Road User Charging and Electronic Toll Collection

Chapter 2: *From Policy to Technology*

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2.1 Historical context

Charging for road use is by no means a new concept. Toll roads can be traced back to at least Roman times, when travelers paid a fee for using a road/track maintained (and in many cases protected) by the authorities of the day. Across the world today toll roads make up a significant proportion of the arterial road networks, and in many countries the tolling of estuarial crossings is commonplace. Tolling is essentially the recovery of a fee from users of a facility to cover the capital building, operation, and maintenance costs of the road [1]. In many cases the responsibility for toll roads have been given over to private operators to design, build, finance, and operate (DBFO), or to operate as a concession for a particular period of time [2]. Other schemes may have a more demand management–led set of objectives, such as managing travel demand by car and the consequential congestion when demand (for travel by car) outstrips the supply (of roadspace) [3, 4].

A variety of electronic technologies in the 1970s and in the mid- to late 1980s [5] were developed and tested with the aim of speeding up the collection of tolls. Subsequently, microwave tags and radio frequency identification (RFID) devices were developed, so that queuing at manual tollbooths could be reduced or completely eradicated, allowing drivers to pass through toll plaza facilities without stopping, their transactions being made automatically using appropriate road charging equipment across the roadside-to-vehicle communications link [6–11].

The first commercial use of e-tolling technology was in 1987 when the Ålesund Tunnel in Norway was equipped with a simple identification (ID) tag using microwave technology. A profusion of similar tag-based schemes was introduced in the United States, Southern Europe, and Japan over the next few years [12]. Chapter 8 describes a number of these schemes in more detail. These schemes were largely limited to single-lane, drive-through tolling arrangements, since the technology could not yet meet the challenge of free-flow, multilane charging that would be required for urban road user charging without the need to build conventional toll plaza infrastructure [13]. The introduction of new technology allowed Trondheim in Norway [14–16] in the mid-1990s, and Singapore [17–21] in the late 1990s, to introduce electronic toll charging rings that were used for revenue raising, and had the ability to influence travel demand and reduce peak-hour congestion. However, these technologies were quite limited in what they could deliver.

In the United Kingdom, innovative road pricing trials were undertaken in Cambridge from 1992 to 1994, which used a set of microwave beacons, delivered by the Automatic Debiting and Electronic Payment for Transport (ADEPT) project.

Microwave beacons were placed in a cordon around the city to trigger a congestion meter in the vehicle, which then charged users based upon either the distance their vehicle traveled within the cordon or on the level of congestion measured by the in-vehicle meter, which had a sensor connected to the vehicle’s odometer [22–24]. It took another 10 years to see further developments in innovative road pricing in the United Kingdom: first, with the launch of the Durham access control system in October 2002 [25], and second, with the launch of the London Congestion Charging

Scheme in February 2003 [26–28]. The success of these schemes, and the potential for developing significant ‘‘intelligence’’ in the transport infrastructure and within vehicles themselves, encouraged the U.K. government to consider the introduction of a national distance-based road pricing system in the future. It is expected that future intelligence will enable innovative forms of road pricing that could have a significant demand-restraining effect, providing an additional tool to deal with traffic congestion [29]. The two currently preferred charging technologies are DSRC (microwave in-vehicle tags communicating with roadside antennas), and satellite-based location systems that locate the position of the vehicle on an onboard digital map (the vehicle is then appropriately charged, based upon cordon-, point-, or distance-based charging). Mobile wireless networks, RFID, mobile phone technology, or camera-based automatic number plate recognition (ANPR) solutions may also offer options that are appropriate to support future nationwide road pricing solutions [30].

This chapter will attempt to provide an overview of tolling and road user charging technologies: how they have evolved, what they can do, what we can learn from the developments and schemes of the past, and where the future will take this important tool for the traffic management and ITS business sector.

2.2 Charging for Road Use

2.2.1 Context

The trend in transport policy in many parts of the world, particularly in Europe and the developing economies, is increasingly towards the recovery of construction, operation, and maintenance costs of new roads by the use of tolls or road use charges. These charges have been also extended to the existing ‘‘free’’ road stock[1]. There has been a reemergence on the political agenda of many governments and city authorities for some form of road use pricing to address the management of traffic demand [31].

It is desirable to introduce an efficient charging mechanism that is able to automatically levy the tolls and road use charges from the drivers, that is, without the need for the drivers to perform any action, other than those associated with normal driving activities. The system should also enable the collection of these charges at normal highway speeds outside of the specific toll plaza environment, and without the need for the physical separation of lanes, as is the constraining requirement with conventional toll collection facilities.

It is infeasible and unworkable, in many locations, to implement manual means of fee collection, in which traffic must be segregated into lanes to allow drivers to stop their vehicles and pay a fee, either manually to an operator, or by inserting coins, cash, or a card into a collecting machine. Manual collection would require the building of plazas (such as across North America, in Europe, and increasingly in Asia), which are costly both to build and operate, and require a substantial land area. Such

[1] As we know, nothing in life is for free. By free road stock, one means roads that are not directly charged for at the point of use through tolling or road user charges, but rather financed through general taxation, vehicle and fuel tax, shadow tolling or other economic mechanisms.

manual collection plazas may only be built when a new road is planned and sufficient land is purchased. It is generally not practical to retrofit a toll plaza to an existing road. This is especially true in urban areas, due to restrictions on land use the likely creation of additional congestion due to queuing at toll lanes the increase in noise and air pollution and the inflexibility of the charging system that could be employed. Newly designed toll roads generally have a limited number of entry and exit points, while existing ‘‘free roads’’ usually are not so restricted, which creates an additional difficulty when introducing urban road charging. It is now mainstream for traffic management theory to consider the potential for introducing some form of road use fee that directly relates to the amount of use of the road. The introduction of these charges may have a restraining effect on the traffic demand, as well as having the obvious attraction of raising relatively large amounts of capital that may be put back into improving the transport infrastructure, supporting public transport, and generally offering alternatives to travel by private car. In the United Kingdom, this policy was enshrined in the Transport Act 2000, which specifically requires local authorities that implement local road user charging or private nonresidential (PNR) parking schemes to reinvest any revenue raised in local transport schemes. It is, however, likely that any national charging scheme will be a tax rather than a locally hypothecated charge. The use of conventional stop-and-pay plazas is unattractive to implement such a policy of efficiently charging motorists thus, some form of nonstop automatic charging of road users must be considered.

We need to clarify what we mean by tolling and road user charging.

(a) Toll Collection

The collection of a toll for the use of road infrastructure is the most common form of pay-as-you-drive fees. A private concessionaire or a government agency levies a fee to recover the costs of the building, operating, and maintenance of the infrastructure. This became a significant instrument for road building after World War II in Southern Europe, the United States, Japan, and Southeast Asia [32–34]. Other countries, including the United Kingdom, Australia, and the Scandinavian countries, until recently had limited the use of tolls to estuarial crossings and other major bridge and tunnel infrastructures. This division has now been blurred, as we shall see later.

Motorway schemes using electronic devices to automate existing toll collection facilities are quite widespread and include numerous examples in the United States, in the ASECAP countries in Europe, in new multilane tolling schemes on Toronto’s Highway 407, and in the Melbourne City Link [35].

