3 SCHEME DESIGN

3.1 INTRODUCTION

It can be argued that decision makers do not always realize the critical nature of the relationship between scheme design and performance for road pricing. Typically, scheme design was only ranked sixth out of nine in importance in the CURACAO User Needs Assessment Questionnaire (UNAQ) survey. Addressing this is therefore a priority, and it is hoped that this chapter will give valuable reflections on features of scheme design that help ensure effectiveness and aid acceptance from practical and political perspectives.

Scheme design is a complicated and time consuming process involving planners, various technical experts, stakeholders and the local political decision making system. This chapter will first discuss general requirements and design criteria, then discuss how to approach scheme design within an overall urban strategy and finally discuss key features and examples of scheme designs.

It is important to recognize that the planning and decision making process for any scheme may take considerable time, and that there is a need to be flexible and adjust to changing requirements during the implementation phase, and indeed after. For instance, the 1991 single cordon system in Trondheim was developed during a six year long planning and decision-making process. During these years, several decisions were made concerning the principles of pricing, the design of the cordons and the charge structure, the use of revenues, and the division of responsibility between different institutional levels. The initial system was fully electronic with non-stop lanes from the start, and it had time-differentiated charges for tag holders.

Already in 1996, the City Council decided on a revised system that divided the city into six zones, and traffic crossing the boundaries was to be charged. Two main objectives motivated this change which came into operation in 1998: Firstly, more revenues were needed to fulfil the transport investment plans. Secondly, a more equitable scheme was called for (interpreted as a system charging a higher proportion of the motorists). This way of thinking was taken one step further in 2003, when an almost complete inner ring close to the city centre was added. This system was in operation until the end of charging 30 December 2005.

Scheme objectives and constraints, as outlined in the previous chapter, clearly have a strong bearing on the details selected for scheme design. A reduction in congestion has been the main objective in the examples we have seen of large scale implementations in Singapore, London and Stockholm. The raising of net revenues for use on new transport infrastructure or public transport is often a strong second objective, and indeed the first objective in the examples of the Norwegian toll rings.

3.2 WHAT ARE THE IMPORTANT REQUIREMENTS OF ANY ROAD PRICING SCHEME?

3.2.1 The Smeed criteria

The nine design criteria set out as important in the Smeed Report of 1964 are still valid as an aid for today's designers:

1. Charges should be closely related to the amount of use made of the roads
2. It should be possible to vary prices for different areas, times of day, week or year and classes of vehicle
3. Prices should be stable and readily ascertainable by road users before they embark upon a journey
4. Payment in advance should be possible although credit facilities may also be permissible
5. The incidence of the system upon individual road users should be accepted as fair

6. The method should be simple for road users to understand
7. Any equipment should possess a high degree of reliability
8. It should be reasonably free from the possibility of fraud and evasion, both deliberate and unintentional
9. It should be capable of being applied, if necessary, to the whole country and to a vehicle population expected to rise to over 30 million

According to Richards (2006), Vickrey (1992) has added two other useful criteria:

1. Charges should not be used as a means of redistribution, on the grounds that there are more efficient and equitable means of achieving redistribution
2. All vehicles should be charged without exception, both on the grounds of avoiding disputes over qualifications for exemptions and to ensure that the true cost of operating vehicles is understood, even if it is only an accounting transfer

Other requirements that have emerged include easy accommodation of occasional users and visitors, the permission of users to check the validity of charges incurred, multi-lane operation and effective enforcement to be operable under all reasonable traffic, lighting and weather conditions.

3.2.2 How do people deal with Scheme Complexity

The various scheme design elements once combined could lead to a permutation of potentially very complex schemes. Some recent research carried out by Bonsall *et al* (2007) recognised the potential conflict between theoretical desirability of differentiation in charging systems and the ability of the travelling public to respond to them effectively. Using both surveys from a variety of transport sectors on pricing and results from theoretical literature; they concluded that it might not be realistic to expect drivers to be able to or even willing to calculate the precise charges that they would incur for their trips. In particular, people might underestimate distance when distance pricing is used as they do not perceive distance as accurately as time.

Even under a simple charging scheme such as in Singapore, unless a driver is one who travels on a fixed route at a fixed time, he is unable to calculate the precise charges each day. The charges vary, and although they are advertised regularly in the newspapers and media, drivers do not keep a copy of the charge table in their vehicles.

