic road pricing in the central business district and on the inbound lanes of two other expressways began later in the year. CBD pricing became electronic in September that year.

Singapore considered two types of electronic pricing systems: passive and active. Under a passive system a vehicle is identified at a control point, and the motorist is billed. He must pay his bill by the time a deadline is reached. In London, motorists are billed on a daily basis. They need not pay on the spot, but must pay up by late in the day – or face a fine. Video cameras take pictures of the license plates of vehicles that enter the priced zone. However, this type of system requires a significant bureaucracy to chase after non-payers. Singaporean officials considered billing motorists on a monthly basis. In addition to the bureaucratic burden, however, Singaporean officials feared a ‘credit card syndrome’ under which motorists would just pay monthly statements without devoting much attention to the specific charges involved. The fact that a motorist was paying a price for every trip into certain areas would not register strongly in his mind—or so it was argued.

With an active system the idea is that every trip into a priced area results in an immediate deduction from the balance on a prepaid smart card, and the driver sees the amount subtracted flash in front of him (every time). Drivers must also regularly top up their smart cards with cash in order to finance their next set of journeys and must habitually check to see if their smart cards are inserted into their transponder. They will have to pay extra if they pass a control point without having inserted their smart card in the transponder.

Thus, an active system constantly reminds motorists that they are paying for the use of priced roads. Motorists’ sensitivity to prices may therefore be higher than it would be under a passive system. In economic terms, an active system is claimed to result in greater price elasticity of demand. Singapore remains unique in its use of smart cards for road pricing.

From a technical standpoint the system has performed almost flawlessly. Recently, billing errors have occurred in less than 0.05% of all transactions, with more than 3.5 million transactions occurring on a typical day (Menon and Chin 2004). The following table shows the prices charged for ordinary passenger cars to enter the Central Business District.

Table 6.1 Prices charged for ordinary passenger cars to enter the central business district (August 1 – November 4, 2005) (Singapore dollars).

Time of day	Price, S$
07:30 - 07:35	$0.00
07:35 - 08:00	$0.00
08:00 - 08:05	$1.00
08:05 - 08:25	$2.00
08:25 - 08:30	$2.00
08:30 - 08:35	$2.50
08:35 - 08:55	$2.50
08:55 - 09:00	$2.50
09:00 - 09:05	$2.00
09:30 - 09:55	$1.00

Table 6.1 (continued) Prices charged for ordinary passenger cars to enter the cental business district (August 1 – November 4, 2005) (Singapore dollars).

Time of day	Price, S$
09:55 - 10:00	$0.50
10:00 - 12:00	$0.00
12:00 - 12:30	$0.50
12:30 - 14:00	$1.00
14:00 - 17:00	$1.00
17:00 - 17:30	$1.00
17:30 - 18:00	$1.50
18:00 - 18:05	$2.00
18:05 - 18:25	$2.00
18:25 - 18:30	$1.50
18:30 - 18:55	$1.00
18:55 - 19:00	$0.50

For example, it now costs S$2.50 to enter the CBD at 08:30 am on weekdays. Note that the demand to use various roadways would have been higher were it not for the limit on the total number of vehicles, and the charges for using priced roadways would then have been higher as well.

The charges are reviewed through a dynamic evaluation of traffic every six months to determine if the fee charged for that entry into the CBD is set correctly. By the measurement of average speed, the LTA can determine if too much or too little suppression of demand is occurring on each individual route. This measurement of average speed provides a sustainable aspect to a changing tide of traffic flows. It is nearly impossible to know if a charge is properly set at the establishment of the system. Giving the LTA the power to regulate the charge based on the average speeds provides the LTA with a constant hedge against inflation, new development or shifting socio-economic conditions.

The limit on the total number of vehicles has been somewhat relaxed with the expansion of the priced area. The total number of registered vehicles was 674,000 in September 1998. Within five years the number had grown to 709,000, an increase of 5% (Menon and Chin 2004). As previously mentioned, technology and, in turn, the transaction costs of road pricing affect the policy optimum—which is not necessarily to say that Singapore has achieved it. However, electronic methods have indeed reduced transaction costs as compared to the old sticker system.

6.2.3.1 Costs

The revenues of the Singapore Scheme design are approximately NZ$83 million. The operating and maintenance costs are suggested to annually be around 20%.

6.2.4 Key management system issues

ERP pricing has extended the success of the ALS in combating traffic congestion in central Singapore. Target average speeds have been achieved in the CBD and approach corridor. It has helped not only to control traffic volumes, but has earned a very healthy rate of return. The infrastructure for electronic road pricing cost about S$200 million in 1998, including the costs of all motorists' transponders. The annual revenues have recently been about S$80 million, and the annual operating costs have been about S$16 million. Even in the early years of electronic road pricing there was an operating profit on the order of S$60 million. With the installation of new gantries there have been some additional capital costs and revenues.

If one considers the up-front capital costs of S$200 million and an operating profit of S$60 million, and if the operating profit were to continue indefinitely, the net present value (NPV) of the system, viewed from 1998, would be given by:

$$NPV = -200 \text{ million} + \sum 60 \text{ million}/(1+R)t$$

Where
R = the annual rate of return
t = time, with the number of years involved being potentially infinite.

By setting NPV = 0 and solving for R, we can calculate the so-called internal rate of return. In this case, the average annual rate of return is seen to be more than 25 percent per year, a very good return as compared to the return available on other capital investments. By just looking at the annual operating profit, one can readily see that the up-front costs of the infrastructure have been already been recovered quite easily.

From a pure investment point of view these results suggest that, even without considering a possible upgrade of the technology used for road pricing, it should be worthwhile to continue expanding the system for the next several years. It is economically worthwhile to expand the system as long as the rate of return for additions to the system exceeds the return which could be had on other investments of similar duration and risk.

There were originally 27 gantries forming a cordon around Singapore's central business district, together with 5 other gantries on expressways and related roads. The long term plan is that a whole new cordon around the original cordon will eventually be completed, with the outer cordon consisting of 22 gantries. More than half of the 22 gantries have by now been installed and put into operation. Thinking even further into the future one can imagine a series of concentric rings around the downtown area. The greater the number of rings through which a vehicle would have the pass to get into the central business district, the more the vehicle would have to pay. It is conceivable that whole new business centres will emerge over time, each with its own toll rings. The authorities are looking to VPS applications for the future expansion.

It is difficult to quantify the environmental impacts (e.g., reduced air pollution) from road pricing, let alone their dollar value although the reduction in volumes provides some benefits. Some people have complained of 'gentrification' and 'visual pollution' as the number of gantries has increased, but there is no clear impact on the associated real estate values. Insofar as road pricing has made Singapore a more liveable city-state than it otherwise would have been, it may have helped to support real estate values.

6.2.5 Urban form

The key urban form to influence the design of the system was the high density layout of Singapore and the small congested central business district. Although bounded on one side by water the scheme shares more in concept with the London situation, with the need to reduce congestion in the busy central area.

The original scheme in Singapore was designed as an area scheme using paper licenses to charge for all vehicle movements within the central area. There was originally a high level of transportation and land use planning in Singapore so the scheme was designed specifically to charge for congestion in the central business district, which is well served by passenger transport.

In 1988, charging was applied to the later afternoon rush hour as well. This coincided with the opening of a new subway system to tempt commuters out of their cars and on to public transport services.

The Singapore scheme design is now a cordon design. It changed from being an area charging scheme to a cordon scheme in 1999 with the introduction of full electronic road pricing. Vehicle drivers are charged for every crossing of the cordon.

6.2.5.1 Environmental impacts

Reduced congestion levels on key routes and in the CBD have meant reduced emissions from motor vehicles overall, despite growth in vehicle numbers. There has been some criticism of the visual impact of the large gantries used for the ERP system, and there can be some local opposition to the installation of new gantries.

6.2.5.2 Land use/transportation integration

Singapore already has a very high degree of land use planning and transport infrastructure planning around roads and public transport. ERP is integrated into overall planning, as new public transport infrastructure (metro rail routes) were opened in advance of the introduction of ERP.

6.2.6 Other characteristics

Key lessons learned include its effectiveness in achieving strong demand management results, its gradual extension (an iterative approach) over the years of operation and a strict enforcement regime applied.

Another key finding is that the use of measurable values (defined as congestion, average speed) provides objective criteria to manage traffic flows dynamically over time. Without such objective factors, increases in road pricing would be up to the whims of the governing body or Central Government and become politicised.

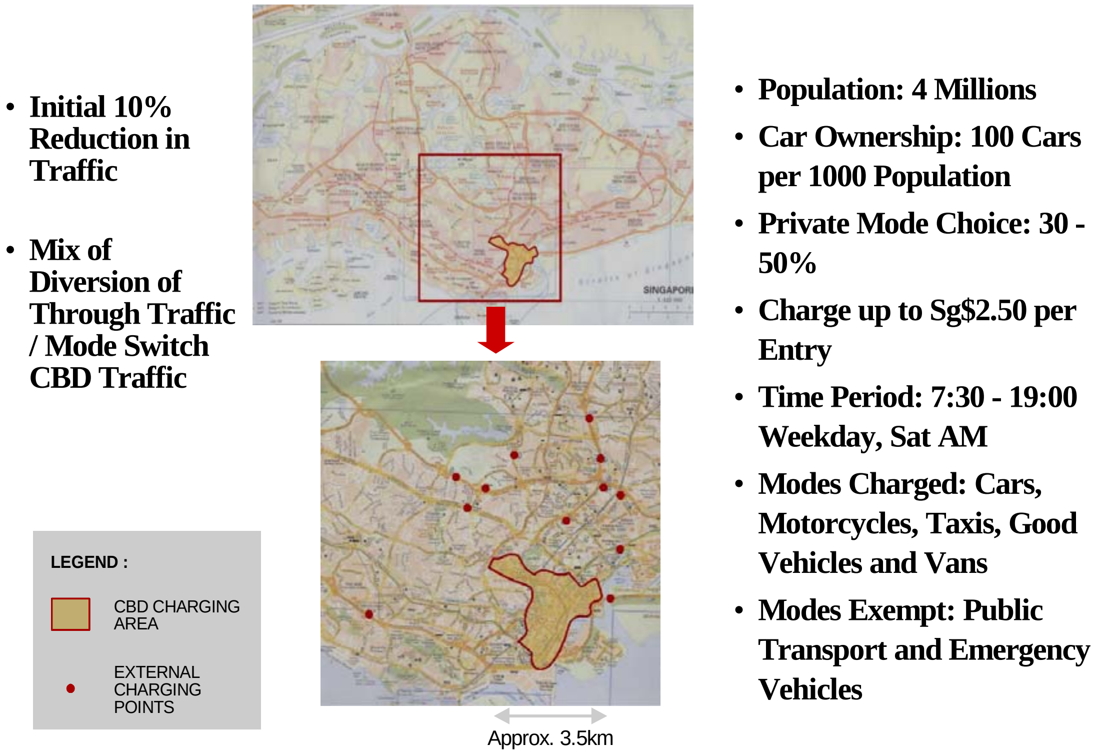


Figure 6.4 Singapore electronic road pricing scheme.

The use of the debiting smart card that is bank issued and maintained is also a good means to minimise operating costs by shifting the capital, operating and maintenance costs to private industry. By having the card issued by the banks also means the fiduciary statutes financially insure the personal accounts under the law. In addition, the use of the card for other commercial purposes increases its value to the users while lowering the transactional costs. Because the card has commercial value to the user, the user is more likely to ensure value is added and the card is working properly.

6.2.6.1 Implementing authority

The Land Transport Authority (LTA) is the Implementing Authority of the Singaporean electronic road pricing (ERP) system. It is also the operating and maintaining authority for the system. There is no change foreseen in this governance in the future.

6.2.6.2 Business impacts

Singapore's long history with different forms of demand management, while experiencing ongoing continued economic growth, has indicated that the Singaporean government sees road pricing as being positive for business growth. The positive effects on business have been enhanced with the electronic road pricing scheme because the net economic impact of reducing congestion on key expressways and arterials has been beneficial to the Singaporean economy. As the charges have been focused on reducing severe congestion, rather than to collect revenue, charges have not been excessive for the purpose (and the reduction in net revenue reflects greater efficiency in achieving congestion reduction, rather than a transfer of funds from road users to the state). In essence, the economic impact of the electronic road pricing scheme has been positive in ensuring more efficient use of the roading infrastructure.

6.2.6.3 Technical feasibility

Singapore was the first to use multi-lane fully free flow dedicated short range communications (DSRC) for tolling. It uses 2.45 GHz technology which has since been superseded in Europe and North America, and also incorporates fast debit smartcard payment. The system was introduced with a wide scale installation of transponders on board vehicles in advance. It was piloted on one road (East Coast Parkway) in 1998 and expanded later in the year to other routes. Technically it has operated virtually without a hitch. Billing errors occur in less than 0.05% of all transactions. Enforcement does not appear to be a problem, as those without transponders or with inadequate payment have their number plate photographed, and are fined S$10.

6.2.6.4 Enforcement

As an island state with quite strict adherence to law and order, Singapore is an 'easy' case in terms of enforcement. Penalties are tied to the COE of the driver. Due to the cost and difficulty to receive a COE, the driver is highly sensitive to not being labelled as violator and risk losing his vehicle COE.

6.2.6.5 Privacy

Unique among road pricing systems, Singapore has ensured a high degree of privacy by use of debit smartcards for payment of the charge. Motorists can acquire the debit card from their bank, and top up the balance from an ATM. This means that the ERP system has no idea whose is paying, and does not enquire as to whose vehicle passed through the system, unless there is no transponder or insufficient funds on the debit card to perform the transaction. Singapore has one of the best protections for personal privacy built into the payment system.

6.2.6.6 Financial

The transition from ALS to ERP saw a 40% reduction in revenue, as charging could be targeted on routes and at times to reducing congestion, rather than being a flat entry fee for entering the CBD area. As ERP is more successful than ALS in relieving congestion, this is still seen as a success (in that motorists are being taxed less for better results). Annual revenues are now about US$51 million per annum, with operating costs of around US$10 million, meaning an operating cost of 20% of revenues. The upfront capital cost of the system was US$127 million, meaning the system has paid for itself within four years and is now generating surpluses for the state. This includes the cost of all vehicle transponders. Expansion of the system is under consideration, to install gantries at further points along the road network, with eventual construction of a new outer cordon. Singapore's system has not been the cheapest to install, but for a system designed to manage congestion rather than generate revenue, is producing a healthy profit above operating costs.