(b) Road User Charging

The concept of direct road user charging is not new. Road user charging has been considered for many decades as a tool for managing congestion and raising revenue, although few trials and implementations have actually taken place, until the recent success of the Singapore and London schemes, among others. Pigou (the father of welfare economics) first proposed the economic theory on which the principle of road use pricing is based in 1920 [36]. Vickrey [37] and Walters [38] further developed the theory, relating it specifically to road traffic. The Smeed Report [39] in 1964 first officially acknowledged the technical possibilities of direct pricing at the point of use. A great deal of research has been subsequently undertaken, and a number of attempts to introduce urban road user charging have been made, most notably the Hong Kong trials (1983–1985 and 1998) [40–42] the Singapore Area Licensing Scheme (ALS) (1975–1998), which is now replaced by an automatic electronic scheme and the toll rings around Bergen, Trondheim, and Oslo (however, these latter three schemes in Norway [43–45] are primarily revenue-raising schemes).

The difference between road user charging and tolling is that the fee is calculated to meet some demand management objective, rather than just recovering a fee for using the infrastructure. In this sense, road operators attempt to internalize some of the external costs associated with transport, including those related to congestion, delay, and environmental impact.

2.2.2 Early Operating Models

Nonautomatic and nonelectronic forms of fee collection have been used at toll facilities since their inception. It is worth reviewing the manual forms of collection that are implemented [46] before proposing automated fee collection systems.

Manual collection methods vary in many ways, depending upon the characteristics of the road. However, the overriding requirement for manual collection is that the vehicle driver must stop the car, open a car window (or door), and either hand over cash or a card, or insert either of these into a machine. These plazas are common across Europe for the collection of road tolls. No actual road pricing scheme employs such methods, although arguably the Oslo and Bergen toll rings in Norway could be regarded as road pricing installations [47].

Manual toll collection usually requires the building of a toll plaza that divides the free-flowing multilane road into a number of single lanes. Each lane is serviced by a tollbooth, which either houses an operator who manually collects toll payments, or has the equipment (e.g., card reader or coin-accepting basket) that the driver must use to pay the toll. The general rule for the design of toll plazas is that there should be at least three tollbooths to service each one lane of traffic leading into the toll plaza. A four-lane road will typically require 12 tollbooths to efficiently service the traffic [1]. This is clearly a nonviable option for road use pricing in urban areas, due to the size of the toll plaza required and the high volumes of traffic that could be expected in morning and evening peaks. Figure 2.1 shows a four-lane toll plaza servicing a two-lane low-flow road in Normandy, France. The number of service lanes in a toll plaza may be reduced on roads with low flows. However, it is necessary to compare the benefits of reducing the number of toll lanes (thus the land required and the number of operators employed) against the costs associated with queuing traffic and their noise and air pollution. The physical security of storing and moving a large amount of coins and paper money can also cause some logistical problems. At the Mersey Tunnels in Liverpool in the mid-1980s, approximately 15% of revenue was stolen systematically by operators. This problem was addressed and solved by the tunnel management, once it was detected however, it is cited here to illustrate some of the issues that may occur when cash is handled. Approximately one-half ton of coins was being moved daily, which was a time-consuming and costly process [48].

Fig 2.1 Typical Toll Plaza Layout (courtesy of Blythe/CSEE)

The enforcement of manual toll systems generally relies on the use of a barrier that is not opened until confirmation by the operator or the collecting machine that the correct toll has been paid. These systems are often augmented by vehicle detectors, to count the vehicles passing through the lane, and by some form of vehicle classification, to distinguish different classes of vehicles that pay different tolls obviously operators can classify vehicles manually, provided the definition of classes is not too complex [49]. Classification is usually based upon axle counters and/or vehicle height-measuring equipment. A video camera may be employed when a barrier is not used. However, this practice is not very common, due to the extra cost with little benefit over the barrier, since the vehicles are expected to stop anyway. Another option is to use a flashing light and alarm on the tollbooth, which attracts the attention of supervisory staff and enforcement vehicles at the toll plaza when a vehicle has violated the system. This approach is used extensively on the U.S. Turnpike network. This is not a particularly workable deterrent for congestion pricing, where very high vehicle flows can be expected and lanes are not normally segregated. Thus, it would be difficult to identify the offending vehicle without sophisticated enforcement systems [50]. Figure 2.2 shows a diagram of a typical toll plaza arrangement with deceleration and acceleration areas and a mixture of payment lanes.

Let us consider the different types of manual system that exist.

(a) Manned toll booths

Manual toll collection using an operator to collect money is probably still the most widely used method of collecting tolls. An operator is situated in a tollbooth servicing one lane of traffic. These booths must be air conditioned and heated for the comfort of the operator. It is generally also necessary to employ some simple auditing systems, such as counting the vehicles passing through the lanes and more commonly now providing a paper receipt on request for each transaction.

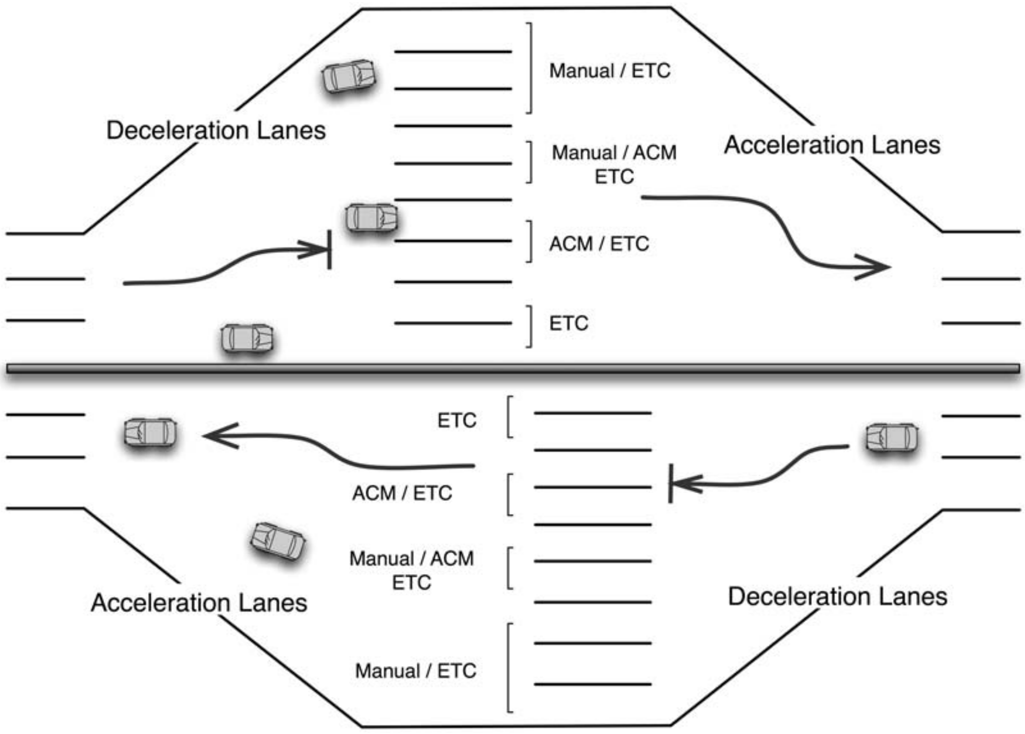

Figure 2.2 Typical mixed payment toll plaza arrangement

The collector takes coins, cash, tokens, or paper tickets from all the drivers passing through the lane. Where only the correct toll may be paid (i.e., no change given), or where prepaid tokens or paper tickets (vouchers) are used, the transaction itself takes only a few seconds. If the transaction requires that change is given or a paper receipt is provided, then this process takes longer. An experienced operator generally can achieve 300 or more transactions per hour, although this depends on the number of coins required to pay the toll. A $1 toll can generally be paid quicker than a $1.30 toll.