3.2.3 What are the key scheme design lessons from CUPID/PROGRESS?

CUPID was a Thematic Network supported by DG TREN of the European Commission. An important part of CUPID was the liaison with eight demonstration cities constituting the PROGRESS project (Bristol, Copenhagen, Edinburgh, Genoa, Gothenburg, Helsinki, Rome and Trondheim). A brief summary from the Executive Summary of the CUPID Final Report of answers to key questions related to scheme design is given below:

WHO SHOULD BE CHARGED?
Cycles, buses, emergency vehicles and disabled drivers should be exempted. Motor-cycles are often exempt for practical reasons.

WHERE SHOULD ROAD USERS BE CHARGED?
This was found to depend largely on urban form and the scheme objectives. If the main objective is to reduce congestion (maximising economic efficiency), then city centre or citywide, using either area licensing or cordon charges. If main objective is “mobility management”, then metropolitan area, using distance-based charging.

HOW SHOULD ROAD USERS BE CHARGED?
In general Dedicated Short Range Communication (DSRC) solutions were preferred. Vehicle Position Systems (VPS) is envisaged to be a useful alternative in the future.

HOW SHOULD ENFORCEMENT OPERATE?
Most cities felt that Automatic Number Plate Recognition technology was the optimal approach.

WHEN SHOULD ROAD USERS BE CHARGED?
Working weekdays, either "all day" or morning peak only. Charging in the evening depends on characteristics of evening traffic in the city concerned.

HOW MUCH SHOULD BE PAID?
€1-3 was suggested by cities with fixed priced schemes. Charges of between €0.01 and €0.6 per km were suggested for distance-based charging (when feasible), with the figure depending upon the size of the charging area.

HOW SHOULD REVENUE BE USED?
Should be used within the transport system (i.e. "hypothecation"). Widespread interest in investing revenue in public transport.

HOW SHOULD PRIVACY BE ENSURED?
All cities were concerned, but privacy did not appear to represent a fundamental barrier.

WHAT IS THE BEST WAY TO INTRODUCE ROAD PRICING?
All cities recommended that it should be part of a package of measures, and most cities recommended that infrastructure investment should be included in the package.

3.3 HOW CAN A SCHEME BE DESIGNED?

3.3.1 Pricing as part of an overall urban strategy

The DANTE project concluded in its summary report that reductions in car use are most likely to occur where a series of policies are in operation which reinforce each other. Other studies e.g. PROSPECTS, OPTIMA and FATIMA have also recognised the need for synergistic combinations of measures via a package approach to combine restraint on car use with promotion of alternatives.

The DANTE project also highlighted two potential problems. Firstly purely restraining car use might lead up to freed-up road space being used by others. This finding points to the need for a coordinated and consistent approach to achieve the best possible results even when road user charging is in place. Secondly, in some cases any travel reduction 'gains' are overwhelmed by travel growth in a relatively short period of time.

Road charging is not a panacea for transport problems and works best when part of a package of complementary and reinforcing measures that combine to achieve the objectives of the policy. These measures include more traditional forms of traffic management, using information technology to direct traffic, public transport improvements, walking and cycling enhancements, parking policies and modification of road infrastructure (Short, 2004).

Road pricing is increasingly being seen as part of an integrated strategy, in which individual policy instruments complement one another, or overcome the barriers to the implementation of other instruments. Recent research has suggested that integration can be achieved by reinforcing the benefits, reducing political and financial barriers, and compensating losers. It highlights that road pricing is able to reinforce the benefits of other types of policy instruments, while at the same time generating income to contribute to their costs. At the same time, other policy instruments can help to reduce the political unacceptability and adverse distributional impacts of road pricing (May *et al*, 2006).

As a result of interest in the development of integrated transport strategies where policy instruments are combined to complement each other and to achieve improved performance against a set of policy objectives, May *et al* (2005) applied an optimisation procedure to identify optimal strategies for packages of urban transport improvements to achieve various policy objectives. One of the conclusions of this study was that well performing strategies for a given set of European cities tended to include peak period cordon charges to enter the city centre. These cordon charges charge traffic for crossing the boundary into the charged area and this boundary serves to separate the charging area from the rest of the network.