6.2.6.7 Institutional

Singapore's political system was conducive to the easy legislative implementation of ERP. The Land Transport Authority was granted all of the powers to procure and operate the system. As it is also responsible for vehicle licensing, road management and public transport licensing, it is able to provide a highly integrated approach to planning and operating ERP. This has contributed towards the relative ease with which road users can use the system. Clear accountability and governance of the scheme is critical to its success.

6.2.6.8 Public acceptability

Given the high degree of political consensus in Singapore, it was relatively easy to implement ERP. However, there is some debate around the expansion of the system on particular roads. Nevertheless, the results of reduced congestion and the provision of relatively high quality alternatives has seen widespread public acceptance of the Singapore scheme.

6.2.7 Level of success

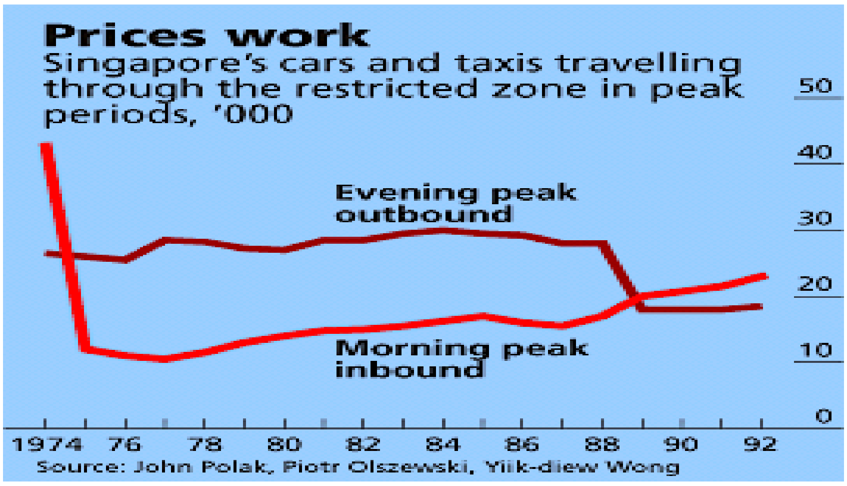


Figure 6.4 Traffic in Singapore's central business district.

The effects on traffic have been dramatic. Among commuters to jobs in the restricted zone, the share commuting in cars with less than four passengers dropped from 48 percent to 27 percent during the first few months of operation, while the combined modal shares of carpool and bus rose from 41 percent to 62 percent (Watson and Holland, 1978, p. 85).

As shown in Figure 6.5, the traffic volume was cut by more than 50% when pricing was introduced. Average traffic speeds in the CBD doubled to 36 km/h (The Economist, 3 September 1998).

6.2.7.1 Traffic impacts

Following the substantial reduction in traffic realised by the ALS, the transition to the electronic system was intended to ensure a more precise management of traffic levels on the various entry points into the CBD. The system has been designed in order to deliver standards of service determined by the Land Transport Authority as minimum speeds of 45 to 65 km/h for an expressway and 20 to 30 km/h for an arterial road. Charges are varied quarterly in order to maintain those speeds (which includes increases or decreases). The introduction of the electronic system has seen road traffic decrease by a further 25,000 vehicles during peak hours, with average road speeds increasing by about 20%. Within the restricted zone itself, traffic has reduced by about 13% during Electronic Road Pricing (ERP) operational hours, with vehicle numbers dropping from 270,000 to 235,000, compared to the ALS. The use of graduated charges (increasing and decreasing at intervals of between 5 minutes and several hours) has avoided the 'bunching' of traffic attempting to access the charged roads outside charging hours. It also allows the scheme to respond to periods of flat economic growth or high growth.

As a scheme specifically designed to manage congestion, the Singapore scheme is a considerable success.

6.2.7.2 Operational performance

In Singapore, the public transport mode share is high and this has grown with the introduction of electronic road pricing (although this also parallels expansion of the heavy rail metro system which was only constructed in the 1990s). The long term impact of a combination of road pricing and enhanced public transport has seen the share of public transport access to the CBD increased from 33% in 1975 (just before ALS was introduced) to 70% in 1991 (with 63% of all motorised trips by public transport, including taxis, by 1999). Electronic road pricing has helped to enhance this, by providing an incentive to use public transport, and by freeing up road space for buses to operate more efficiently.

6.2.7.3 Network utilisation

With road pricing focused on peak congestion periods and management of traffic flows, it can be said to have enhanced mobility and accessibility overall. Only the most congested roads at congested times are charged, so that motorists using un-congested roads or travelling off peak are not penalised. This has meant travel at peak times is enhanced with reduced congestion, and off peak travel has not altered (some increases in off peak traffic, although not to congested levels, suggests spread of demand has been one response to road pricing). Mobility has been further enhanced by the increase in the number of licenses allowed for new vehicle registrations, meaning that ownership of vehicles is allowed to be wider, with controls on traffic focused on road pricing rather than restricting private mobility overall.

6.2.7.4 Summary

Key conclusions from the Singapore scheme are:

- Specific congestion charging scheme – not for revenue raising.
- ALS replaced as expensive to operate, unwieldy and not optimal in economic terms.
- Conversion from daily ALS to Cordon Charging more effective at pinpointing and relieving congestion.
- DSRC-based system with smartcard payment proven.
- Mixed charge zones and arterial charging possible.
- Variable charges by time period possible.
- Variable charges by mode possible.
- Charge per crossing/direction.
- System technology proven.

6.3 Stockholm

6.3.1 Scheme type

The scheme design for Stockholm is a cordon design with special concessions for bypass traffic. Bounded by water, there were no good bypasses. The strategic road network was used instead as the free bypass. Travellers are now charged by their destination, in other words, if they stay on the strategic road network and do not terminate their trip in the CBD, the trip is not charged. If they turn off the SRN, the trip is charged. This design has merit for urban designs that do not have natural bypasses like London's inner ring road.

The Stockholm congestion tax or The Stockholm Trials was a traffic congestion and environmental tax imposed on most vehicles in Stockholm, Sweden during a trial period between January 3, 2006 and July 31 2006. There was a referendum in September 2006 for the residents of Stockholm municipality to decide whether to implement it permanently or not.

As stated, the congestion tax trial period lasted from January 3 2006 to July 31 2006, after which the congestion taxes was lifted until a municipal referendum regarding this matter. The referendum was held in the Stockholm municipality in September 2006, and it will determine whether the congestion taxes will be implemented permanently or not.

Note: The result of the referendum was not available at the time of preparation of this Report.

The municipalities surrounding Stockholm in Stockholm County, especially those which are part of the Stockholm urban area, have shown discontent with the fact that the people of those municipalities get no say whether the congestion taxes will be implemented permanently or not. A substantial number of the inhabitants of the nearby municipalities travel to and from work through the congestion tax area.

Initially this scheme was planned as a congestion fee, not a tax. But the Swedish government ruled that this kind of scheme was considered a tax and not a fee, and thus the Stockholm municipality couldn't implement it without some changes in Swedish legislation, as municipalities in Sweden are not allowed to create new taxes.

The primary purposes of the congestion tax are to reduce traffic congestion and improve the environmental situation in central Stockholm. "It is important to me for Stockholm to become an exciting region in Europe," said Mayor of Stockholm Annika Billstrom. "From an international perspective, it is important to not only have economic growth, but environmental growth. Many cities have serious environmental issues. We are now doing this trial with a modern, exciting, new system which the rest of Europe and the world can learn from." (http://www.public-cio.com/newsStory.php?id=2006.03.06-98651)

The parts of Stockholm that are located within the congestion tax area are Södermalm, Norrmalm, Östermalm, Vasastaden, Kungsholmen, Stora Essingen, Lilla Essingen and Djurgården. This area can be seen in Figure 6.6 on page 101. Due to the fact that Lidingö has its only access to the mainland through the congestion tax affected area, all traffic to and from Lidingö from the rest of Stockholm County is exempt from the tax, provided that the vehicle passes through the Ropsten payment station and another payment station within 30 minutes of each other. Another geographic anomaly to the Stockholm charging zone is that the Essingeleden freeway goes through the congestion tax affected area. As a result, it is also exempt, due to its being the main road when travelling through central Stockholm.

6.3.2 Technology

The Stockholm Congestion Charging scheme is the largest implementation of a microwave tag and beacon system in a European city environment. The full system trial has been implemented by IBM and QFree of Norway. The chosen tag and beacon technology allows the city authority to vary the charge throughout the day, allows the drivers to have direct debit accounts and provides a more efficient total operation.

The Stockholm system is cordon-based, with 18 barrier-free control points around the charging zone equipped with roadside beacons and cameras to identify vehicles. All eligible vehicles entering or leaving the charging zone are charged based on time of day, with fares highest during peak rush hours, and up to a maximum charge per day.

As part of the trial, an extensive impact evaluation was conducted and communicated to voters, comparing before and after results in a number of key areas such as impacts on traffic, public transport, local business and the environment.

The vehicles passing the payment stations are photographed and their license plates registered. An optional transponder can be used also to identify the vehicles, with which one can utilise an automated payment method. Camera and number plate recognition technologies were chosen that identify those vehicles without tags, and are also used to verify tag readings and provide evidence to support the enforcement of non-payers. This technology allows the city authority to vary the charge throughout the day. Payment is made by a number of channels including by direct debit triggered by the recognition of an electronic tag that is loaned to drivers.

6.3.2.1 Technical feasibility

The technology used is a combination of DSRC tags (voluntary) using the European 5.8 GHz standard and ANPR for non-tag equipped vehicles. Payment is through direct debit from accounts, and the use of the DRSC tag allows variation of the tolls by location and time.

6.3.2.2 Enforcement

There are no details about levels of non-payment, but the Swedish taxation system has a rigorous approach to non-payment that imposes fees for failure to pay [70 SEK (NZ$15)] if not paid within five days. If the debtor still hasn't paid the tax within four weeks, another additional fee of 500 SEK (NZ$106) is charged. Ultimately the Swedish Enforcement Administration has the legal right to deduct fees from the suspected debtor’s bank account. The suspected debtor would need to legally challenge the fees to get the funds back.

6.3.2.3 Privacy

Sweden prides itself in having high standards of privacy. The DRSC tag system is designed to ensure that payment of the tax on a direct debit basis is done without the use of vehicle or customer data for other purposes. Only those who do not pay ultimately face their private details being accessed for enforcement, as with all such schemes.

6.3.3 Pricing structure

The System is operational during the charging hours of 6.30 a.m. to 6.30 p.m. Monday to Friday.

The amount of tax that a driver has to pay depends on what time of the day one enters or exits the congestion tax area. The tax is not in effect on Saturdays, Sundays, public holidays or the day before public holidays, nor during nights (18:30 – 06:29).

Table 6.2 Prices charged for entering or exiting the congested tax area.

Time of day	Fee
06:30 – 06:59	10 SEK (NZ$2.10)
07:00 – 07:29	15 SEK (NZ$3.15)
07:30 – 08:29	20 SEK (NZ$4.20)
08:30 – 08:59	15 SEK (NZ$3.15)
09:00 – 15:29	10 SEK (NZ$2.10)
15:30 – 15:59	15 SEK (NZ$3.15)
16:00 – 17:29	20 SEK (NZ$4.20)
17:30 – 17:59	15 SEK (NZ$3.15)
18:00 – 18:29	10 SEK (NZ$2.10)
18:30 – 06:29	0 SEK

Since a vehicle is charged at each toll gantry, repeat transits into and out of the charging zone can accumulate a high tax in a single day. To minimize this effect, the Stockholm authority implemented a tax cap. The maximum amount of tax per vehicle per day is capped at 60 SEK or NZ$12.6.

If a vehicle has not pre-paid the tax or does not sign up for a transponder account, the registered vehicle owner will be assessed a demand for tax payment. The Debtor is required to pay the tax within five days of the official notification. This failure to pay the tax within the allotted five days, will be issued a reminder bill that will add an administrative fee of 70 SEK (NZ$15). If the debtor still hasn't paid the tax within four weeks, another additional fee of 500 SEK (NZ$106) will be added. In the end, cases of unpaid taxes will be forwarded to the Swedish Enforcement Administration. Taxes have a special procedure in Sweden regarding this payment. They must be paid within the assigned time even if the person owing them considers them wrong. The Enforcement Administration will claim the money from the suspected debtor (e.g. the debtor's bank account) without asking. This will immediately be noted in the public 'bad payer' record. If the tax claim is later considered wrong the money will be paid back. For other types of debts the claim can be disputed in a court of law before the claim is enforced.

Exemptions are employed in the system. The classes of vehicles that are exempt from the congestion tax are:

- Emergency services vehicles — while responding to an emergency.
- Buses with a total weight of at least 14 tonnes.
- Diplomatic corps registered vehicles.

- Vehicles of the transportation service for the disabled with a total weight of under 14 tonnes.
- Military vehicles.
- Cars used by persons who have been granted a parking permit for disabled people.
- Environmental cars — cars that are driven entirely or partially with electricity, alcohol or other approved fuel.
- Motorcycles and mopeds.
- Foreign-registered vehicles.

6.3.3.1 Costs

The trial was established at a cost of US$517 millions.

6.3.4 Key management system issues

6.3.4.1 Evaluation of the scheme

Following the January 2006 launch of the Stockholm Congestion Charging Scheme, initial data indicated that the pilot has successfully reduced traffic by 25%; increased public transport usage by 40,000 users per day; and dramatically cut peak-time road congestion. The city has three objectives in implementing congestion charging: reduce traffic volumes in the inner city by 10-15% during rush hour; improve accessibility for buses and cars; and improve the environment. The congestion charge is a national tax, with the revenues returned to the Stockholm region for investment in the public transport infrastructure. Payment is via a number of channels including by direct debit triggered by the recognition of an electronic tag that is loaned to drivers. Camera and number plate recognition technologies identify those vehicles without tags, and are also used to verify tag readings and provide evidence to support the enforcement of non-payers. Payment channels for those without transponders include, via a Giro system at banks or over the Internet, and through designated retail outlets.