(b) Automatic Coin Machines

Automatic coin machines (ACMs) are widely used at many toll plazas to replace the need for a manned tollbooth. The coin machines are generally able to accept prepaid tokens (if used) and coins. Most of these machines use a basket or hopper, into which the drivers throw coins or tokens. These are generally read and validated within 2 to 3 seconds, and the barrier is raised (or some other indication of a correct toll charge given to the driver). The driver can press a button requesting a receipt to be printed. These basket/hopper arrangements are regarded as an efficient way to pay tolls, and are now quite reliable and environmentally robust (usually, they contain a heater/cooler to ensure operation in all conditions). The sophistication of the coin validation unit enables the machine to reject foreign currency and other objects thrown into the hopper. Figure 2.3 shows a combined stop-and-pay coin hopper, card reader, and read-only tag reader on a highway near Lyon, France.

Fig 2.3 Coin, Card and Tag Payment Booth (courtesy of Blythe/CSEE)

Payment may be relative quick for regular users of a toll plaza who are familiar with the operation of the basket and the coins it requires. Where barriers are not used, many regular drivers do not completely stop at the baskets, but throw their coins in the basket from their slowly moving vehicle. Inexperienced users of the system can considerably hamper the proceedings, particularly if they do not possess the correct coins, or if they miss the basket.

A single lane of a toll system may service up to 400 vehicles per hour, based upon the results of studies in the United States, where these hopper arrangements are widespread. These figures are exceptionally high, compared with throughput figures on most toll roads in France and Italy. Figures 2.4 and 2.5 illustrate the reduction in transaction and stopping time that can be achieved by a drive-through system, when compared to a stop-and-pay system.

(c) In-lane Card Readers

Prepaid cards (magnetic or paper-based), credit cards, and smart cards are all now used for toll payment purposes. All of these methods of payment require that the driver to insert an appropriate card into the card reader, waits for that card to be debited (or validated), and then collects the returned card (together with a receipt, if requested) before continuing the journey. Contactless ‘‘proximity’’ smart cards, which communicate using a radio frequency interface and comply with the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) 14443 standard, are increasingly being used for tolling. These cards only need to be presented to the reader (usually at a range of less than 10 cm), rather than being inserted into a reader, which speeds up the overall transaction process [51]. An example of a contactless smart card–based tolling system was introduced in Turkey in 2005 [52]. New generations of smart cards that use the ‘‘vicinity’’ standard (ISO/IEC 15693) may be read from a range in excess of 1m, but as of yet, these cards have not been deployed in toll applications.