3.3.2 Judgmental approaches to cordon design

The performance of any road pricing cordon or boundary will be affected by the combined effects of a reduction in traffic entering the area and an increase in traffic bypassing it. While congestion will be reduced within the area, it might well be aggravated outside it. Since these conflicting impacts will depend on both the topology of the road network and the pattern of demand for its use, it is difficult to offer general advice on cordon location. All that is known is that the benefits of road pricing, usually measured in terms of welfare economic impacts, are critically dependent on the choice of cordon (May *et al*, 2002).

Yet it has been observed that there has actually been very little technical advice on the best location for such boundaries. Most designs are based on a mix of professional and political judgment, with little or no assessment of whether alternative locations would be more effective.

A study on judgmental approaches to cordon design among six UK local authorities at different stages in the development of road pricing proposals is reported in May *et al*. (2002). It involved an initial questionnaire and a subsequent in-depth interview with a responsible transport planner. The study covered the context of the proposal, the objectives of the scheme and the detailed design process. A general finding was that the context and objectives had little impact on detailed design. The key elements in the design process were to avoid adverse impacts and to gain public acceptance. The practical aspects were generally less important. The criteria which emerged from the survey are listed below, under the same three headings.

- Avoid adverse impacts
    - Alternative routes for drivers who want to bypass the charged area
    - Avoid dispersion of environmental or congestion problem to other areas
    - Should only cover area having good public transport service
    - Interchange facilities outside the cordon
    - All entries to the charge area should be charged
    - Entry points should not be visually unattractive
    - Cordon should be placed at boundaries between land use types

- Gain public acceptance
    - Simple and easy to understand cordon and charge structure
    - Charge levels to be perceived as fair and acceptable by the public
    - Avoid the problems of local and commercial inequities
    - Traffic which contributes most to congestion and pollution should be charged
    - Traffic which is of least benefit to the area should be charged
    - The city's residents should not be charged
    - People from low income areas of the city should not be charged

- Practicality
    - The number of charging points should be minimised
    - The design should limit the scheme's operating costs
    - Avoid types of road that cannot be tolled
    - Avoid areas or locations that may cause communication problems for the system
    - Locate cordon wholly inside the city authority area

3.3.3 Theoretical approaches to cordon design

There has been some work carried out at ITS on Cordon Design and to some extent this represents the state of the art of research at present. Two separate methods have been developed thus far. The first of these uses an application of genetic algorithms to represent design options and to highlight those which are most effective. The second provides a short cut method which is analytically less complex and involves the planner directly in the design process. Both have been shown to provide two- to three-fold improvements in performance over judgmental designs. They are not, however, intended to supplant the need for professional and political judgment; rather they are offered as design tools which will help to focus such judgment on those designs which are likely to be technically the most effective.

Further details on current research on optimal designs by a genetic algorithm based approach and a “short cut” approach are given in Appendix A in this report.

3.4 KEY FEATURES AND EXAMPLES OF SCHEME DESIGN

Key characteristics of road pricing schemes include type of charging regime, the level and structure of the prices, where and when the prices are levied, and the extent to which prices and/or exemptions are allowed to vary by class of users (DfT, 2008).

3.4.1 Type of charging regime

Pricing schemes can broadly be classified into four types:

- Point based charges (e.g. tolls to cross a bridge or to enter a section of motorway)
- Cordon based pricing: A charge is levied when a cordon is crossed, and may vary with time of day, direction of travel, vehicle type and location on the cordon. There could be a number of cordons with different prices.
- Area licence based pricing: A charge is levied for driving within an area during a period of time. The price may vary with time and vehicle type.
- Distance or time based pricing: Price is based upon the distance or time a vehicle travels along a congested route or in a specified area, and may vary with time, vehicle type and location.

There is a need to distinguish between charging that are more for toll collection rather than for road pricing since their objectives are not similar. In a simple point based charging scheme for crossing a bridge, the operator is happy if more vehicles use the facility because it means more revenue. In road pricing systems, the operator will be quite happy if the less numbers of vehicles use the road because it will reduce congestion.

In real applications, there can be combinations of the above generic charging schemes. For example it is possible to combine say, a distance based pricing on a zonal basis. In this method, charges vary not only by distance travelled but also by spatial location of travel.