The use of the transponders fitted in vehicles means the system has a more reliable capture rate and a more cost-effective back-room operation than congestion charging systems that do not use such devices. It also makes it far easier to operate variable charging with automated direct debit after the passage.

The scheme has been under development for several years. The municipal council first approved a congestion charging trial on 2 June 2003. This was followed by approval from the Swedish National Parliament on 16 June 2004, and a contract was awarded to IBM on 9 July 2004 to design, build, implement and operate the system.

In preparation for the scheme, the Swedish government and the city of Stockholm have invested significantly in public transport, including 12 new express bus lines, 18 bus lines with extended service, and 1800 new park and ride places at stations outside the inner city.

6.3.4.2 Implementing authority

The three principal participants in the Stockholm Trial are the City of Stockholm, the Swedish Road Administration and Stockholm Transport (SL). SL is responsible for expanding public transport services and park-and-ride sites.

All the costs for the Stockholm congestion charging trial are to be paid for by the National Government. The total budget for the trial is SEK 3.8 billion.

The City of Stockholm is responsible for providing general information about the Stockholm Trial, evaluation, information on the evaluation, and extended park-and-ride sites.

The Swedish Road Administration is responsible for the design and operation of the technical system and information about how the congestion tax can be paid.

The trial ran for a period of 7 months to 31 July 2006, followed by a public referendum on 17 September 2006 to decide if the system should be retained or ended.

6.3.5 Urban form

The urban form of Stockholm greatly influenced the final scheme design. It is a cordon design with special concessions for bypass traffic. Bounded by water, there were no obvious bypasses so the strategic road network was used instead as the free bypass. Travellers are therefore charged by their destination, in other words, if they stay on the strategic road network and do not terminate their trip in the central business district, the trip is not charged. If they turn off the strategic road network, the trip is charged. This type of scheme is of particular benefit to cities that do not have natural bypasses, such as in the case of London’s inner ring road.

One urban form consideration to the Stockholm charging zone is that the Essingeleden freeway goes through the congestion tax area. As a result, it is also exempt from the charge, due to its being the main road through central Stockholm.

Following the start of the congestion charging trial, it was noted that there had been a modal shift and that public transport usage was up by 40,000 users per day. Stockholm was originally developed as a high density city with a good public transport network, but there were still a large number of extra public transport services put on over the trial to deal with this modal shift.

6.3.5.1 Environmental impacts

There is little detailed data about environmental impacts, but it is clear that the significant reductions in congestion and vehicle traffic as summarised above have seen a corresponding reduction in vehicle emissions and pollutions levels in Stockholm.

6.3.5.2 Social impacts

There is little detailed data about social impacts, but much in the scheme design was done to incorporate the groups impacted by the scheme design. The unique charging mechanism did not isolate the island community or divide the community lines.

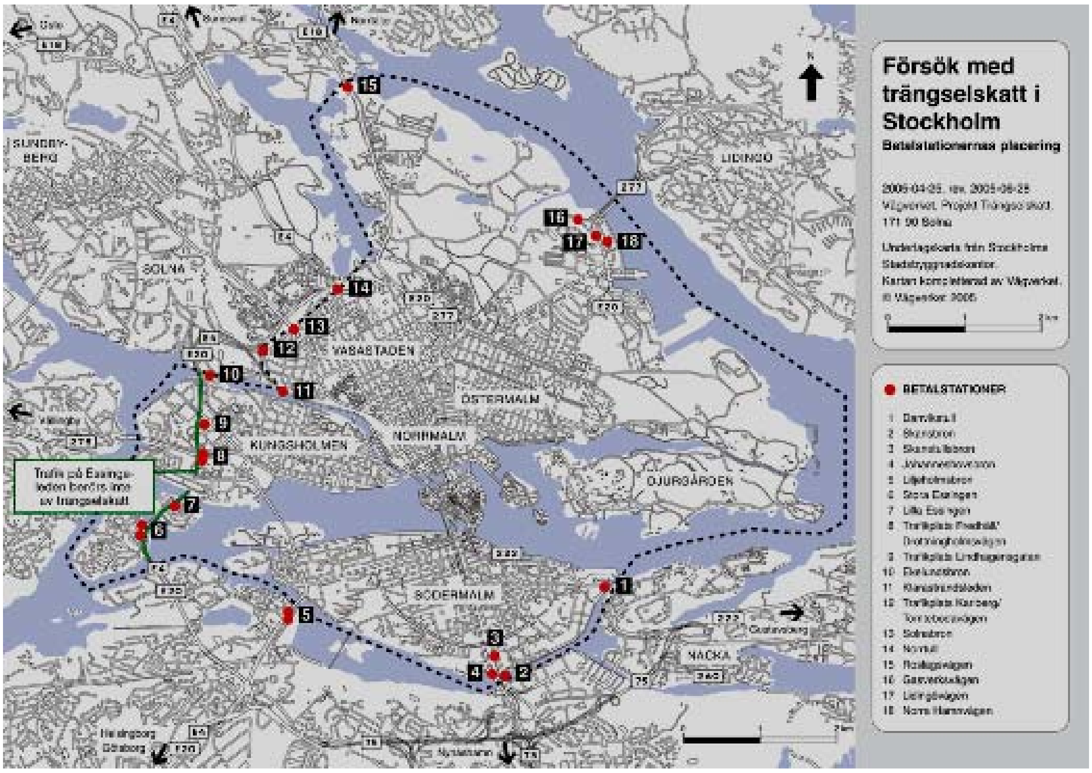


Figure 6.6 The parts of Stockholm located within the congestion tax area.

6.3.5.3 Land use / transportation integration

As a trial, no land use planning changes have been implemented, although Stockholm has been developed as a high density city with a high level of public transport service. One hundred and ninety seven new buses and 16 new bus routes were implemented to carry any mode shift. 2000 new park and ride spaces near public transport terminals have been added.

6.3.6 Other characteristics

6.3.6.1 Business impacts

The business impacts from the charge appear to be positive, partly it seems, because local residents prefer to shop locally rather than travel within the zone. Residents are not exempt or discounted, so are prefer to not drive (and pay to enter the zone after exiting it) to shops outside the zone.

6.3.6.2 Implementation

The trial consisted of 18 gantries, which were erected in eight months. The Central processing system and software were also established in this time frame. Since this was a trial, no assessment can be made of its durability for long term usage.

6.3.7 Level of success

Initially there was a large public resistance to a charging scheme in Stockholm, but as the trial progressed, public support increased and the benefits of the reduction in congestion and air pollution are clear to see. Before the introduction of the charge, 80% of Stockholm residents were opposed to the charge.

Prior to it's referendum on the matter in September 2006, polls suggested that this may have shifted to approximately 60% in favour of the charge.

Initial highlights from Stockholm Congestion Charging trial include:

- Traffic at cordon points reduced by 100,000 vehicle passages per day or 25%.
- Train and transit passengers increased by 40,000 per day.
- Congestion during peak hours dramatically reduced.
- No major re-routed traffic problem.
- Time tables for inner city bus lines have to be redesigned due to the increased average speed.
- Parking fines reduced by 29%.
- The automatic charging system in operation from day one.
- About 350,000 vehicle passages identified per day.
- The system was fully operational during the charging hours of 6:30 am to 6:30 pm Monday to Friday.

The Stockholm trial has yielded a 25 percent reduction in the first months of operation. Data indicates that approximately 100,000 vehicles were removed from the roads during peak business hours. Of this reduction, approximately 40% or approximately 40,000 commuters shifted to public transit per day. Of the remaining 60,000, approximately half or 30% shifted their trips to occur before or after the charging period whilst the other 30% or 30,000 trips were consolidated or suppressed.

6.3.7.1 Traffic impacts

Reports indicated a 23% reduction in traffic crossing the cordon with 100,000 less vehicles entering the city during the charging period. As public transport patronage had only increased by 50,000, this would indicate that journeys were being consolidated, time shifted or vehicle occupancy had increased. Traffic on the bypass route (Essingeleden freeway) was within a 1-4% range compared to the previous year. This range is within the norm of variable traffic flows along the freeway. Congestion on inner city streets and radial routes decreased significantly, with delays reduced by between 10% and 35%, congestion levels on radial routes outside the zone did not increased, despite fears.

Clearly the Stockholm scheme has made a considerable difference to traffic conditions within the zone.

6.3.7.2 Impacts on alternative modes and mode change impacts

There was a 50,000 passenger daily increase in public transport patronage entering the zone, although some of this is not attributable to the congestion tax. The trial generally appears positive in encouraging a shift from private car to public transport, particularly bus services.

6.3.7.3 Financial

The cost of the trials was fully funded by central government at the cost of SEK3.8 billion (US$517 million). At the time of writing, revenue levels had yet to be reported for the scheme, but the longer term intention if the scheme is continued is for it to be sufficient to fund improvements to public transport.

6.3.7.4 Institutional

The Stockholm municipality could not implement the trial without some changes in Swedish legislation, as municipalities in Sweden are not allowed to create new taxes. The scheme is designed and operated by the Swedish Road Administration, with the City of Stockholm responsible for the trial and providing information. Stockholm Transport is responsible for enhancements to public transport. This clear separation of functions helped ease the implementation of the trial.

6.3.7.5 Public acceptability

Survey figures indicated 47% oppose the charge, but 44% in support – compared to 50% opposition and 43% support before it was introduced. This would indicate that the longer the scheme operates and the reduced congestion is appreciated, the more likely that people are to accept it and notice the benefits. Nevertheless, the true test will be the result of the referendum in September 2006. Stockholm residents will be able to compared traffic levels without the charge and decide whether they want to retain a congestion charging scheme.

6.3.7.6 Summary

The trial scheme indicates the following:

- Single Cordon DSRC-based scheme using proven technology.
- Mixed with ANPR for infrequent users.
- Free bypass/through routes provided by charging on exit of SRN.
- Time period variation for charge.
- Impact at 20-30% similar to London.
- Accompanied by complimentary bus improvements.

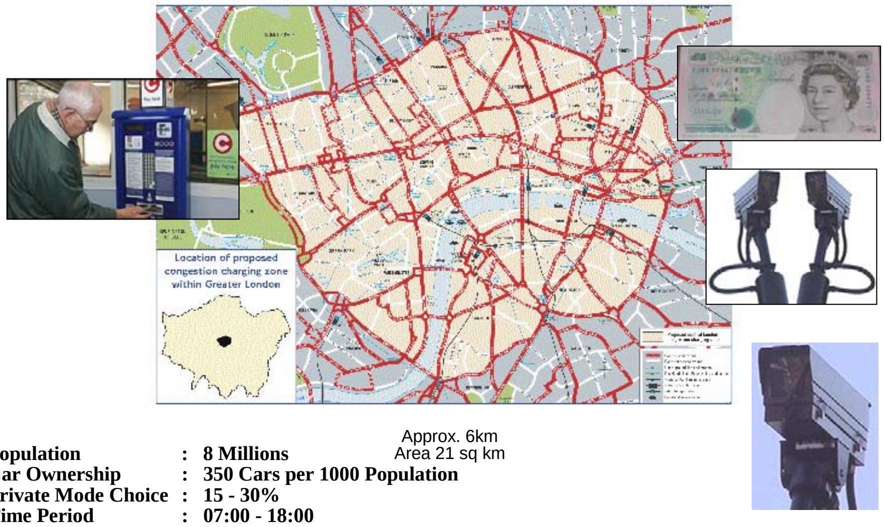
6.4 London

6.4.1 Scheme type

The London Scheme design is an area charge. All vehicles originating inside the zone or crossing into the zone are subject to the charge during the charging period.

Much has been written on the high profile case of London, where a £5 congestion pricing fee was introduced for trips made by car through the inner city cordon during weekdays between 7 am and 6.30 pm. Revenues generated from the charge are directed at public transport improvements. The charge has recently been increased to £8.

London Congestion Charging Scheme



Population	:	**8 Millions**
Car Ownership	:	**350 Cars per 1000 Population**
Private Mode Choice	:	**15 - 30%**
Time Period	:	**07:00 - 18:00**
Charge	:	**£ 8 / day approx.**
Location	:	**Within Inner Ring Road**
Modes Charged	:	**Cars, Vans and Goods Vehicles**
Exemptions	:	**Public Transport, Taxi, Emergency and Social Services**

Figure 6.7 London congestion charging scheme.

Key issues that have led to the introduction of the scheme are as follows:

- London suffers the worst traffic congestion in the UK and amongst the worst found in Europe.
- Drivers in central London spend about 50% of their time in queues.
- Every weekday morning, the equivalent of 25 busy motorway lanes of traffic tries to enter central London.
- It has been estimated that London loses between £2–4 million every week in terms of lost time caused by congestion.

These set the stage for the Mayor’s key objectives for the London Congestion Charging scheme. They were:

- To reduce congestion.
- To make radical improvements in bus service.
- To improve journey time reliability.
- To make the distribution of goods and services more reliable, sustainable and efficient.

While not stated in the original set, TfL Congestion Charging Managers have also highlighted that an objective was also to generate net revenue to improve transport on a sustainable basis in London.

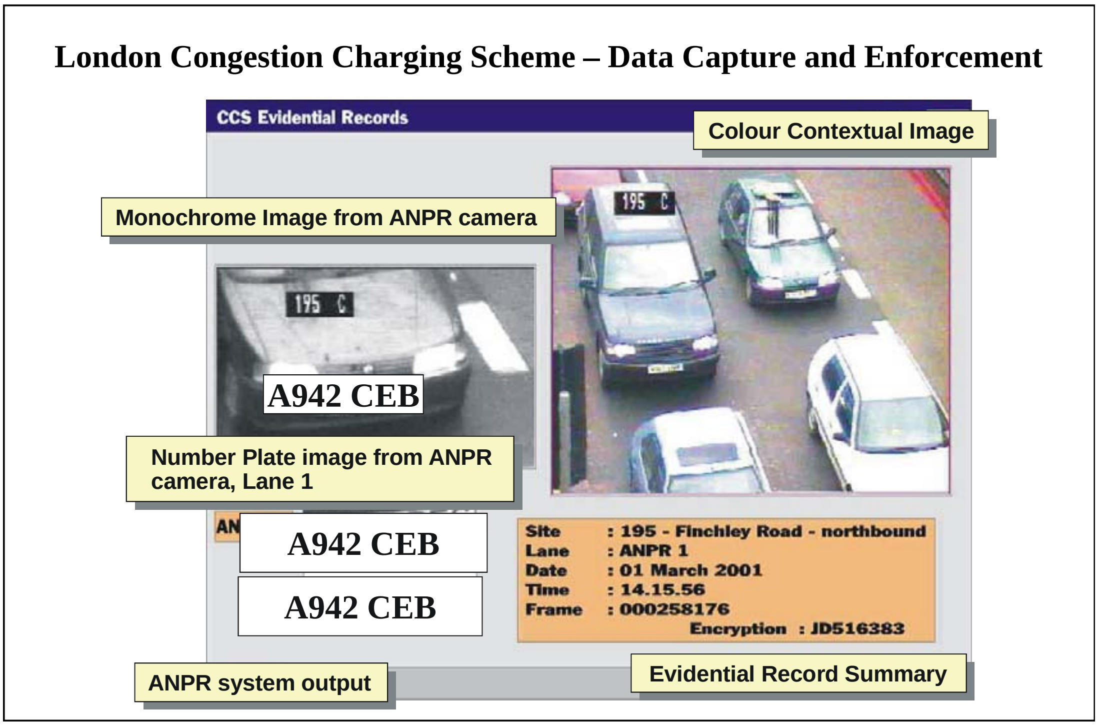


Figure 6.8 London congestion charging scheme – data capture and enforcement.