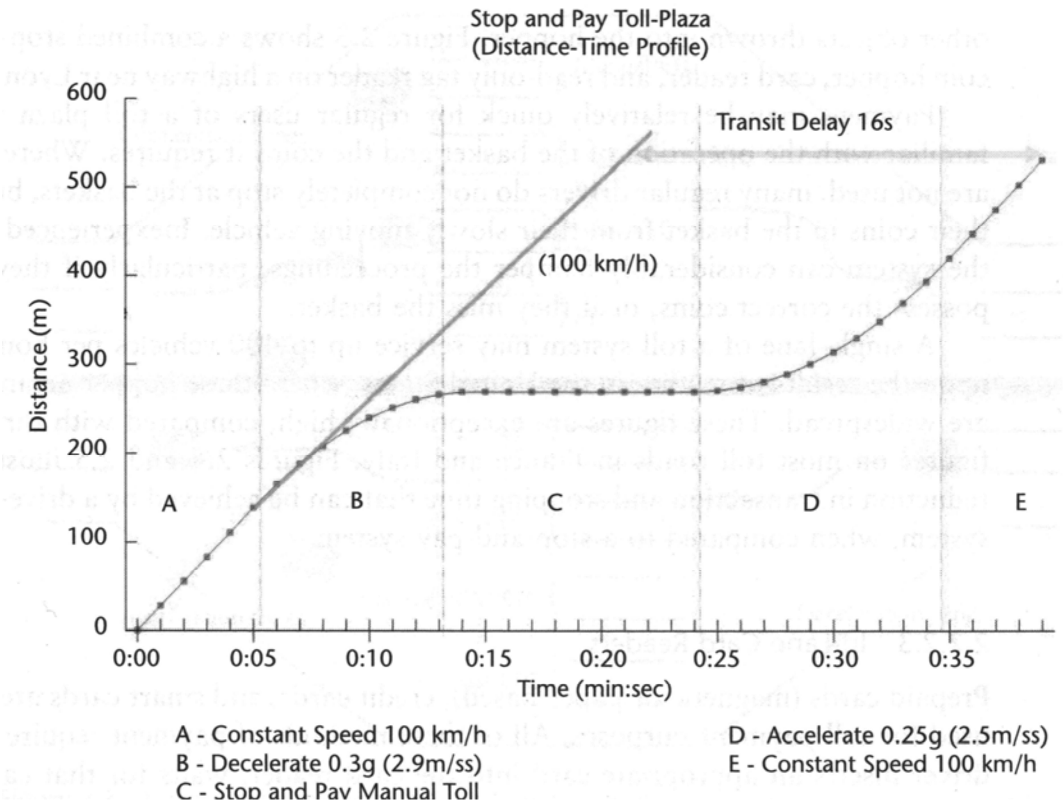

Fig 2.4 Distance-speed profile for stop and pay toll-collection

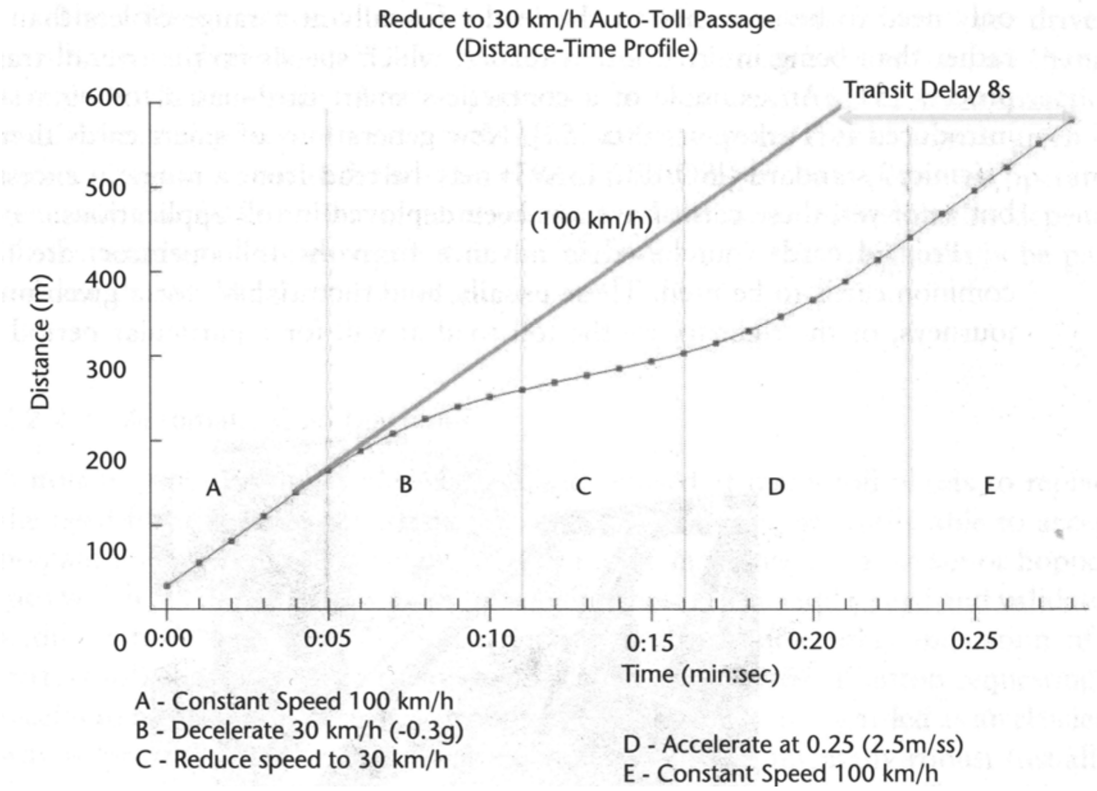

Fig 2.5 Distance-speed profile for vehicle passing through toll-site at 30km/h

Prepaid cards (purchased in advance from the toll operator) are the most common cards to be used. These usually hold the ‘‘rights’’ for a given number of journeys, or the right to use the toll road at will for a particular period of time.

Smart cards may also hold the same information, and they may be used to hold electronic cash or credit, which is deducted from a card’s balance for each toll transaction. Smart cards also can be recharged with credit or subscription rights. Such usage could spread now that numerous banks have adopted electronic accounts held on smart cards.

The use of credit cards is not so widespread, for two good reasons:

- The value of the toll transaction is generally low, and credit card operators see no commercial viability in allowing credit card payments for such small amounts. One exception is on long-distance closed toll highway networks in Italy, Spain, and France, where drivers pay a charge related to the journey distance on the network, which may amount to several tens of dollars, make credit card payments viable.
- The time it may take the credit card reader to validate a transaction (typically from 10 to 15 seconds, if dial-up lines to a card validation computer are used) make this form of payment less than attractive at tollbooths, where long lines may develop if this form of payment were employed. The recent introduction of compulsory chip and personal identification number (PIN) payment in many countries may further slow down this transaction process. However, some PIN reader credit card machines speed up the transaction by only validating the PIN locally and not connecting to the card’s central system.

Based upon an ergonomic study in France, the total time required for payment using journey tickets is 15 seconds (a rate of 240 vehicles per hour), while the total time for a credit card payment is 22 seconds (a rate of less than 170 vehicles per hour).

(d) Paper Stickers, Area Licences and Vignettes

Systems that use paper permits or vignettes are an additional nonelectronic system. A driver purchases an additional license to use a particular toll road or road network on a specific day or time of day. Many toll road operators introduced such an option for regular travelers, prior to the introduction of electronic systems. Manual reading of the sticker or vignette, often supplemented by ANPR, enforces this system. The most significant examples of their use are found in citywide access control schemes.

A paper sticker–based system is a nonautomatic means of identification, which conveys to a manual observer (or camera) visual information regarding the rights of that vehicle user to drive on a specific road network for a specific period of time, or during certain times of day.

A paper sticker or license can only convey a small amount of fixed information, and, depending on the sophistication of the sticker, the information may only be read from a short distance in slow-moving or stationary traffic. This is usually achieved using brightly colored stickers, prominently displayed in the vehicle’s windshield. The stickers are practically impossible to read with any degree of accuracy in fast-moving or multilane traffic, although Singapore did employ such a method.

The paper sticker has the advantage of being easy to implement and easy for drivers to understand. The difficulty with the approach lies in the enforcement of the system. The licenses must be read at a distance, either by a manual operator at the toll site or by a random inspection by police or another agency. It is also necessary to make the permits fraud-resistant and flexible enough for the different subscriptions and licenses that may be offered in a scheme. However, the potential for the counterfeiting of these printed permits is increasingly a risk, due to modern desktop publishing systems and high-quality color printers/copiers. Manual reading of paper stickers was used effectively at toll sites in Bergen, Norway, for more than a decade. Special drive-through toll lanes were dedicated to those drivers possessing a paper sticker. This system was effective for enforcement, but it required that the road be divided into single lanes and that a manned tollbooth be used. A video camera was used to take digital photographs of all vehicles that did not possess a valid license. It was estimated that up to 600 vehicles per hour in Bergen could be checked manually. However, the system relied on the vigilance and integrity of an operator to perform a repetitive and less-than-fulfilling job. The Bergen scheme was upgraded to use ‘‘Autopass’’ (the Norwegian National charging technology) in 2001.

Fig 2.6 Gantry Indicating the Boundary of the ‘Restricted Zone’, Singapore

In Singapore, the Area Licensing Scheme (ALS) was successfully employed from 1973 to 1998. This scheme used paper licenses of different colors to depict different access rights. The entrance roads into the central zone, where the licenses applied, were clearly marked by gantries that used lights to indicate when the zone was ‘‘active,’’ as shown in Figure 2.6. These roads were generally two- or three-lane roads, and there was no restriction in traffic flow. Enforcement was manually performed by inspectors in booths at the side of the road, although it is not known how effective they were at detecting violators across three crowded lanes of traffic. Police patrol cars were also used to check licenses through random inspections.

Violators faced a hefty fine, and the official figures in Singapore suggested less than 1% for violations.

2.3 From Policy to Technology

2.3.1 Background

A degree of technology sophistication is needed to ensure that road user charges are collected in an efficient and effective way. Technology is the enabler in every system that ensures that road user charging policies can be delivered. Technology can be the means of introducing demand management policies for cities gripped by gridlock, or as the means of enabling a cost-effective toll collection scheme for a privately operated (concession) highway that provides access between areas of employment and the residential areas of labor. Technology can also enable the efficient collection of taxes from road users who are paying according to other parameters of travel, such as distance traveled or a fee reflecting the environmental impact of the journey. Technology is a means to an end and not the end itself without technology, many of the opportunities opened by road charging would not be feasible [53].

Technology offers a range of options for a user to pay for road use. The charging technology may also include a means of measuring the road usage in parameters that are defined by local needs and charging policy, such as the distance traveled by the vehicle on a road segment that is charged at a higher tariff than an alternative parallel link. This tariff may depend on the vehicle classification. Heavier commercial vehicles may be required to pay more than light goods vehicles, and highly polluting vehicles more than environmentally friendly vehicles, for example. The charging technology may also provide a means of instant communication with a road user. It may confirm that the means of payment was accepted, or allow the user to modify the information on which the charges are based (e.g., declaring that a truck has a trailer attached). Historically, toll collection operators have employed RUC as part of a pay per- use service. The evolution of new charging, communication, and enforcement technologies also enable the principles of RUC to be implemented at a local and national level for selected road users.