Distance based pricing is potentially the most effective type of road user charging. However, it will require Vehicle Positioning Systems (VPS), and the complete technology is not yet available commercially for full scale implementation in an urban environment and is currently restricted to inter-urban Heavy Goods Vehicles (HGV) charging in Austria, Germany and Switzerland.

Multi cordon or zonal based charging, like the scheme implemented in Trondheim in 1998, could be viewed as a stepping stone towards distance based charging. However, the Trondheim scheme had charging for crossing a zone boundary in one direction only, and charging was limited to a maximum of one per hour. Obviously, in such a scheme the charge could be levied to every vehicle crossing the boundary, both inwards and outwards. The charge could be varied depending upon factors such as time, location and vehicle type.

Neighbouring urban sub regions would be encircled by cordons, and trips taking place within a cordon would be uncharged.

Concentric cordons, like the inner and outer toll ring proposed for Edinburgh (Saunders, 2005) are an alternative variant of a multi-zonal system. Conceptually, more than two cordons could encircle a city centre, and charges could be varied according to a range of factors.

Cordons are simply combinations of point-based charges located to form a continuous boundary around an area. Point based charges are reasonably commonplace, but they are generally limited to specific small locations and not spread across the network. In modern times, estuary crossings in the UK such as the Forth Bridge, Severn Crossing and the Dartford Tunnel all involve some form of point based charges.

It is possible to combine point based charges with a cordon or area pricing system such as in Singapore where there are charges for expressways as well as for crossing into the Central Business District.

With regard to the selection of charging regime, complex schemes are likely to be more expensive to implement and run and harder for travellers to use. The problem of system complexities was discussed in more detail in Section 3.2.2.

The scheme design also involves the choice of charging technology, which, as illustrated in the Hong Kong case, can be critical for the acceptance and image of the scheme. The choice of technology will also depend on the complexity and requirement of the charging structure, e.g. time-based or complex zoning.

3.4.2 Level of charge

A flat price may be more acceptable and straightforward to implement. On the other hand, letting the prices vary in accordance with time and location of congestion, will improve the efficiency and benefits of the scheme. Also it is important to allow for some flexibility over time. Travel patterns will evolve and, consequently, the demand for road space will vary. A relatively fixed system may become inefficient over time.

With respect to actual levels of charges, the Central London congestion charge is probably the most expensive with a basic daily charge of £8 since July 2005. When the scheme was introduced in February 2003, the daily charge for driving or parking a vehicle within the congestion charging zone between 07:00 and 18:30 Monday to Friday was £5.

The 2007 permanent Stockholm congestion tax is an example of charges that are highly time differentiated. The tax per passage is SEK 10, 15 or 20 depending on the time of day. The highest amount charged is during rush hours 07:30 to 08:30 and 16:00 to 17:30. A maximum amount per vehicle and day is set to SEK 60.

With the exception of Trondheim, the Norwegian toll rings have no time differentiation during charged periods. In Oslo, the basic charge for a light vehicle is NOK 20, in force 24 hours a day and all days of the week. In Bergen the charge level is currently NOK 15 for a light vehicle and in force 24 hours a day Monday to Saturday. During 2005, the last year of operation of the Trondheim charging scheme, the basic charge (manual payment) was NOK 15 for all hours of operation (06:00 to 18:00 Monday to Friday). However, electronic tag holders enjoyed rebates on the basic charge, which depended on the time of day and the amount having been prepaid. Prices per passage (NOK) for light vehicles are shown in Table 3-1. Heavy vehicles pay twice these amounts.

Table 3-1 Charges for Trondheim Toll Ring

The Trondheim toll ring	06:00-10:00	10:00-18:00
Manual payment (basic charge)	15.00	15.00
Prepayment of NOK 500	12.00	9.00
Prepayment of NOK 2500	10.50	7.50
Prepayment of NOK 5000	9.00	6.00
Post payment by bank giro:		
5 or less passages/week	15.00	12.00
10 or less passages/week	13.50	10.50
More than 10 passages/week	12.00	9.00

Rates in Norwegian Kroner (NOK)

The scheme objective and equity factors clearly dictate whether there are discounts available for the scheme. Since the primary objective in Norway is generally to raise revenue for highway construction, providing discounts for an increased number of passages does not conflict with the scheme objective.