The scheme also adopted an area scheme approach rather than a cordon. In other words, rather than being charged when entering the designated cordon, the vehicle registered owner was subject to the congestion charge if the vehicle was on the public streets of London during the operating hours of 7:30 am to 6:30 pm, Monday to Friday. Residents who lived in the congestion charging area could receive a discount of 90% if they properly registered their vehicles with TfL. Taxi's, Motorcycles, buses and energy efficient vehicles received a 100% discount. TfL made the distinction in the Congestion Charging policy between exemptions and discounts that could be changed by TfL with adequate notice without changes in the legislation.

To make the Congestion Charging easy to pay and convenient to purchase, TfL established a number of authorised agents to sell the Congestion Charging in addition to:

- Purchase over the telephone or mobile phone to a toll free number (currently about 18% of average daily transactions).
- Purchase over the internet (currently about 26% of average daily transactions).
- Purchase from strategically placed kiosks at car park facilities (together with retail about 34% of average daily transactions).
- Purchase by sending details via facsimile to the Congestion Charging facility (less than 1% of average daily transactions).
- Purchase via a registered SMS account whereby the individual establishes an account and provides his personal details and credit card for which he receives an SMS unique account number that he references in his text message to the Congestion Charging facility. (Currently about 21% of average daily transactions).

Enforcement was processing approximately 26,000 Penalty Charge Notices (PCN) a month or about 1,200 a day. Of these, approximately 17,000 per month were paid on demand or within fourteen days to receive a 50% discount on the fine which was £80 and has now been increased in 2005 to £120. Of the remaining 9,000 PCNs approximately 7,800 appealed the PCN of which 51% in 2005 were found in favour of TfL. Approximately 1,200 per month paid after 28 days which incurred an additional penalty charge of £120 which has now been raised to £160.

6.4.2 Technology

The London Automatic Number Plate Recognition (ANPR) technology is a simple and direct technology application for a congestion charging scheme. It makes use of the existing supply of number plates already installed on every vehicle. It is, however, operationally expensive and restrictive to policy flexibility. ANPR technology is also blunt in its application as it requires the addition of internal screen lines to ensure that the scheme captures vehicles originating inside the zone and not crossing the cordon. The additional screen line stations, however, do provide the possibility to capture a number plate several times on a single trip across the charging zone.

In London, it is estimated that the system captures each number plate an average of 3.5 times. This means for the 330,000 trips generated each day in the charging zone, there are over one million images to be sorted and reconciled. This is part of the overall high cost of an ANPR system. The system actually eliminates all the plates associated with buses, taxis, and other discounted/exempt vehicles that are approximately 60% of the total number of images. Therefore there are roughly about 120,000 actual paying transactions or approximately 400,000 images.

One of the major issues with video image capture and optical character recognition is the accuracy of the system. The worldwide best accuracy for such a system is only about 84%-85%. London is actually experiencing a level of accuracy that is approximately 70%. Since it averages 3.5 reads per vehicle, the chances of a single good read are high. Unfortunately, so is the chance that the second and third read of the number plate is causing the system to look up and validate these misreads as number plates belonging to other vehicles. The handling and processing of these misreads generate higher manual processing costs. Unlike Information Technology costs, these manual processing costs are escalating every year as labour rates increase.

Another drawback on the technology scheme is the unitary charge for all vehicles. In Singapore, their PCU value or vehicle length charges the vehicles. In other systems, trucks and cars are charged differently. With an ANPR system, the number plate can make no distinction to the vehicle classification. Therefore the potential to charge by vehicle classification is not practical.

Yet one further issue with ANPR is the inability to chain or link the passage of the vehicle accurately across multiple cordons. The low read accuracy of an ANPR system would create too many mismatches of number plates and create too many errors in the billing and accounting process. This is one reason why the expansion of the London Congestion zone will only enlarge the original zone and not create new charging areas with multiple charges across multiple zones.

TfL is planning to extend the Charge Zone to including Kensington and Chelsea and to change technology to enable a more sophisticated scheme to be applied. Also TfL is looking at local congestion throughout London and may introduce satellite schemes in suburban centres.

London adopted proven Automatic Number Plate Recognition (ANPR) technology in its system. It uses no new technology for installation on vehicles, and was quick to install, albeit highly dependent on the reliability of the motor vehicle licensing database. As the design was simple and effective, it proved itself to be functional and effective.

Sixty percent of the plate images are discarded, as these are associated with exempt and discounted vehicles. One of the key issues is accuracy for ANPR. With the accuracy level of around 70%, 3.5 reads is necessary to get reliable results, but these also generate more images that may be inaccurate and need manual processing. ANPR is also expensive, due to the level of manual processing and checking, and amount of image data that needs storing and processed. It also suffers from a lack of flexibility, as it becomes extremely difficult to link the passage of a vehicle accurately across multiple points. This makes it difficult to effectively vary charges by location and time of day. As a result, TfL is now looking at implementing DSRC technology which has accuracy levels over 99.95%, is far cheaper to operate and more flexible (as the DSRC transponder can record events to be charged at different rates for crossing different points more effectively). Nevertheless, the Western extension of the congestion charging scheme will also use ANPR technology, with the minor change of having some automatic image processing at the camera site, rather than through a live continuous video feed (which will reduce costs).

6.4.2.1 Enforcement

The ANPR system is essentially an enforcement system. TfL uses the camera images to check against the list of subscribed users for the day and then sorts those that are violators. The number of violators has dropped since the second year of operation. If a violator is detected, a Penalty Charge Notice is mailed to the violator. The penalty can be discharged at a 50% discount if paid within 14 days of issuance. After that period, the charge is a full charge and as of 2005, the charge escalates on a monthly basis.

6.4.2.2 Privacy

As no new technology was introduced into vehicles, privacy concerns were focused upon the use of ANPR images which identify vehicle number plates, but not vehicle occupants. Central London already uses ANPR cameras for red light and bus lane enforcement, and CCTV cameras for security, therefore there were only limited concerns that the technology would be used to track motorists (as the images were only retained to ensure vehicles paid the charge and discarded once the charge was paid). The relatively low proportion of London residents who actually drive into central London during weekdays also meant that those affected were not high in number.

6.4.3 Pricing structure

The London congestion charging is an area pricing scheme in the city centre of London and is operated by the Transport for London (TfL) authority. Each vehicle passing the area border (cordon) into the city is charged £8 per day (there are exceptions for taxis, buses, and disabled people). The charge can be paid in advance, during the trip or later (surcharge). The enforcement system uses cameras distributed in the charging area.

The London scheme was predicted to have the following costs and revenues between 2000 and 2008, including three years of development and five years of operation, as indicated in Table 6.3. However, charge revenues have been lower and penalty revenues higher than anticipated. The 2004-05 budget year is projected to earn £190 million in total revenues (£118m in fees and £72m in fines), with £92 million in overhead expenses, resulting in £97 million in net revenues. This is up from the £78 million from the previous year.

Table 6.3 Congestion charging program projected costs and revenues.

	Total (NPV)	Per operating year
Start-up costs	£180M	£36M
Operating costs	£320M	£64M
Total cost	***£500M***	***£100M***
Charge revenues	£690M	£138M
Penalty revenues	£110M	£22M
Total annualised revenue	***£800M***	***£160M***

Source: London Congestion Pricing by Todd Litman, Victoria Transport Policy Institute in http://www.vtpi.org/london.pdf

6.4.4 Key management system issues

6.4.4.1 Costs

The London scheme cost £256 million. Of this, approximately £36 million was spent on public relations and £126 million was spent on traffic calming efforts on the inner ring road. The high O&M costs are associated with the handling of over one million images a day in the system of which only about 400,000 are associated with charging customers. There are approximately 120,000 charging transactions per day in the London scheme and the processing of this volume of images results in such a high O&M cost.

6.4.5 Urban form

The urban form of the centre of London provided a relatively straight forward solution to the scheme design. There was a natural bypass around the scheme in the form of London’s inner ring road, and the surrounding streets formed a natural outer boundary to the charge area. This was complimented by high levels of passenger transport which lends itself to being enhanced over time using the revenue generated.

London is a very high density city with a large central population and over a million jobs in the central business district alone, providing the city with unique transport difficulties at peak times. The aim of the congestion charge was to reduce the number of unnecessary trips and to force commuters to consider alternative forms of transport.

The London Scheme design is an area charge. All vehicles originating inside the zone or crossing into the zone are subject to the charge during the charging period. It is therefore simply a means of charging motorists for use of the central area during the designated hours.

Since its introduction, it has seen a large reduction in traffic and a modal shift to public transport services.

6.4.5.1 Network utilisation

The scheme reduced overall traffic volumes in the charge area by around 22%, whilst flows on the approach corridors reduced relatively little. Network utilisation in person trip terms was improved by the switch to bus and the efficient traffic flow.

6.4.5.2 Transport benefits

London has seen a credible shift in travel toward non-car modes, albeit with a large mode share already existing for public transport trips towards central London (over 80%). The increase in bus trips parallels critical improvements in services and reliability (though bus priority measures) improving the competitiveness of bus to car travel. Economic analysis indicated high returns.

6.4.5.3 Business impacts

There has been considerable controversy about the business impacts of the London scheme. Extensive research by TfL indicates a broadly neutral impact, as some businesses have gained (due to reduced congestion) others have lost (due to the nature of the business and location close to the edge of the zone). Claims of reduced business activity can be attributed to overall economic fluctuations that are independent of the congestion charge. The net impact of the London scheme is likely to be neutral and property values have not been negatively affected. The impact of the proposed Western extension to is less clear, as more retail activity in that area may be affected by the charge than in central London.

6.4.5.4 Environmental impacts

TfL reports a continued 12% reduction in emissions of NO_x and PM_{10} from road traffic within the charging zone, and little overall change on the Inner Ring Road. This sustained reduction in emissions is a notable improvement on the inner city health environment, and is also reflected in a reduction in CO_2 emissions. There is no evidence of any effect on ambient noise levels from the congestion charge.

6.4.5.5 Land use/transportation integration

Implementation of the congestion charge was done in co-ordination with relevant local road changes together with a significant boost to bus services and investment in bus infrastructure. No investment was made in rail and underground services due to the long lead in time and high capital cost for infrastructure. The relatively low level of net revenue was only adequate for investment in relatively low cost bus and road improvement schemes that could be implemented quickly. Environmental traffic management schemes, such as Trafalgar Square have been implemented in parallel.

6.4.6 Other characteristics

6.4.6.1 Implementing authority

Although the London area scheme was refined for several months after the start of operations, the scheme was essentially complete and ready for operations 18 months after the decision to implement.

The London scheme was procured and implemented by Transport for London (TfL), which was formed under the Livingston Government to be the transport authority for the Mayor. The Congestion Charging department is located under the Street Management Branch of TfL. TfL is also looking earnestly to new technologies to reduce the operating costs of the existing Congestion Charging scheme. Tests have been conducted of DSRC technology, GNSS technology and cellular technology. These tests are still ongoing and more evaluation and planning is forthcoming from TfL on how they would employ these new technologies in particular for the planned expansion to Kensington and Chelsea.

TfL is also contractually obligated to Capita, a private company, for the operations and data processing of the current scheme. Whilst that contract is active, there is little chance to change technology. Therefore, no new introduction of technology will occur until the current contract arrangement with Capita expires.

6.4.6.2 Financial

In 2004/05 the London scheme generated NZ$334 million in revenue from the charge and NZ$224 million in revenue from enforcement (fines and surcharges). From that revenue, it cost NZ$286 million to operate the system, leaving net revenue of NZ$272 million. In effect, the system generates most of its surplus from fining those who are non-compliant. With costs at around 46% of revenue, the London scheme is a high cost system. There are no statistics yet on the effect of raising the charge to £8 in 2005, although this is likely to have increased net revenue overall. The high net costs explain why Transport for London is investigating introducing DSRC technology (similar to that in use in Singapore) to reduce collection costs. Using a wholly ANPR system is cheap in terms of vehicle equipment (nil cost), but very expensive to operate.

6.4.6.3 Institutional

Implementation of the charge was possible due to legislative changes that allowed Transport for London and other British local authorities responsible for transport to implementation congestion charging schemes. That legislation puts a requirement on the revenue from the charge to be used on transport projects in the area that it is collected. Governance has been simple in that TfL is responsible for the scheme, for management of the arterial roads and for public transport (except surface rail). Co-ordination with local boroughs has been necessary in respect of installation of equipment and road changes related to local streets outside TfL's control.

While the charge itself is a simple £8 daily charge, there is administrative complexity in the discounts and exemptions, with 60% of all images from number plates applying to vehicles that are subject to discounts or exemptions.

6.4.7 Level of success

6.4.7.1 Evaluation of the scheme

These are alternative bypassing routes for those who do not need to cross the charging area. The affected drivers are switched to public transport or other modes or car sharing. Direct benefits of the London scheme were a 33% reduction in private car congestion in the first year, together with a reduction in traffic volumes of 18%. Vehicle speeds have also increased on average by 20%. Public transport buses have increased ridership by approximately 14% and average speed for buses measured prior to the Congestion Charging start and afterwards have been upward to 18%. Air and noise pollution have also been reduced as well as a general reduction in accidents in the Congestion Charging zone.