Technology can deliver services that depend on several factors: the local charging policy, user preferences for information relating to the fees accrued, the means of payment, and the classification of the vehicle. This list is not static the charging policy may vary, depending on the location of the vehicle, and the user preferences may vary over time and by journey. The vehicle classification may vary according to the local classification scheme a commercial tractor unit may be able to lift one of its axles if it is not carrying any substantial load, and this lower axle count may enable the road user to claim a discount [54].

2.3.2 Policy Options

Wherever there is a need to differentiate categories of road users for charging or enforcement, or to define a boundary between areas of different charging levels, such as entering a charged area or passing to a lower tariff zone, there is a need for technology. The required technology may be situated at the roadside or in the vehicle, and should be capable of detecting and recording that the vehicle has, or is about to, cross a tariff boundary of a charged road or network of roads [55]. Charging technologies are most likely to be found where the charging policy requires an action, as the examples in Table 2.1 show.

Policy Requirement	Policy Requirement (subset)	Examples
Detect entry to chargeable area or across boundaries between different tariffs	Detect when a vehicle crosses a tariff boundary or measurement of vehicle position relative to tariff boundary	Entry to toll road, exit from toll road (e.g. closed toll road), entry to or travel within a charged area, entry to different tariff road (e.g. highway)
	Area	Transition from one charged area to another at a different tariff
	Time of Day	Proxy for measured congestion, charges depend on time of day as a simple charge/no-charge scheme or graduated charges applied over whole day
Measure Road Usage	Distance traveled	Measuring distance traveled on chargeable road segments by identification of road segment or incremental distance traveled
	Congestion	Measure vehicle's contribution to congestion or measure overall congestion with external fixed sensors.
	Class of Road	Identify road type on which the vehicle travels e.g. motorway, public versus privately owned roads
Declare Vehicle Attributes	Emissions Class	Manufacturer-declared emissions class
	Weight	Manufacturer-declared gross carrying capacity, dynamically measured axle weight on the vehicle, in-ground dynamic measurement of weight.

Policy Requirement	Policy Requirement (subset)	Examples
	Quantity of axles	Total or separated into tractor and trailer
Correlate Charging and Enforcement records	Off-line payment	Off-line payment linked to declared vehicle registration
	On-line payment	Spatially and/or temporally correlate means of payment with vehicle at point of payment.
Communicate with roadside infrastructure	Interface to Roadside System	Temporary or offline connection to deliver payment-related information and to permit declarations to be transferred for charging and enforcement purposes
	Interface to Road User	To communication result of payment transaction, allow declarations to be changed or other value-added services.
	Interface to other in-vehicle system	To capture incremental distance traveled information from odometer or tachometer
Payment	On-board account	Account specific to toll operator or electronic purse containing authenticated value.

Table 2.1 Policy Requirements

Some or all of the functional requirements are also needed to enable a charge for road use to be calculated and applied. If the road use is measured by equipment located within the vehicle, or if a roadside system is triggered by equipment in the vehicle, then a means of connecting the in-vehicle equipment to the roadside equipment is also needed.

2.3.3 Basis of Charging

If RUC is based on a network of separate chargeable road segments, then the subsystems that perform the tasks listed above will need to be integrated at some point, to enable full-service ‘‘roaming’’ between geographically disparate operators, otherwise known as interoperability. As mentioned previously in this chapter, there are a number of different ways of implementing a charging scheme based upon the charging objectives and the type of road network to be charged [12, 56]. The following section briefly considers a selection of these options, although many of the examples given are described in more detail in the case studies of Chapter 8.

(a) Open Toll Road

An open toll is the term given to a tolling scheme that implements a charge at a specific point on a road, as illustrated in Figure 2.7. This usually applies to a particular piece of managed infrastructure, such as a bridge or tunnel at an estuarial crossing, or some significant geographic barrier, such as passing through a mountain range. A toll is levied on vehicles passing through the toll plaza. The toll generally is a fixed charge and does not relate to the distance the vehicle travels on the road network, but instead is purely a charge for the use of the infrastructure. The charge may vary by time of day as an attempt to spread peak-hour traffic. The first example of peak-hour charging on a toll road was implemented on the Paris-Lille toll road in the mid-1990s, as a means of controlling the high traffic demand generated on a Sunday evening for Parisians returning after a weekend in the countryside.

It is important to note the distinction between the term open toll defined here as a fixed fee for use of a single facility and the ‘‘open road toll’’ (ORT), which is now a commonly used term, particularly in North America to describe a toll road with two or more express tolling lanes using electronic tolling equipment, such as Highway 407 near Toronto and some of the EZ-Pass installations in Illinois [57].

Such toll schemes usually charge on pay-per-use methods, whether the user pays in cash or pays electronically by using a tag to identify a centrally held user account. This is often the simplest approach, as used by the M6 Toll or Dartford Thurrock Crossing in the United Kingdom, and by various electronic toll roads elsewhere. The trend in the United States is moving towards interoperable toll tags at such sites.

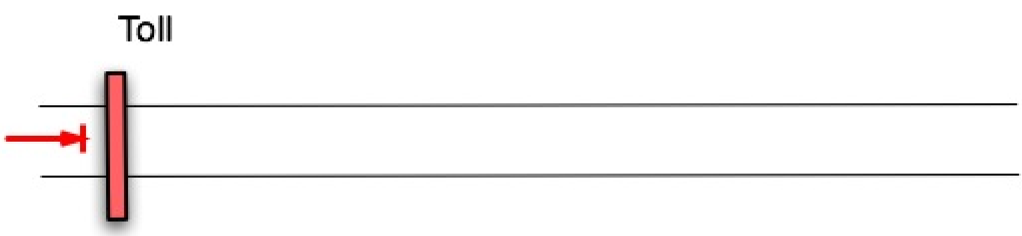

Fig 2.7 Open Toll Road

(b) Closed Toll Road

The most common form of interurban highway tolling is closed tolling, in which the toll is related to the distance the vehicle travels on the toll road. The toll charge is measured by registering when and where the vehicle enters the toll road network, and when and where it leaves the network. Thus, there is a need for a series of entry and exit points on the toll road network, as illustrated in Figure 2.8.

The system can generally be configured in two ways when using automatic tolling technology. In the first configuration, the in-vehicle tag identifies itself to the toll system upon entry to the network, and again upon exit from the network, where the appropriate toll is calculated. In the second configuration, the entry data is recorded onto the tag itself and then presented back to the toll system on exit from the network, so the appropriate toll can be calculated. Closed toll systems increasingly are migrating towards open road free-flow tolling systems, as seen on Highway 407 [58] around Toronto, the Melbourne City Link, and the recently opened toll facilities in Chile [59].