On the other hand, since the objective is congestion reduction in Singapore, the electronic road pricing system sets tolls that vary with travel time but does not provide discounts for multiple crossings. One of the shortcomings of the early ALS scheme (Holland and Watson, 1978) was that a one-time payment offered multiple entries. Hence there was no incentive for the driver to plan his subsequent journeys once he had bought the licence. At present, following the introduction of electronic toll collection, the charges are revised regularly and differentiated by vehicle type. An example of how the charge is differentiated by time period and by vehicle classes is shown in Table 3-2. The ability to employ differential pricing is a function of the technological elements of the scheme design. Similar time-differentiated toll charges apply on SR91 in California, USA.

Table 3-2 Abstract of charges on one major Singapore arterial during AM peak hours

Time Slice	*Motorcycles*	*Cars/Light Goods/Taxis*	***Heavy Goods Vehicles***
7.30am -7.35am	$0.25	$0.50	$0.75
7.35am -7.55am	$0.25	$0.50	$0.75
7.55am -8.00am	$0.25	$0.50	$0.75
8.00am -8.05am	$0.75	$1.50	$2.25
8.05am -8.25am	$1.25	$2.50	$3.75
8.25am -8.30am	$1.25	$2.50	$3.75
8.30am -8.35am	$1.25	$2.50	$3.75
8.35am -8.55am	$1.25	$2.50	$3.75
8.55am -9.00am	$1.25	$2.50	$3.75
9.00am -9.05am	$1.00	$2.00	$3.00
9.05am- 9.25am	$1.00	$2.00	$3.00
9.25am -9.30am	$0.75	$1.50	$2.25

Rates in Singapore Dollars (SGD$3≈ £1)
Source: http:// www.onemotoring.com.sg accessed April 2007

In theory it is possible to estimate the speed flow curves using traffic engineering relationships and apply economic theory to derive optimal charges that make drivers fully cognisant of the road user charge. The methods for doing so have been documented in the literature since Walters (1961) applied this to deriving optimal charges for the Lincoln Tunnel in New York.

In practice, for reasons of political acceptability, charges are generally derived through a trial and error process in view of information gathered during the scheme development stages. In addition, the charge level would depend on the objectives of the scheme and the associated price elasticities. This is the view articulated for example in the UK Transport Select Committee (Transport Select Committee 2006) which stated that

"If the Government led with the introduction of a national distance charge as the core component of the price structure, it would then need to work with local authorities and other

stakeholders to agree the calibration of variations, and establish where and when they should apply."

Once the charge has been set, it is not easy to make immediate changes if they are found to be excessive or too low, because authorities will be unwilling to admit that the charges they defended were far from correct. An example can be provided by the 1975 Singapore ALS. The initial objective with a daily charge of $3 for cars was to get a total reduction of traffic for all vehicles of 30 % during the peak hours. However, there was a reduction of 44 % which invited adverse comments of an "overkill" situation (McCarthy and Tay, 1993; Phang and Toh, 1997).

3.4.3 Variations by vehicle type

Charges are not differentiated by vehicle type in the London and Stockholm examples. The Norwegian urban charging schemes have always charged heavy vehicles (gross weight more than 3.5 tons) twice the amount chargeable for light vehicles. An equitable way of charge variations by vehicle type will be using the passenger car equivalents if road pricing is meant to reduce congestion. Hence vehicles pay in relation to their dynamic occupation of space on the road. This was the basis for determination of charges in Singapore (Olszewski and Xie, 2003).

3.4.4 Exemptions

Public service vehicles like waste management, fire services etc are almost always exempted, as well as vehicles for disabled drivers and electric vehicles. Rules for exemptions are strongly related to obtaining acceptability, and for example the London scheme seems to have a large proportion of exempted vehicles for this reason.

Extensive exemptions have operating cost implications, and may undermine to a certain degree the objectives of a scheme. It can be argued that all vehicles that contribute to congestion should pay. For example in the London scheme, motorcycles and mopeds are exempted. This led to a large increase in the number of these two wheel powered vehicles entering the charging area following the introduction of the scheme (Santos, 2004).