The scheme has been very successful in terms of reducing peak period car trips by 33%, a greater reduction than was predicted implying a higher price elasticity than was expected. The scheme has been criticised by at least one major retailer because of its possible adverse effects on retail activity in the city. However, as a congestion charge, it has had public support, was included upfront as a political objective of the Mayor of the city and has been successful in reducing congestion in the inner city.

The Mayor of London. Mr. Ken Livingstone has summarised the success of the London Congestion Charging as follows:

"Congestion charging was a radical solution to a long standing problem. It has helped to get London moving again after years of choking traffic. London has become the first of the great world cities to set about substantially reducing congestion in the central area." He has gone on to add that the *"Latest studies show that more than two thirds of Londoners now say that the scheme is effective in reducing congestion and nearly twice as many people support the scheme as oppose it."*

6.4.7.2 Summary

The conclusions for the London Scheme are:

- Simple all day area charge scheme.
- Easy to install and implement, generally successful operation.
- At £5 and £8 achieved congestion relief objectives.
- Flat charge applied to cars and goods vehicles; 60% of vehicles identified are exempt/discount (motorcycle, public transport, taxi, special).
- APNR-based system.
- System operations cost high, 46% of revenue due to technology (manual checking of images) and proportion of exemptions.
- Switch to DSRC or mixed DSRC/ANPR planned.
- 100% discounts to taxis and motorcycles resulted in increased mileage.

- Discounts to environmentally friendly vehicles may have to be reduced/withdrawn.
- Expansion to Kensington & Chelsea will increase (90% discounted) residential vehicles.
- Not suitable for large area application because of operating costs.
- Not suitable for multi-zone/cordon or variable vehicle types and time periods.

6.4.7.3 Traffic impacts

The London scheme has been focused on congestion reduction, and has been successful in reducing levels of congestion in the central zone. In 2005, TfL reports that delays to travel within the zone were around 30% less than that observed before the charge was introduced in 2002. This level of service has only been maintained by the recent increase in the charge from £5 to £8. There was a 33% reduction in private car traffic in the first year and an 18% reduction in overall traffic (note that buses, taxis and certain other categories of vehicles are exempt). Vehicle speeds have increased by 20%. These are within the expected results of introducing the scheme. London can be seen as a success in reducing congestion, within an area which contains some of the most congested roads in the UK. However, it should also be noted that the scheme is a blunt tool – un-congested roads in the congestion charge area are also subject to a charge, and the charge does not vary according to congestion. The periphery roads at the boundary of the zone have not experienced the predicted increases in congestion, as the reduction in trips to the centre has had a positive effect on traffic levels on those roads.

6.4.7.4 Operational performance

The London scheme saw a 37% increase in bus patronage in 2003 compared to 2002 (before the charge was introduced). This can partly be attributed to substantial spending on improved services and bus priority measures, but around half is attributed to the introduction of the congestion charge. There was a net decline in underground railway patronage, reflecting other factors (subsuming any diversion from car traffic) and no net increase in surface rail patronage. Overall around 35,000-40,000 daily car trips are estimated to have been replaced with public transport, and 5,000-10,000 daily car trips replaced by a shift to walking, cycling, taxi, motorcycle and car sharing.

As a comparison, a similar scheme in Edinburgh, Scotland, was intended to parallel a 50% increase in public transport capacity to handle a shift in mode, which was expected to be substantial in order to generate significant reductions in congestion.

6.4.7.5 Key findings

Key findings of the London Congestion Charging Scheme are:

- Simple design backed by very strong political leadership.
- Solid results in terms of providing immediate congestion relief to the cordoned part of the city.
- Technically simple and not necessarily very well designed.
- Orders of magnitude too costly to operate.
- In urgent need of a technical refresh.
- Scheme success independent of technical shortcomings.

6.4.7.6 Public acceptability

While opinion polls in advance of the introduction of the London scheme tended to see a narrow majority against it, subsequent polling (supported by the re-election of Ken Livingstone, as the Mayor responsible for the scheme) shows a majority in favour of it. Support tends to be due to the reduction of congestion and related improvements to public transport, while opposition is more closely related to the effects on some local businesses. Nevertheless, overall the London scheme demonstrates that scepticism before its implementation tends to be subsumed by recognition of the benefits of reduced congestion.

7. Application to the New Zealand Environment

7.1 Identified initiatives and concepts

The following section sets out the main initiatives and concepts identified through the evaluation of the example systems reviewed. This summary list provides the basis for consideration in a New Zealand context through the subsequent sections.

The main centres in New Zealand that are considered against these issues are:

- Auckland
- Wellington
- Tauranga
- Christchurch

7.1.1 Rome – access control and pricing

7.1.1.1 Characteristics of the urban form that have influenced the scheme design

The central city which is the primary focus for the scheme is characterised by a network of often narrow streets creating significant restrictions to traffic movements. These features, while being a principal cause of the problems identified have also been used in the development of the solution. The narrow network of streets provided the opportunity to establish zonal gateways to traffic access.

The Electronic Gateway system in Rome allows residents and key businesses and services to have free access to the city centre, while requiring all other vehicles to either register for access or bypass the designated area. It uses bypasses, park-and-ride, bus services and public transport from the edges of the zone to support access into the historic centres of the city, thereby reducing the impact of traffic pollution on the historic buildings. The Rome system is customised to the geographic layout and recognises the natural boundaries of various districts and access routes into and out of each zone. The electronic gateway scheme also recognises the need for special treatment or needs of medical or business related trips and provides free 'home' zone movement.

7.1.1.2 Use and modification of the existing e-toll systems to deliver an enforcement solution

The extensive scale of the Italian electronic toll system provided the opportunity to introduce transponder based verification using the widespread TELEPASS units. With over 5 million of these units in use across Italy they provide an effective means of accurate checking, reducing the number of transactions processed by the more labour intensive and less reliable ANPR systems. The system used in Rome is operated by Autostrade (the organization responsible for the national toll system). The use of this wider system as a base also provides significant economies related to scale; benefiting from the large scale management and distribution systems already in place for the toll systems.

7.1.1.3 Results of the measures against the main project objectives

The main project objectives for the Rome system were to reduce congestion and emissions in the central city through the management of access, while limiting inconvenience to those with legitimate access rights, and limiting adverse impacts on tourism and general business in these areas. The scheme is generally viewed as successful in all of these areas; it has resulted in a reduction in congestion in the order of 32%, while maintaining a relatively strong level of public support, as part of a wider transportation management package. The flexible access condition management facility ha played a major part in this success, allowing authorities to adapt controls to suit specific areas and issues.

7.1.1.4 Elements of the system that have been modified, or are planned to be changed in subsequent projects

The major aspect of the scheme that is being considered for change is the ability to charge vehicles by individual trip, an potentially by time and route. The only charging element at present is by annual permit, and current legislation does not provide for charging by individual trip; however, this is being reviewed as studies into the potential application of widespread individual trip charging are being undertaken.

7.1.2 Singapore road pricing

7.1.2.1 Characteristics of the urban form that have influenced the scheme design

Singapore's relatively small central business district suffered from a high degree of congestion due to the number of vehicles entering each day. This was despite a high degree of land use planning and public transport services.

Singapore is a high density city with a large number of jobs in the central business area, so it suffered from similar problems to London with the sheer volume of commuters trying to get to work in the central business district each day. The geographic layout of Singapore did not require any measures such as free bypass routes or alternatives to the congestion charging area.

The charging scheme was introduced to the area defined by the central business district in order to price vehicle owners out of that area, and has been very successful. Now an electronically controlled system, it is not hugely influenced by urban form as there are no distinct bypass routes or zones that can be used to free up the traffic flow. It is simply a method of preventing congestion in the city centre.

7.1.2.2 Impact and relationship between vehicle ownership restrictions and the operation of the scheme

Being an island state the Singapore scheme benefits from a relatively small and controlled vehicle fleet, which is closely controlled through restricted ownership legislation and pricing. The relatively small and controlled fleet provides for greater enforcement efficiency, and greater flexibility in the fitting of specific vehicle based units.

7.1.2.3 Migration to an ERP cordon system from the original area license scheme

The introduction of the current ERP system provided a more efficient and cost effective means of collecting and enforcing congestion charge in Singapore, but also provided for a more versatile charging mechanism. The change to a cordon based electronic system allowed charges to be varied across a range of time periods and routes, thus increasing the influence of these charges on travel behaviour.

7.1.2.4 How spot charges on routes outside the main charging cordon have been used

In addition to the main cordon boundary, charges are also applied on selected arterial routes approaching the central city. These charges are used to influence demand on these specific routes, mainly aimed at spreading peak demand an encouraging the more balanced use of these major routes.

7.1.2.5 Effectiveness of the system; how well it has met expectations

The migration from the previous license system to the full ERP facility has resulted in a more efficient system; and has improve the spread of peak demand. The flexible charging facility has been continually modified to adapt to conditions and is one of the main factors in the success of this system.

7.1.3 Stockholm congestion tax

7.1.3.1 Characteristics of the urban form that have influenced the scheme design

The urban form of Stockholm greatly influenced the final scheme design. The scheme's shape and form has been influenced significantly by the restricted transport corridors that are a result of Stockholm's location and limited water crossings. It is a cordon design with special concessions for bypass traffic. Bounded by water, there were no obvious bypasses so the strategic road network was used instead as the free bypass. Also the main freeway which is used by travellers passing though central Stockholm was exempt form the charge. This type of scheme is of particular benefit to cities that do not have natural bypasses, such as in the case of London's inner ring road.

7.1.3.2 Level of coordination between the increased public transport and the operation of the scheme

The Stockholm scheme was complemented by significant spending on improved public transport before the scheme was introduced, including new and extended bus services, and park and ride facilities outside the boundaries of the scheme.

7.1.3.3 Results of the measures against the main project objectives

As the Stockholm system was established as a trial, there were a range of studies carried out to assess its impact and effectiveness. It was anticipated that traffic reductions would be seen near the congestion-charge zone, with a relatively quick fall in the reduction as distances to the charge zone lengthened. Expected effects on accessibility were more doubtful than those for traffic volumes, with uncertainty about the connection between traffic volumes and travel times/congestion. Actual reactions in traffic volumes exceeded expectations with an overall reduction of 22%, accessibility improved with reduced travel times and an overall positive influence on reliability of travel times.

7.1.4 London congestion charging

7.1.4.1 Characteristics of the urban form that have influenced the scheme design

The urban form of the centre of London provided a relatively straight forward solution to the scheme design. The natural bypass around the scheme provided by London's inner ring road and the surrounding streets formed a natural outer boundary to the charge area. High levels of passenger transport were already present in the London central business district which lended themselves to being enhanced and upgraded over time with the revenue generated by the congestion charging scheme.

The London Scheme design is an area charge. All vehicles originating inside the zone or crossing into the zone are subject to the charge during the charging period. It is therefore simply a means of charging motorists for use of the central area during the designated hours. It has seen a large reduction in traffic and a modal shift to public transport services.

7.1.4.2 Development of bypass route and public transport enhancement

Prior to implementation significant work was done in developing the boundary routes to provide an effective bypass route for traffic, and to improve and extend public transport alternatives, with a particular emphasis on bus services on those routes that would benefit form reduced congestion.

7.1.4.3 Simple enforcement scheme concept

The scheme concept adopted, being a simple area charge enforced by number plate recognition, allowed the scheme to be implemented relatively quickly. With an extremely large vehicle fleet this simplified system eliminated a range of potential delays and costs associated with user interaction (e.g. requiring full fleet installation of units such as Singapore).

7.1.4.4 Planned future technology changes

Although the current system was an effective solution to deliver the initial congestion charging scheme it is recognized as having several limitations in its operation and future flexibility, and as a result alternative electronic systems are being trialled to replace and expand the scheme in future, including the use of DSRC units.

7.1.4.5 Effectiveness of the scheme

Just over a million people enter central London during a typical weekday morning peak, with over 85% of these trips by public transport. Prior to the congestion pricing program about 12% of peak-period trips were by private automobile. During the programs first few months automobile traffic declined about 20% (a reduction of about 20,000 vehicles per day), resulting in a 10% automobile mode share. Most people who changed their travel patterns due to the charge transferred to public transport, particularly bus. Some motorists who would otherwise drive through Central London during peak periods shifted their route, travel time or destination. Others changed mode to taxis, motorcycles, pedal cycles, or to walking.

The scheme has also significantly increased traffic speeds within the zone, with average speed during charging days increased 37%, from 8 miles-per-hour (13 km/hr) prior to the charge up to 11 miles-per-hour (17 kms/hr). Peak period congestion delays have declined about 30%, and bus congestion delays have declined 50%. Taxi travel costs also declined significantly (by 20-40%) due to reduced delays.

7.2 Auckland

There has already been a review into the future possibilities of congestion charging in the Auckland region, carried out by the Ministry of Transport.

7.2.1 Auckland road pricing evaluation study

Traffic congestion is a significant problem for Auckland, as it is in many large cities. Population and vehicle numbers in Auckland are growing and current projections show that, in spite of investment, by 2016 congestion in Auckland is unlikely to be reduced without additional measures. As a result, road pricing has been put forward by the Auckland Mayoral Forum and others in the region as a possible means of tackling congestion.

The Ministry of Transport's Auckland Road Pricing Evaluation Study was undertaken to examine road pricing and parking levies as a means of reducing congestion and raising revenue for investment in land transport. The study examined several alternative schemes, to consider if road pricing should be progressed further as a concept.

The study reviewed the schemes developed against NZTS objectives:

- assisting economic development;
- assisting safety and personal security;
- improving access and mobility;
- protecting and promoting public health; and
- ensuring environmental sustainability.

The study aims and objectives were:

- how much the proposed schemes would reduce congestion at peak times;
- what the positive and negative social, economic and environmental impacts of the schemes are, and the extent to which the negative impacts can be mitigated;
- whether there is a financial business case for each of the schemes, and assuming there is, how much net revenue might be generated over time;
- whether the schemes are technically feasible to implement;
- whether the schemes are acceptable to the public; and
- whether the schemes are consistent with central and regional government policies and development strategies.