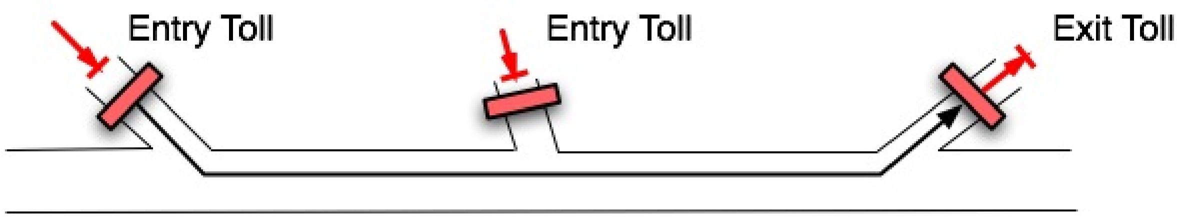

Fig 2.8 Closed Toll Road

Wide area systems that calculate the distance traveled using on-board equipment could be used for closed tolling. They are not necessary if a dedicated toll plaza has been built to service entry and exit points. Where distance-based charging is introduced to previously free road stock, as may happen in the United Kingdom, then wide area systems utilizing GNSS or Groupe Speciale Mobile (GSM) solutions may be viable. This is also the case for national schemes that have been introduced for heavy goods vehicles, such as in Germany, Austria, Switzerland, and parts of the United States.

(c) Cordon and Area Charging

The charging of a fee for crossing a cordon is by far the most common configuration for urban demand management. There is a boundary into a central business district or environmentally sensitive area that will incur a charge if crossed, as illustrated in Figure 2.9. The charging rings around Trondheim, Norway, and the Singapore ERP are often cited as examples of such an approach [60]. The cordon need not necessarily be operated on a charging basis, and may be configured to allow certain users to cross the cordon without penalty [61]. Another early example was the access control scheme established around some of the residential areas of Barcelona, to restrict access only to residents and business owners during the 1992 Olympics [62]. This scheme, partly funded under the EU's DRIVE II Programme GAUDI project, used first generation Q-Free (Kofri) AVI tags.[2]

One problem with a cordon is that it is a relatively blunt instrument—if you travel into the cordon, then you pay a fee, regardless of the time spent and road space used by the vehicle. Experiments have been undertaken to reflect more specific charging once the vehicle enters a cordon. This essentially changes cordon charging into an area charge. In 1992, Cambridge tried a cordon-based scheme, in which an in-vehicle meter was activated using microwave beacons as vehicles entered the city. Once inside the cordon, the vehicle only accrued charges when the vehicle was deemed to be in a congested situation [22, 24]. The same

[2] Refer to chapter 8 for further details on the Norwegian systems.

system demonstrated the accrual of charges based upon the measured distance that the vehicle travelled inside the cordon, as illustrated in Figure 2.9. In the same year, GEC ESAMS[3] demonstrated a variant of this scheme, which charged for time spent in a cordon in Richmond, United Kingdom. Another possibility could be to charge a fee related to the levels of environmental pollution generated by vehicles in a particular area.

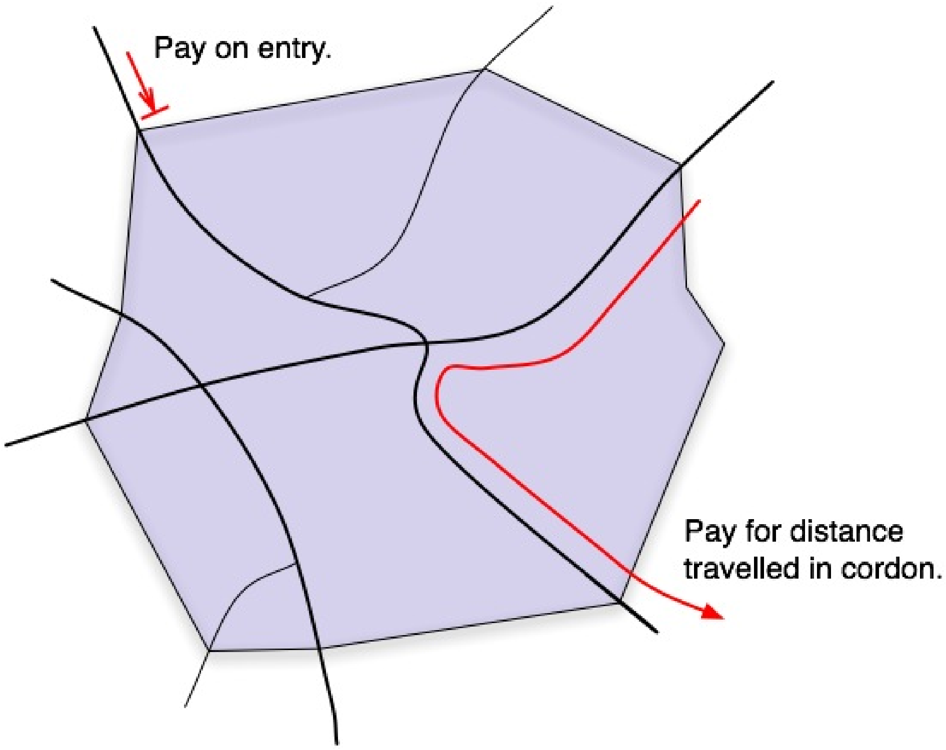

Fig 2.9 Cordon Charging

Most cordon-based systems currently use microwave tags to initiate payment. However, London introduced their congestion charging scheme based upon the preregistration of vehicle license plates, which are then checked, and violators recorded, using ANPR [28, 63]. The advantage of the London scheme is that no vehicle is required to have electronic equipment installed, so regular users and occasional users pay in the same way. The scheme is fairly inflexible, because it is difficult to vary the charge, and relatively costly to operate in comparison to schemes with a high penetration of DSRC tag usage. This is due to the need for manual intervention to register users on a daily basis, and to check unclear license plate images, prior to the issuing of penalty charge notices. London is currently experimenting with electronic charging schemes as a possible replacement or supplement for the ANPR-based scheme, in order to introduce more flexibility in the charging regime, reduce operating costs, and retain charging options for unequipped occasional users [64].

Wide area systems[4] that use in-vehicle location systems linked to a digital map could probably deliver a solution for cordon charging, without the need for physical charging points at every entry location [12, 31]. Experiments in several major cities suggest that GNSS may not

3 Refer to the section on the Cambridge trial and in-vehicle metering systems in chapter 8 for more details on this system.
4 Wide area systems are also often referred to as MPS (Mobile Positioning Systems) and VPS (Virtual Positioning Systems). The technology options available for such systems are presented in more detail in Chapter 3.

(currently) be sufficiently accurate to define the cordon charging boundary, due to the obscuration of the satellite signals by tall buildings. This is frequently known as the ‘‘urban canyon’’ effect, which is discussed further in Section 3.5.3.

(d) Concentric Cordon Charging

A variation on the conventional single cordon is the concentric cordon scheme. Outer and inner cordons were established, with the driver required to pay at both boundaries, as illustrated in Figure 2.10. Such arrangements may be used to reflect the additional demand management measures required to deal with the congestion in the center of a city. The inner cordon could also be used to encourage park-and-ride and modal shift before reaching the inner cordon. Charge levels can be different at each cordon, and be operated on an area-pricing arrangement, as discussed in Sections 2.3.3.3, 2.3.3.5, and 2.3.3.6. In all the cases of the cordon and zonal configurations, it would be possible to implement charges in both directions of travel, which could be used to tackle problems associated with the evening rush hour.