On the other hand, there are issues of spatial equity that are inextricably linked to scheme design. Residents in the London charging zone receive a 90% discount (Santos, 2004) while residents in the charging area in Singapore do not receive any exemptions. An interesting case in point reflecting the public's concern regarding their interpretation of spatial equity and its relationship to exemptions can be seen in the Edinburgh congestion charging proposals (Saunders, 2005). In Edinburgh the proposed urban congestion pricing scheme involved two cordons. The outer cordon was to be located just inside the city's bypass in an attempt to control the increasing congestion on the edges of the city; while the inner cordon was designed to protect the World Heritage Site located in the inner city.

The Scottish Executive's guidance required that fair treatment be a high policy goal; however, the City Council included an exemption from the outer cordon charge for city residents who lived outside the outer cordon. (Saunders, 2005) During the formal public review process the issue of geographic equity was raised and a recommendation was made to remove the outer cordon exemption for city residents living outside the outer cordon in order to achieve fair treatment. (Saunders, 2005). While the City Council agreed to many of the public's recommendations, they did not remove this particular exemption. The referendum went to the public in February 2005 with the exemption still included, and the referendum failed. While the inclusion of the exemption for outer city residents was not the only reason for the cordon pricing initiative's failure, it did exacerbate public concerns about the equity of the scheme.

3.5 WHAT ARE THE IMPLICATIONS FOR OTHER THEMES?

- **Objectives:** Scheme design should be derived from the overall objectives of the scheme. A scheme design aimed at maximising revenue from a cordon charge would be theoretically very different from one that is aimed at curbing congestion (Sumalee, 2004b). Demand management and revenue generation are the two prominent objectives of existing schemes.
- **Technology:** Different charging regimes require different technologies. For instance DSRC and ANPR technologies are most appropriate for cordon or area based charging, whilst distance based charging would require GNSS technology. Technology has implications for scheme design in terms of the possibility for the tolling authority to fine tune the toll levels.
- **Business Systems** : One issue not addressed in this chapter is the link between scheme design on the one hand and administration and enforcement on the other. While the evidence on this is limited, some practical advice can be gleaned from existing schemes and taken up in Chapter 5.
- **Prediction:** It is recognised that some schemes cannot be modelled within some tactical models. It is still relatively difficult, given the state of the art, to model say an area license scheme without the use of tour based representation.
- **Appraisal/Evaluation:** The appraisal/evaluation process of a scheme focuses on assessing the scheme to consider how well a particular scheme design has fulfilled the objectives. Information obtained through this process can be used to iteratively refine scheme design elements such as charge levels, location of toll points and mitigation measures to counter negative impacts.
- **Economy:** More research is needed to understand the nature of land use and the wider economic implications of various scheme design options. For example, the exact location of tolling points on the network might affect businesses since some businesses located inside the cordon might lose out due to reduction in shopping traffic.
- **Environment:** The impact of scheme design on the reduction and relocation of traffic will directly affect the environment.
- **Equity:** This bears close relationship to acceptability. Accessibility to jobs and opportunities might be increased for disadvantaged groups travelling by public transport since they benefit from reduced congestion; on the other hand, disadvantaged groups that are captive to the car may be made worse off.
- **Acceptability:** Decision makers focus on the simplest designs, and may be overlooking designs which achieve greater economic benefit. On the other hand, acceptability of the scheme may dictate a simpler design. Hence cities might approach the scheme design process with “one hand tied behind their backs” and scheme design is subject to practical acceptability constraints. On the other hand, extensive exemptions, to cater to acceptability and for political expedience, might reduce the effectiveness of the scheme in meeting other objectives. Further discussion of this issue can be found in Chapter 11.
- **Transferability:** Scheme designs that are considered optimal will vary from region to region. This is due to factors such as network topology, local geography etc. However, the process of generating insights from various prediction/appraisal tasks will be similar and the ensuing iterative scheme design refinement can be applied.

3.6 WHAT ARE THE RESEARCH GAPS?

While there is a general understanding of the range of design options for road pricing schemes, guidance on good practice in scheme design is still limited. This is true both of specific road pricing schemes and of their incorporation into wider transport strategies. This is an issue which interacts with several subsequent themes, including technology, prediction and appraisal, acceptability and transferability.