The underlying causes of congestion in Auckland are multifaceted, relating to regional growth, geographical and capacity constraints, and a high reliance on cars. In 2004, the Auckland region had a population of over 1.3 million, or 32% of the national total, and a total vehicle fleet of 837,000 including 721,000 passenger cars or vans. The city's current population growth averages 1.5% a year, significantly higher than the rate for New Zealand as a whole (0.6%).

Auckland displays high levels of car ownership, comparable with the USA, Australia and Canada, and low public transport utilisation - currently around 7% of all trips during the peak period (compared with around 17% in Wellington, for example).

The combination of these factors has meant that Auckland's recent growth has outstripped the capacity of its transport system to cope with demand. In addition there is a gap to bridge to provide a realistic alternative to cars for much of the population.

The study developed schemes as follows:

(1) Single Cordon scheme - charging vehicles that cross a single, defined cordon (inwards travel only). Charges would not apply to travel entirely within the cordon.

(2) Double Cordon scheme - charging vehicles that cross either of two cordons (inwards travel only). Charges would not apply to travel entirely within either cordon.

(3) Area scheme - charging vehicles entering or travelling within a defined area.

(4) Strategic Network Charging scheme - charging vehicles that use motorways and major limited access arterial routes.

(5) Parking Levy scheme - parking levies for parking on public and private property within defined areas, in addition to any parking charges already in place.

In addition to these five schemes, consideration was also given in the project to:

(6) Toll Lanes - use of toll lanes on specific parts of the strategic (motorway) network.

(7) Full Network Charging scheme - charging for the use (by distance) of all roads within the network.

These two schemes were not progressed further.

7.2.1.1 Technology assessment

The proposed technology for all the schemes (excluding Parking Levy) in the Auckland Study was based on microwave based Dedicated Short Range Communication (DSRC) technology with on-board transponders, combined with video camera enforcement technology (Automatic Number Plate Recognition, or ANPR). The primary reasons for this choice are that it:

- provided for charge collection under free-flow traffic conditions;
- is proven technology;
- provided a low operating cost compared with other options; and
- provided payment methods for infrequent users.

This choice was aligned with the technologies and processes being developed for the Toll Systems Project (TSP) by Transit NZ and Land Transport NZ.

There were some differences between each of the four road pricing-based schemes, primarily in the number of tolling points required to cover each scheme.

The systems required for the parking scheme's revenue collection and enforcement differed significantly from those required for the other four schemes examined. Similar to the on-street parking scheme in Wellington, drivers would be required to display a valid coupon for parking in the Parking Levy zone between the hours of 6.00 am and 10.00 am. The potential difficulty with this parking scheme is that for it to be effective, the enforcement authority must have access to parking locations within all private premises in order to confirm that vehicles parked there are correctly paying parking charges.

While there are various technical solutions for the automated collection of parking charges, no system suitably covers the variety of parking ownership options or access regimes anticipated. The Parking Levy scheme generates the lowest revenues of the schemes examined, but benefits from lower operating costs and capital expenditure requirements than the other schemes. The Parking Levy scheme does not generate significant adverse social impacts and hence the mitigation costs are low as well.

7.2.1.2 Key findings

The Study only presented technical findings which are now underpinning a public consultation process. The key findings were:

- Congestion relief – Double Cordon most effective; Single Cordon and Area schemes next most; Parking Levy and Strategic Network schemes least.
- Revenues – findings as for congestion relief although Area scheme performs better than Single Cordon.
- Costs – based on DSRC technology, Area Scheme most cost-effective.
- Parking Levy – worst performer overall.
- Double Cordon Scheme was calculated to perform best overall and most effectively meet The New Zealand Transport Strategy Objectives.

7.2.1.3 Auckland growth

The Auckland Regional Growth Strategy (1999) recognises that a doubling of the Region's population by the year 2050 will have major impacts on the transport system and that major transport improvements are needed. It also recognises that these will have significant environmental and community implications. Car use is growing by around 4% per annum and vehicle use, especially under congested conditions, is a major source of pollution. Reducing or managing vehicle pollution requires a comprehensive strategy that addresses all of the elements illustrated below. The Auckland Regional Growth Strategy envisages a shift in land-use patterns toward a more compact urban form which focuses growth along passenger transit corridors and main arterial roads. The key elements of the Auckland Regional Land Transport Strategy (2003) (RLTS) include:

- Passenger transport investment in bus, ferry and rail. Key projects outlined in the RLTS 2003 include completion of the North Shore Busway, Rail Rapid Transit in the Western, Southern and Isthmus Rail Corridors and an extension to Manukau City Centre, and high quality ferry services linking coastal suburbs adjacent to the Waitemata Harbour with the Downtown Ferry Terminal;

- Completion of major roading projects within the Region's main transport corridor; and
- Travel demand management (TDM) measures to reduce the need for vehicle travel by influencing and changing travel behaviour - when, how or whether a person travels. Key TDM projects include developing initiatives to encourage ride-sharing (car pooling), supporting travel planning programmes and implementing strategies to improve walking and cycling in the region.

7.2.2 Urban form

The Auckland region's urban form, particularly its harbours and waterways, impose constraints on the transport system. This means the main transport links are confined to narrow corridors. For many trips, these constraints mean that few alternatives are available, and providing new routes or additional capacity has significant financial, environmental and community costs. Some major structures are operating at capacity in places where expansion would pose major difficulties.

The patterns of development in Auckland, combined with limited public transport, have fostered a strong reliance on private vehicles as the dominant mode of transport. This can be attributed to low-density development of the region, with peripheral expansion based on historically good accessibility by road, resulting in a central business district with a relatively low share of regional employment (currently 12% of total employment).

The low density city, with limited passenger transport, leading to reliance on the private car creates a need to be careful of the approach to implementing a road pricing scheme. This would need to be done in a way where those paying the charge would have a viable alternative. A method of doing this could be to start with a restricted scheme in areas where there are reasonable passenger transport alternatives.

As with the Stockholm example the shape and form of an Auckland scheme would be influenced significantly by the restricted transport corridors and it may be necessary to provide some specific free through routes and exemptions for users passing through charging zones.

7.2.3 Discussion

The key issues that would influence any potential congestion charging scheme for Auckland are most closely related to the Stockholm example. With congestion experienced most on primary arterial routes restricted by water crossings, the need to deal with traffic demands that are not only focused around CBD commuting but also a range of cross demand streams and through traffic demands.

The main objectives for an Auckland system would be to reduce congestion, improve trip time reliability and reduce emissions on the wider city through the management of peak demand, encouraging travel by alternative modes and at off peak times. To achieve this, a system with the ability to apply varying charges by time and route would be most likely, similar to the Singapore and Stockholm models.

The use of spot charges on routes outside the main charging areas as has been used in Singapore could also be used on selected arterial routes to influence demand and improve the balanced use of major routes.

With a relatively small and closed vehicle fleet in New Zealand, any scheme implemented in Auckland could benefit from some of the advantages experience in the Singapore example, such as greater enforcement efficiency, and greater flexibility in the fitting of specific vehicle based units.

As with the Stockholm example the shape and form of an Auckland scheme would be influenced significantly by the restricted transport corridors and it may be necessary to provide some specific free through routes and exemptions for users passing through charging zones.

A key issue highlighted by all of the examples is the need for targeted improvement of PT services, to provide an effective alternative. In Auckland these improvements would need to be significant, as existing bus and rail services are limited. However, the potential improvements in reliable bus services highlighted by London and Stockholm illustrate how the reduced demand and congestion achieved by a CC scheme can be used to free space on key routes that can then be used to provide reliable PT services.

7.3 Wellington

The Wellington regional transport network is characterized by an arterial road network of limited capacity and relatively high levels of PT use, particularly for peak commuter travel. Traffic congestion levels in Wellington are also lower than many comparable cities, in part due to being a compact city with short travel distances and a good level of connectedness.

However, imbalances in the current strategic roading network result in choke points from Ngauranga to the CBD in the north and between the airport and the CBD in the south. Road space in the CBD is also at a premium, and key strategic choices on the allocation of this space (between private cars, buses, cyclists and pedestrians) are a significant issue in the management of the central city network.

The most recent report on the Wellington Regional Land Transport Strategy indicates that, over the five year period from 1996 to 2001, the regional population grew by 2.5% while vehicle ownership increased by 6%. Total passenger movements grew by 25% between 1997 and 2006. Freight movements in the same period grew by 41%. Growth rates of total vehicle ownership by household are lowest in Wellington city, reflecting a trend for inner-city apartment living and proximity to employment. Conversely census data indicates that the highest rates and growth of vehicle ownership are in the more remote Wairarapa and Upper Hutt areas.

The highest rates of population increase continue in the western corridor serving Kapiti, while Wairarapa and Hutt Valley growth remains relatively subdued. A trend towards CBD living is expected to suppress growth in travel demand, but may be offset by the desire of many to live outside the Wellington urban area, increasing demand for peak-time commuter travel. The main routes to and from the region, SH1 and SH2, account for around two-thirds of passenger movements across the regional boundary. SH1 accounts for over 80% of total movements, highlighting its national importance.

Current initiatives to discourage peak-period car use (e.g. Travel Planning) rely mainly on a voluntary change in travel behaviour only and are anticipated to affect the demand for travel at the margins. Ultimately tolls, congestion pricing and parking fees have been identified as being needed to give travellers direct financial incentives to change their behaviour and ensure the network can efficiently accommodate this future demand.

Model forecasts indicate that by 2021 on the Western Strategic Network, vehicle hours (up 44%) will increase much faster than VKT (up 19%), while the number of vehicles will only increase by 7%. Also, more than 75% of the modelled network is anticipated to operate at LOS A or B (free-flow conditions or some minor delays) in the morning peak.

Initiatives encouraging the use of public transport especially for peak-period commuter trips remain important, but travel by car will continue to be the predominant form of regional transport. This is partly due to dispersed development in the Wellington region. Traffic volumes are expected to grow alongside economic activity. Increasing traffic demand will not be met without the construction of significant new infrastructure.

The current RLTS proposes to maximise road network efficiency while encouraging travellers to use public transport and active modes for appropriate journeys. Current measures are relatively passive and rely on voluntary behavioural change. It is likely that direct incentives, such as road charges, congestion pricing and tolls, will be required in future to change travel behaviour. While already a relatively high number of people make short trips by active modes, the current strategy aims to encourage significantly more trips by walking and cycling.

Supporting and advocating for integrated land use and transport planning through district plans, the Regional Policy Statement and the Wellington Regional Strategy will influence higher density development around public transport infrastructure. Specific integrated land use strategies that can encourage public transport use and other more sustainable modes of transport include downtown redevelopment and intensification, clustered suburban development, more compact residential development in and along public transport corridors, mixing land use activities (work, recreation, residential), pedestrian and cycle-friendly urban design, and the physical integration of new development with public transport services. This is planned to provide an environment for implementing other TDM strategies and ultimately reducing automobile dependence.

The Current RLTS includes objectives to:

- “Price the strategic transport network to encourage its efficient use”

- "Provide for additional pricing for the use of the roading network as a step towards ensuring all users pay the cost of their use, including externalities."
- "Undertake a more detailed investigation of the role of road pricing in the region."
- "Provide for pricing at peak times to manage road demand and reduce road congestion"

Greater Wellington Regional Council completed a study into the potential application of road pricing in 2005.

A technical group, comprising officials from the Ministry of Transport, Transit New Zealand, local authorities from the region (including the City Council) and GWRC, was set up to investigate whether a road pricing scheme would have benefits for the Wellington regional transport network and what form this would take. This study also examined what specific transport issues road pricing might address, the pricing level appropriate for Wellington, and what the impacts would be.

The study concluded that the key objective for road pricing should be to reduce congestion on the regional road network, and has investigated the use of cordon charges, as they are the most practical option available with currently proven technology. Other possibilities, such as full network charges with varying prices depending on route and time of travel throughout the network are recognised as options for the future, as technological advances take place.

The study suggests that a road pricing scheme can be designed for the Greater Wellington region which would be financially self-sustaining, reduce congestion and provide other environmental, economic, and safety benefits, with modest surpluses reinvested back into the transport network.

The Draft Regional TDM Strategy addresses road pricing by setting out the steps that will pave the way for the introduction of road pricing in the region. The strategy authorises the further work needed to fully investigate road pricing options for the region. Consideration of pricing proposals will form a separate process at a later stage.

Any timeframe for the introduction of road pricing would depend on;

- Whether and when the necessary changes to legislation might take place to allow for road pricing on existing roads in New Zealand.
- The completion of investigations into a road pricing scheme which will be appropriate for the Greater Wellington region and acceptable to its residents.

7.3.1 Urban form

The Wellington regional transport network is designed around the urban form of the region and is characterised by an arterial road network of limited capacity with relatively high levels of PT use, particularly for peak commuter travel. Traffic congestion levels in Wellington are also currently than lower than many comparable cities, due to the short distances involved in getting around and the well connected road and passenger transport network. There are however limited parking spaces available in the central business district and a relative increase in traffic congestion year on year.

As with the Stockholm and London examples the shape and form of a Wellington scheme would need to consider the need for bypass and/or through routes to provide access to state highways for some suburbs to the south and east of the city. When travelling into Wellington from the North, there is no choice but to travel through the city centre for access to both the hospital and the airport. Now the inner city bypass is open this may provide the desired free route through the city with consideration to airport and hospital access. A Stockholm type approach to charging vehicles by their trip terminating in the central business district would be facilitated from a technological point of view by Wellington's one way systems.

Although Wellington already experiences high levels of PT use, and has a relative well developed PT network, targeted improvements would still be required to ensure sufficient capacity and reliability of service.

7.3.2 Discussion

The key issues that would influence any potential congestion charging scheme for Wellington are most closely related to the Singapore example. Congestion is experienced most on primary arterial routes generated by traffic demands focused mainly around CBD commuting.

The main objectives for a Wellington system would be to reduce congestion, and reduce emissions on primary arterial routes through the management of peak demand, encouraging increased use of alternative modes and travel outside of peak times. To achieve this, a system with the ability to apply varying charges by time and route would be most likely, similar to the Singapore and Stockholm models.

The use of spot charges on key routes outside the main charging areas may have potential to influence demand and improve the balanced use of major routes.

As with Auckland, because of the relatively small and closed vehicle fleet in New Zealand, any scheme implemented could benefit from some of the advantages experience in the Singapore example, such as greater enforcement efficiency, and greater flexibility in the fitting of specific vehicle based units.