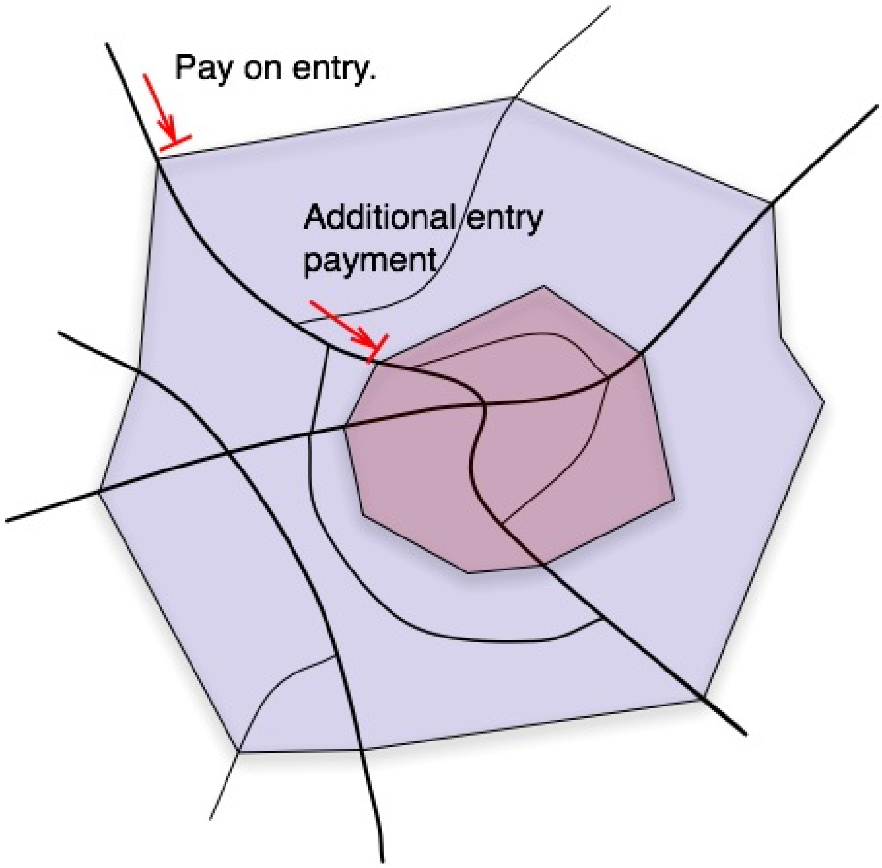

Fig 2.10 Concentric Cordon Charging

The concentric cordon approach has not yet been implemented in an urban charging scheme. It was the basis for the proposed Edinburgh, Scotland, road pricing scheme, but this scheme was rejected by the residents of Edinburgh in a referendum in February 2005 [65, 66]. An inner cordon was initially proposed for the Stockholm congestion charging solution, although rejected in favor of a single cordon scheme, which began a 9-month experimental period in January 2006.

(e) Area Charging with Through Route

It may be necessary to allow some through traffic where a cordon scheme has been implemented, to avoid generating a large number of trips by circular routes around the cordon. Figure 2.11 shows a dedicated ‘‘free’’ corridor that could be established to enable these transits. The extension to the Central London Congestion Charging Scheme to the Royal Borough of Kensington and Chelsea allows for such a transit route.

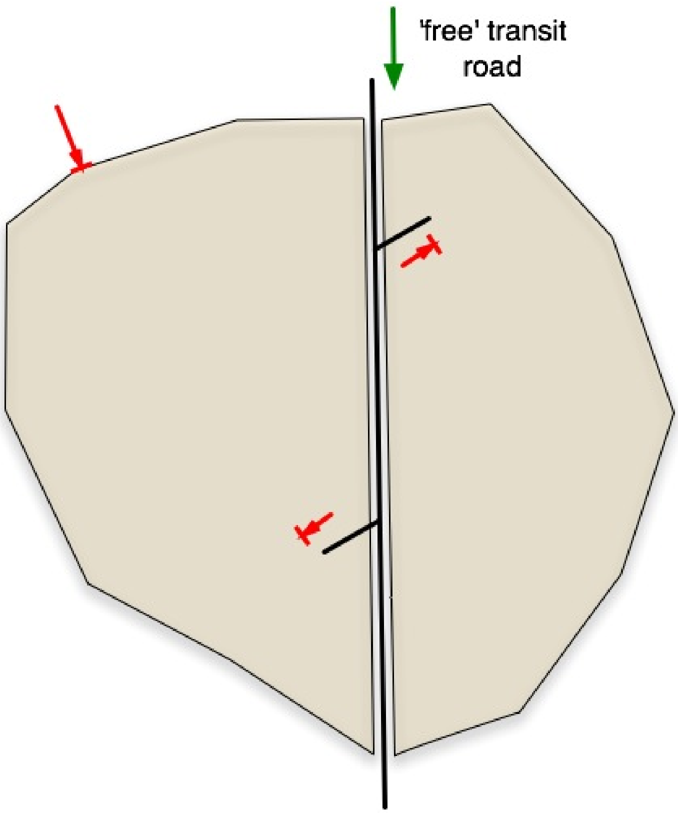

Fig 2.11 Area Charging with Through Route

(f) Quasi-distance / Zonal Charging

Another arrangement is to introduce a series of interlocking minizones, where a charge is levied at the interface of each zone, as illustrated in Figure 2.12. Such an arrangement would assume charging using tags or ANPR, as if using a wide area scheme. The charge could be fine-tuned in a different manner, such as using distance based charging [67]. The Hong Kong ERP trial in 1983–1985 came the closest to such a configuration, since the trial scheme had four charging zones [2]. The scheme also varied the charge for crossing the cordon by time of day, with a peak, shoulder[5] peak, off-peak, and no-charge fee bands [42].

[5] A shoulder charge is an intermediate level charge set to try and offset the step-change between a high-priced ‘peak’ charge of say US$5 and off-peak low-cost charge of, say US$1. The purpose being to try and discourage many users from waiting for the charges to switch from the high price to the low price, and thus cause unnecessary

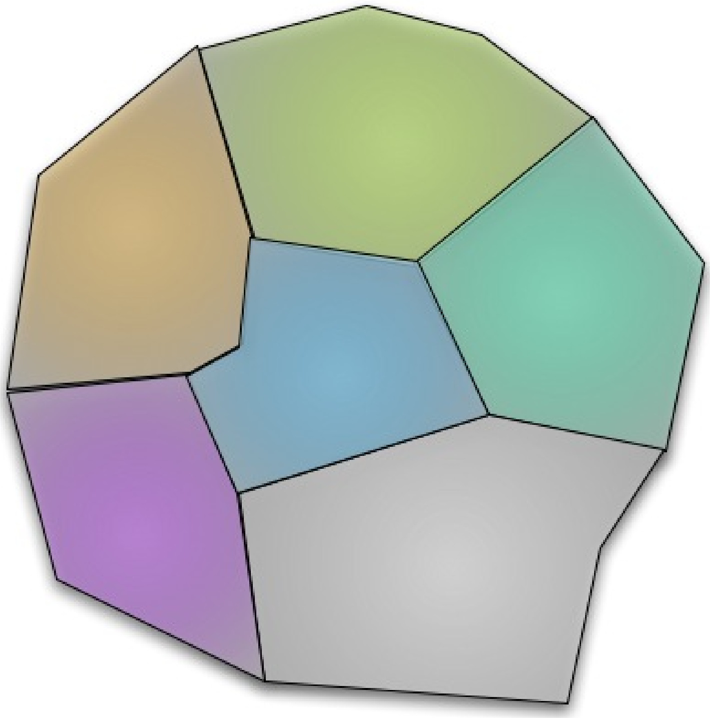

Fig 2.12 Quasi-distance / Zonal Charging

(g) Road Segment Charging

Road segment charging is a charging configuration specifically designed for wide area charging systems. A boundary is defined around the road that is to be charged, which usually extends to some distance beyond the boundary of the road section to account for errors in the location calculations made by the vehicle on-board unit [68, 69]. The road segment identification may be performed within the onboard unit or central system. Once it is recognized that the vehicle is within the boundary, charging is initiated. A network of such segments could be defined to cover a large network of roads, or the entire national network of mapped roads [70, 71]. See Figure 2.13.