Similar to the Stockholm and London examples, the shape and form of a Wellington scheme would have to consider the need for bypass and/or through routes to provide access to state highways for some suburb to the south and east of the city.

7.4 Tauranga

Tauranga is one of the fastest growing cities and regions in New Zealand, it continues to grow more rapidly than forecast, placing increased pressure on infrastructure of all forms, including the transport network.

Tauranga is well served by high quality roads. The spaciousness of the town and the convenience of private transport are reflected in that more than half (52%) of those employed in Tauranga drive a private car, truck or van to their place of work. The second most popular mode of transport there was driving to work in a company car, van or truck (12%). The percentage figures for mode of transport as at 2001 Census remains remarkably unchanged from 1996.

Tauranga is a low-density city where traffic congestion and transportation has been shown in several recent surveys to be the number one concern for its residents. An important consequence of this is that it is difficult to provide an effective and efficient passenger transport system. People and businesses are expected to continue to rely on motor vehicles to access places where they live, work and play.

Tauranga City (along with close surrounding portions of the Western Bay of Plenty District) is the Bay of Plenty region's largest residential, commercial and industrial area. The predominant land uses in Tauranga City are urban, horticultural and grazing.

The city has a number of transport links including road, rail, air and sea and most notably the Port of Tauranga. There are 4,460 kilometres of road in the Bay of Plenty region. The roading network comprises state highways, local roads and Special Purpose Roads.

Many of the major arterial routes have record annual increases in traffic volumes. Congestion occurs between Mount Maunganui and Papamoa to and from the Tauranga CBD and Cameron Road. Significant congestion also occurs in Te Puke and Katikati and in particular spots between Bethlehem and Te Puma. Rotorua also has traffic growth with morning and afternoon peak congestion at Te Ngae, Fairy Springs and Lake Roads.

Growth has a major impact on the transport network; the eastern Bay of Plenty generally has sufficient capacity and services to manage any growth in the shorter term. Here, Whakatane is experiencing significant coastal growth on the northern side of the Whakatane River. There is an increasing amount of large format retailing with a new retail development currently underway on the western side of the Whakatane River. Future transport linkages and changes in travel demand will need to be considered.

The western Bay of Plenty sub-region has undergone significant growth which has placed a strain on the existing infrastructure, with the roading network in that sub-region becoming severely congested. The sub-region has previously had great difficulty in obtaining central government funding in order to complete the roading network within the timeframes that the infrastructure is required, due predominantly to the high costs of construction (including land costs, as well as weak ground conditions which require expensive engineering solutions) which has resulted in the previous benefit to cost ratio funding criteria working against the provision of funding. The sub-region is in a serious lag position owing to a lack of key arterial roads. The resultant traffic congestion is having a negative effect on the region's economy.

There are also social/environmental issues of concern as the large volumes of (primarily port-related) traffic traverse the regional network. For instance in Te Puke and Katikati the State Highway dissects the community and causes noise, vibration, health, safety and pollution issues for people shopping in these towns. As particular areas continue to grow the protection of key corridors becomes increasingly important. This means that potential transport corridors will need to be secured and protected to ensure that growth pressures do not encroach upon important corridor links that may be needed in the future.

Traffic volumes in the western Bay of Plenty sub-region have increased significantly along with the high growth rate. Many of the major arterial routes have record annual increases in traffic volumes.

This Demand Management Strategy for the Bay of Plenty region has been developed in order to identify packages of initiatives that are available to Environment BOP, TLAs, and Transit New Zealand. The strategy does not recommend the introduction of congestion charging, or tolling existing roads, in spite of the fact that the preferred strategic option is to manage demand. While it has been possible to show through transport modelling undertaken that introducing a charge to manage demand could have an influence on the infrastructure demands in the region, this needs to be considered alongside the positive and negative economic, social and environmental impacts of such a charging regime to determine whether it would in fact be beneficial in the Bay of Plenty. There are also no legal tools currently in place to support congestion charging.

7.4.1 Urban form

The urban form of Tauranga is characterised by many waterways, which gives choke points for peak hour traffic such as the Tauranga harbour bridge. Due to Tauranga's low density arrangement, people of the region continue to rely on the motor vehicle to get around. This causes significant traffic congestion and is affecting the regions economy. There is not the high level of public transport use as seen in the Wellington region. The low density arrangement of Tauranga is further characterised by a small central area and no distinct employment centre. Origins and destinations are wide and varied across the region.

Tauranga City is the Bay of Plenty region's largest residential, commercial and industrial area. The region has undergone significant growth which has placed a strain on the existing infrastructure.

As with the Stockholm example the shape and form of a Tauranga scheme would be influenced significantly by the restricted transport corridors and it may be necessary to provide some specific free through routes and exemptions for users passing through charging zones. Thus, it may also be necessary to charge vehicles by trip destination and time of day to encourage flexible working hours and reduce unnecessary trips during peak hours. However, the complexity created by the varied origins and destinations with no distinct central business district, could prove too complicated when considering a road pricing scheme for Tauranga. This may therefore not be the approach for managing the increasing congestion in the region.

7.4.2 Discussion

The key issues that would influence any potential congestion charging scheme for Tauranga would be similar in some respects to Auckland, and most closely related to the Stockholm example, but with some potential application of principles adopted in the Italian systems.

With congestion experienced most on primary arterial routes restricted by water crossings, the need is to deal with traffic demands that are not only focused around CBD commuting but also a range of cross demand and seasonal streams, and through traffic demands.

The main objectives for a Tauranga system would be to reduce congestion, improve trip time reliability and reduce emissions on the wider city through the management of peak demand on specific routes, encouraging travel by alternative modes and at off peak times. To achieve this, a system with the ability to apply varying charges by time and route would be most likely, similar to the Singapore and Stockholm models.

The seasonal tourist demands that have a significant impact in the Tauranga area could also lead to consideration of the Italian access zone approach where tourist demand is managed through a range of special conditions and provisions.

The use of time and season based spot charges on routes external to primary charging areas, as has been used in Singapore, could also be used on selected arterial routes to influence demand and improve the balanced use of major routes.

Targeted improvement of PT services would need to be developed as existing services are limited. However, the developing strategic network in Tauranga, coupled with reduced congestion on those routes targeted for charging would be likely to provide opportunities for improved services to be developed.

7.5 Christchurch

Historically Christchurch has had a very good transport system, with little congestion, good access, and freedom of movement.

In recent years traffic demand has grown in the region driven by a combination of increased economic activity, steady population increases, decreasing household size, increased travel demand (especially social and recreational trips), land use changes and an increasing, high vehicle ownership rate.

The main initiative that are being promoted as a means of addressing congestion in the region are based on reducing travel demand, include reducing the need to travel (for example home shopping and home based work), shortening trips (by providing for needs close by - land use issues), encouraging high occupancy (by car pooling, parking and traffic management incentives for high occupancy vehicles), space efficient vehicles (such as cycles or buses, through promotion or advantages provided for these modes over lower occupancy vehicles), encouraging walking and changing the time a trip is made to less congested times.

Traffic congestion on a number of city streets is already creating problems, particularly during commuter periods and is predicted to get worse, with the Greater Christchurch area having the highest rate of car ownership in New Zealand.

By 2011, Christchurch expects a threefold increase in congestion on the roads from 1996 levels unless significant improvements are made to the transport system and demand can be managed. This level of congestion is expected to seriously affect quality of life and create economic and environmental impacts for the entire region.

Analysis using the Christchurch Transportation model has indicated that congestion in Christchurch will increase substantially from 28 lane kilometres in 1996 to 78 lane kilometres by 2011.

Key transport routes in and out of Christchurch, such as across the Waimakariri River to the north and along Main South Road and Blenheim Road to the southwest are already congested.

This affects residents of, for example, Kaiapoi and Rolleston who work in the city, and also delays and increases costs for businesses such as farmers and manufacturers trying to get goods to economically important destinations such as Christchurch International Airport, the Christchurch Saleyards and the Port of Lyttelton.

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Appendices

1 Rome – Access Control and Pricing

2 Singapore Road Pricing

3 Stockholm Congestion Charge – Summary

4 London Congestion Charging

Appendix 1

Rome – Access Control and Pricing

Appendix 1: Rome – Access Control and Pricing

A1.1 Rome transport challenges

The metropolitan area of Rome covers 5,352 km^2 and has a population of 3,981,000. Rome is the administrative, political capital of Italy and accommodates high levels of activity in the service and tourist sectors. These activities are generally concentrated in the geometric centre of Rome, particularly in the historic sections that are focused mainly in the central city.

The relatively high proportion of private vehicle traffic in Rome is particularly difficult to manage, given the urban fabric of Rome, with narrow and uneven roads, and a limited and incomplete hierarchy.

The City's transport administration (The Rome Municipality) has targeted these problems with a range of 'sustainable mobility policies' and ITS initiatives, aimed at reducing congestion, limiting the impact of air pollution, improving trip times and reliability, and reducing current high transportation costs.

A key initiative is the "Piano Generale del Traffico Urbano" (PGTU – Urban Traffic General Plan). This plan has been developed to tackle the mounting problem of public transport, mobility, and transport related emission. The key elements of the PGTU are:

- Updating of the road classification according to the relative function (i.e. pedestrian, local traffic, main traffic).
- Transport demand policies and control systems (e.g. controlled access zones, parking pricing).

In order for the PGTU to succeed broad local acceptance was essential, and the administration adopted a collaborative approach, with the PGTU being developed as an element of a broader 'Master Plan', including an Integrated Transport Plan, Urban Parking Plan (PUP) and the other local and regional plans.

The PGTU divides the metropolitan area into zones consisting of a central area and three concentric rings. Permission to enter is given free of charge to residents within the LTZ (Limited Traffic Zone). Other users may obtain permission to circulate and park in the LTZ area if they fall into certain categories, such as doctors with offices in the centre. Non-residents are required to pay annually the equivalent of a 12 month public transport pass in order to obtain a permit for the access control area.

A1.2 Objectives

The main objectives of the system are, to reduce the number of vehicles accessing LTZ to those strictly necessary, and to promote the use of public transport routes away from the historic centre, in conjunction with the adoption of a fully integrated public transport fare system.

A1.3 Technology

Enforcement of the system is automated, using a combination of toll tag technologies and license plate recognition. The system is operated in conjunction with the Italian national highway toll system, using the standard Telepass microwave tags used for electronic toll payment.

Although the system does not currently operate on the basis of payment per trip, this approach is being considered for future evolutions of the scheme, along with other similar schemes in Italian urban centres, subject to changes in current legislation and policies.

A1.4 Pricing objectives

The overall goal of the system is to produce a mechanism that encourages modal shift away from private transport to public transport.

The reduction of congestion and lowering of pollution through road pricing is expected to improve the health conditions of residents and visitors to the restricted area. When the scheme was first introduced the historical centre suffered from high levels of pollution – in particular benzene, CO, NO and PM_{10}. The improvements already achieved are expected to improve attraction to the historical centre and, subsequently, economic growth.

Rome's fiscal objectives for road pricing are to dedicate all revenue to mobility related projects. After operating for one year, the ACS+RP system showed a 20% reduction of traffic flows as well as a 6% increase of public transport.

A1.5 Consultation and measures

Throughout the project continuous information interchange with citizens and representative associations was targeted at the evaluation of five major areas, with emphasis on users:

- User reactions (driving, attitudes, behaviour, choices made).
- Car user evaluation (acceptance, preferences).
- System design (basic feasibility evaluation of the system).
- Traffic effects (also using traffic models).
- Environmental effects (in relation to benzene directive).

A1.6 Key areas of interest

Key areas of interest with this system, in the context of this research study include:

- Impact of restricted urban transport network on the development and operation of the scheme.
- Use and modification of the existing e-toll systems to deliver an enforcement solution.
- Results of the measures against the main project objectives.
- Elements of the system that have been modified, or are planned to be changed in subsequent projects (e.g. trip based payment and the main reasons for this).

Appendix 2

Singapore Road Pricing.

Appendix 2: Singapore Road Pricing

Since 1975 Singapore has priced vehicle entry into its central business district. The main purpose of this pricing has been to manage traffic volumes rather than the collection of revenue, with prices adjusted as traffic conditions have changed.

Road pricing is viewed in Singapore as only one part of an eclectic approach to transportation management. Singapore practices both price discrimination and two-part pricing. Different types of vehicles pay different charges for using priced roadways, and charges vary by location and time of day.

Further, in 1990 the government announced a ceiling on the total number of vehicles allowed in the city-state. People must bid for rights (represented by "certificates of entitlement") to buy a limited number of new vehicles each year, with the number of new vehicles allowed being related to the scrap rate for older vehicles. The economic argument for this measure is that, at least in the context of the technology in use, the transaction costs of implementing congestion pricing throughout the entire country would be too high, and that even though it is not sensitive to circumstances of time and place, a limit on the total number of vehicles has benefits in terms of general traffic control that outweigh the welfare loss that it otherwise entails.

A2.1 Objectives

The main objective of the Singapore scheme has been the control of congestion levels in this densely populated centre. Although associated environmental benefits have been a consideration, the economic impacts of congestion have been the main driver of the original scheme. The pay-as-you-use principle of ERP makes motorists more aware of the true cost of driving, optimising road usage with charges levied on a per-pass basis and rates set based on traffic conditions at the pricing points.

A motorist is encouraged to decide whether to drive, when to drive and where to drive. This allows motorists to choose a different route, mode of transport, time of travel, or to not travel at all. Those who choose to pay and stay on the road will enjoy a smoother, less congested ride.

A2.2 Technology

The Electronic Road Pricing (ERP) system uses a dedicated short-range radio communication (DSRC) system to deduct ERP charges from CashCards. These are inserted in the In-vehicle Units (IUs) of vehicles before each journey and each time a vehicles passes through a gantry while the system is in operation, the ERP charges will be automatically deducted.

A2.3 How it works

Whether the vehicle is a foreign-registered one or registered in Singapore will decide what rules apply to the vehicle.

All motorists have to pay a fee for driving into and out of Singapore. If you drive a Singapore-registered vehicle, you pay tolls using a Cashcard. If you drive a foreign-registered vehicle, you pay tolls and a vehicle entry permit (VEP) using an Autopass Card.

Singapore citizens, permanent residents (regardless of their place of residence), student pass holders and residents of Singapore are NOT allowed to use or keep their foreign-registered cars and motorcycles in Singapore.

Any employment pass and work permit holder, who is neither a permanent resident nor a resident of Singapore, may drive his/her foreign-registered car and motorcycle in Singapore only if certain conditions are met.

Visitors driving into Singapore in foreign-registered vehicles must use an Autopass Card, a stored-value smart card, to pay their VEP fees and/or toll charges at the Singapore land checkpoints.

VEP fees are calculated on a daily basis. You do not have to pay VEP fees on Saturdays, Sundays and all Singapore Public Holidays.

A2.4 Ten VEP-free days

All drivers of foreign registered cars and motorcycles can drive into Singapore for a maximum of 10 days in each calendar year without paying VEP fees.

After the 10 VEP free days have been utilised, VEP fees for subsequent days are chargeable if you continue to use or drive your foreign-registered car or motorcycle during VEP operating hours.

Toll charges still apply. Toll charges are calculated on a per trip basis. You have to pay toll charges on arrival and departure from Tuas Checkpoint but only on departure at the Woodlands Checkpoint.

A2.5 Key areas of interest

Key areas of interest with this system, in the context of this research study include:

- Impact and relationship between vehicle ownership restrictions and the operation of the scheme.
- Use and modification of the ERP systems to deliver an enforcement solution in this environment.
- How the effectiveness of the system has been evaluated over time; how well it has met expectations and been modified or adjusted to improve effectiveness.
- The challenges and opportunities presented by variable pricing and the Singapore experience with this issue as technologies have advanced.

Appendix 3

Stockholm Congestion Charge - Summary

Appendix 3: Stockholm Congestion Charge - Summary

Stockholm City Council has conducted congestion charge trials. These trials started in August 2005 with the introduction of extended public transport, and in January 2006 the congestion charge regime was introduced.

The trials concluded on 31 July 2006 and a referendum on the permanent implementation of congestion charges was held in conjunction with the general election in September 2006. The outcome of the referendum was not available at the time of preparation of this report.

Although a Stockholm City Council scheme, all of the cost associated with the trial was covered by national government.

A3.1 Purpose

The primary objectives of the trials were to reduce congestion, increase accessibility and improve the environment. The purpose of the (full-scale) trials was to test whether the efficiency of the traffic system can be enhanced by congestion charges. In addition there were several secondary objectives, including:

- Reducing traffic volumes on the busiest roads by 10-15%.
- Improving the flow of traffic on streets and roads.
- Reducing emissions of pollutants harmful to human health and of carbon dioxide.
- Improving the urban environment (as perceived by Stockholm residents).
- Providing more resources for public transport.

From January 2006 through to the end of July 2006 the trials were evaluated continuously against these objectives.

A3.2 The scheme

Ahead of the introduction of charges public transport was extended, with 197 new buses and 16 new bus lines. This provided an effective and fast alternative for travelling at peak times from the municipalities surrounding Stockholm into the inner city. Where possible existing bus, underground and commuter train lines were reinforced with additional departures.

To facilitate travelling a large number of new park-and-ride facilities were built in the region, and existing park-and-ride facilities made more attractive.

The charging system had a single zone boundary encircling the inner city of Stockholm. Charges were made for passage into and out of the inner city on weekdays from 06.30 to 18.29, with higher charges during peak periods. The maximum charge was SEK 60 per day (approximately $NZ11.00).

The payment technology used was based mainly on DSRC transponders and provided for the free flow of traffic through charge points.

Some exemptions for special road user groups are provided, including;

- Emergency vehicles
- Vehicles registered abroad
- Diplomat vehicles
- Military vehicles
- Buses with a total weight of at least 14 tonnes
- Eco-friendly vehicles (electric, ethanol, biogas)
- Taxis
- Disability and social services, etc. transportation service vehicles
- Motorcycles
- Holders of disabled person's parking permits may apply for exemption for one vehicle

A3.3 Scheme boundary

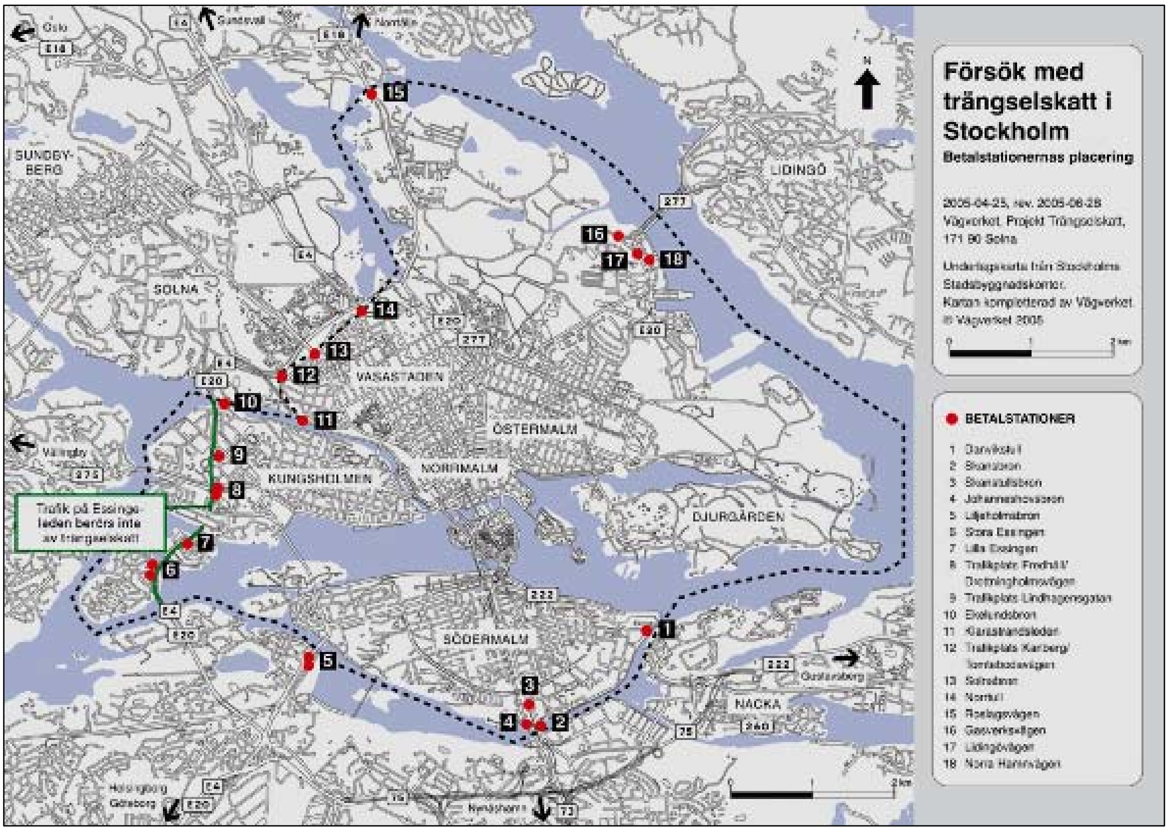

Figure A3.1 Stockholm congestion charge scheme boundary.

Journeys between Lidingö and the rest of Stockholm County were exempted, provided the vehicle passed two separate charging points, of which one included one of the charging points at Ropsten, and the time between the passages did not exceed 30 minutes.

A3.4 Charges

The congestion charges applied on weekdays from 06.30am to 18.29.There were no charges on evenings, nights, Saturdays, Sundays, public holidays and the day before a public holiday.

Charges were not imposed for the Essingeleden ring road during the trials.

The City of Stockholm set up an implementation office, the Congestion Charges Secretariat, whose mandate is to plan, implement and evaluate the congestion charges trials in collaboration with the relevant stakeholders.

A3.5 Key areas of interest

Key areas of interest with this system, in the context of this research study include:

- How the scheme and technologies used have been designed to address the specific challenges of Stockholm; including in particular the ring route and specific cross city exemptions.
- Level of coordination between the increased PT and the operation of the scheme.
- Results of the measures against the main project objectives.
- Elements of the system that have been modified, or are planned to be changed in subsequent projects (e.g. trip based payment and the main reasons for this).

Appendix 4

London Congestion Charging

Appendix 4: London Congestion Charging

A4.1 Introduction

The go-ahead for the London congestion charging scheme was given in February 2002 and was driven by a number of factors.

- London suffers from the worst traffic congestion in the UK and amongst the worst in Europe.
- Drivers in central London spend 50% of their time in queues.
- Every weekday morning, the equivalent of 25 busy motorway lanes of traffic tries to enter central London.
- It has been estimated that London loses between £2–4 million every week in terms of lost time caused by congestion.

The congestion charging zone is shown in figure A4.1 below:

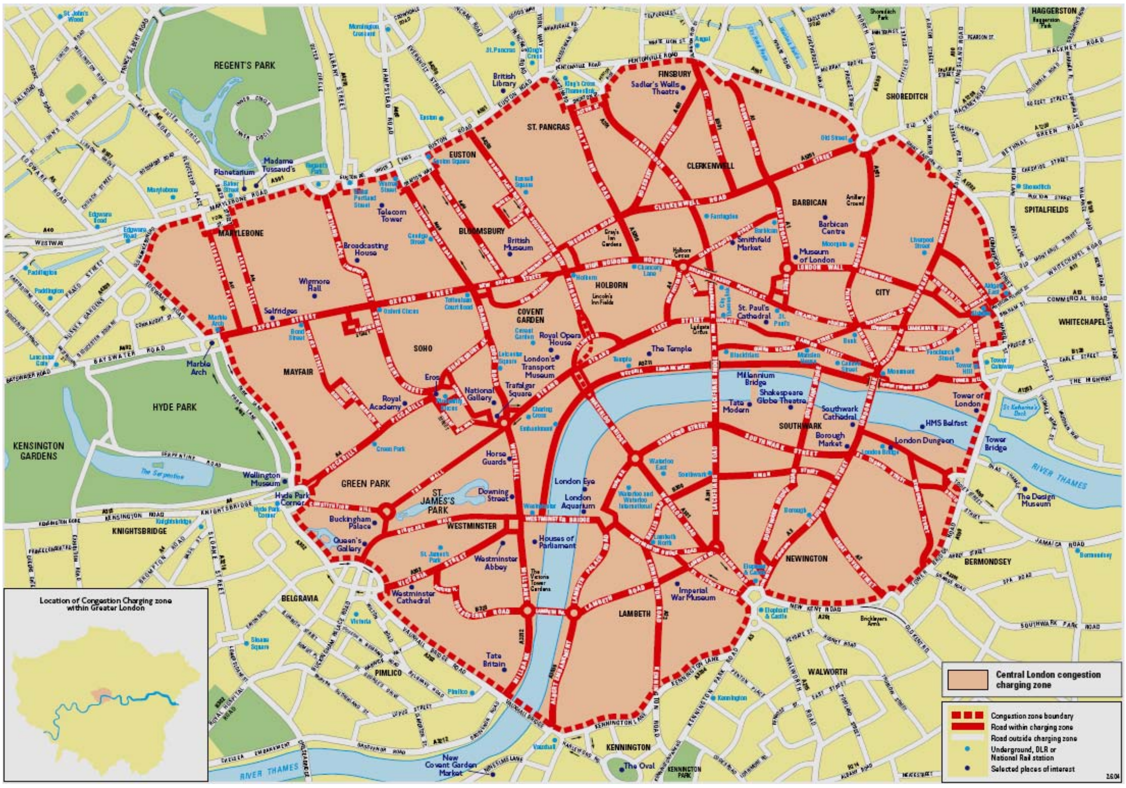

Figure A4.1 London congestion charging zone.

The scheme has been varied since its inception and has recently had the charge increased from £5.00 to £8.00. It is also now providing discounts for users of fleet vehicles and for users who pay monthly or annually.

A4.2 Objectives

The Mayor of London has a transport strategy that was published in 2001 ahead of the introduction of congestion charging. It outlines several key points that will be addressed.

- Reducing congestion.
- Reducing through traffic.
- Further encouraging the use of public transport in central London.
- Benefit business efficiency by speeding up the movement of goods and people.
- Create a better environment for walking and cycling.

The key objective for the congestion charging scheme was to tackle the major congestion and parking problems facing the capital.

A4.3 Technology / model

There were extensive technology trials performed in 2004 comparing DSRC, GPS mobile positioning, and Automatic Number Plate Recognition (ANPR) technologies. The result of these was that ANPR was chosen.

There is a network of 203 enforcement camera sites, not just on the boundary of the charging zone, but sited throughout the zone. Cameras are situated at all entry and exit points to the charging zone. There are an additional 64 monitoring camera sites in central London. They are CCTV-type cameras, similar to those used for ports, airports and the City's 'ring of steel', providing high quality video-stream (analogue) signals to an Automatic Number Plate Recognition (ANPR) computer system. Every single lane of traffic is monitored at both exit and entry points to the charging zone.

A4.4 How it works

Vehicle owners are required to pre-register, online or by telephone, their intention to enter the zone by creating an account. Entering the congestion charging zone without pre registering is an offence. Entry and departure from the zone is then monitored by the network of ANPR cameras.

Congestion charging will result in substantial decreases in traffic according to modelling predictions.

Inside the zone:

- traffic would be reduced by 10 - 15%
- queues would be reduced by 20 - 30%
- traffic speeds would be increased by 10 - 15%

Outside the zone:

- traffic may increase on orbital routes by up to 5%
- traffic would be reduced on radial routes by 5 - 10%
- overall reduction in traffic by 1 - 2%

In addition, all the revenues generated will be invested in transport in London for at least ten years.

A4.5 Data use

The primary use of the data collected is the enforcement of vehicles entering the zone and monitoring of medium to long term traffic trends to assess the effectiveness of the scheme.

It encourages the use of other modes of transport and is also intended to ensure that, for those who have to use the roads, journey times are quicker and more reliable.

A4.6 Key areas of interest

Key areas of interest with this system, in the context of this research study include:

- The ongoing impact of the scheme on the congestion problems in London, how this is being monitored and used to plan future evolutions of the system.
- Planned future technology changes and how these are being considered and evaluated.
- How the effectiveness of the scheme has been evaluated and how these compare with original expectation.
- Elements of the system or policies that have been modified since project inception, and their effects on the scheme.