2.3.4 Operational Requirements

In simplistic terms when looking at the possibility of introducing automatic road user charging system there are several basic questions that must be considered. To introduce electronic charging schemes, these are presented in this chapter as generic options. The more specific detailed implementations of each element are considered in chapters 3-6, where the operator requirements and the customer-centric requirements are considered in much more detail.

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levels of congestion and queuing. So an intermediate level charge of, say US$3.00 may off-set this effect. For more detail of the Hong Kong trials refer to chapter 8.

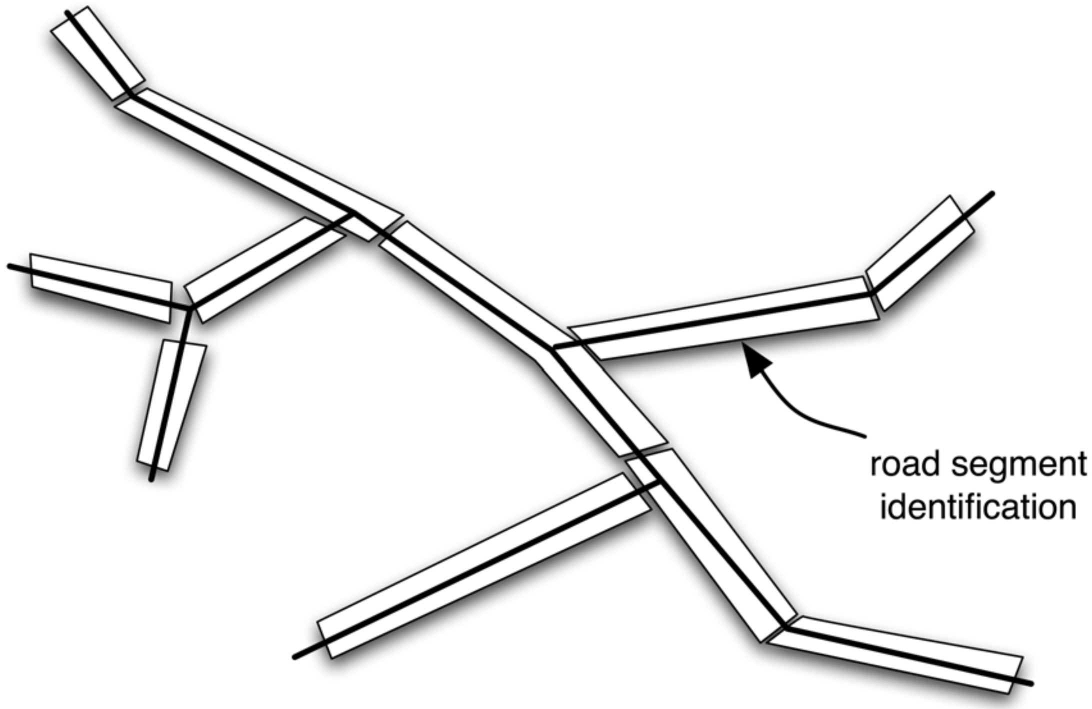

Figure 2.13 Road Segments for use with Wide area/VPS Charging Systems

These basic considerations are as follows:

- What payment methods will be allowed, and what types of accounts will be offered by the operator? The sophistication of the methods may change, based upon whether it is a toll collection scheme or a road user charging system.
- What is the likely traffic flow through the charging locations, and what kind of toll collection facility will be used? The operation may incorporate a toll plaza, or may be a more free-flow operation, as we are beginning to see with new toll road implementations (e.g., Toronto 407 ETR and Melbourne City Link). It may be for urban road user charging (e.g., Trondheim, London, and Singapore).
- How will the fees be collected? Will it be manual, or by some form of automated system?
- Will the charging basis be a point charge on a toll road, a distance-based charge, or some other parameter? Is the road a single road, a network, a cordon, or some multizonal arrangement? What parameters will be measured to calculate the charge?
- What level of enforcement is required, and what complexity of vehicle detection and classification is necessary?

Many of the products and services required to successfully implement road user charging depend on technical innovation, technology development, and end-to-end systems deployment. The role of technology in enabling a charging scheme can be viewed from several perspectives, including national government, local government, road operator, technology vendor, system integrator, and road user.

Looking beyond the front end of the system that actually facilitates the onroad charge, a complete charging scheme will require many or all of the following systems and services:

- Service provider and clearing operator system development to manage high volume payment collection, clearing, and funds transfer
- Customer relationship management (CRM), billing, and general support, particularly immediately following the start-up of a scheme
- A system to distinguish between vehicles that are equipped with technology [often known as ‘‘tags’’ or ‘‘on-board units (OBUs)’’] to facilitate charging from those that are not equipped
- Identification of suspected violators and management of the evidence of the violation
- IT infrastructure development, deployment, and maintenance [e.g., wide area network (WAN) backbones], for distribution of tariff information to vehicle-based equipment
- Road use information collection, dissemination, and display [e.g., to signal charge levels and alternative means of travel, using roadside variable message signs (VMS) or in-cab displays]
- The manufacture, personalization, distribution, delivery, and installation of OBUs (if used)
- Evidential enforcement record management, registered user identification, and penalty collection
- Service quality level auditing, security risk assessments, and environmental impact reduction for all on-road infrastructures.

Project management, financing, risk absorption, integration, maintenance, and operations are the elements that would also be needed for a complete scheme. While a scheme for 400,000 heavy trucks may be appropriate for a single service provider, it is likely that a national, mass-market scheme serving 30 million vehicles, for example, would need a multitiered national and local service and maintenance operation. This may be further complicated by the possibility that the objectives and operation of a local scheme may be very different than a national scheme if both are operated simultaneously.

2.3.5 Functional Requirements

Several functions are generally needed for all road user charging schemes that require the use of a tag or OBU installed in participating vehicles. The following functions need to be supported, in order to meet the operational objectives listed in Section 2.3.4.

- User registration and access to in-vehicle equipment
- Declaration of user and vehicle-related information, to allow the correct charge to be determined
- Enforcement if the correct charge cannot be applied (e.g., missing or incorrect user declarations)

- Collection and management of records relating to user and vehicle charging and enforcement events
- Collection and settlement of charges and penalties.

Every scheme that depends on electronic means of payment, from the simplest to the most complex, needs to employ a selection of these service elements. The business model of a local scheme may suggest that several charging products must be offered by the scheme operator, depending on the frequency of user access to the charged road segments, the vehicle type, the payment options, and the level of privacy and anonymity required by the driver or allowed by the scheme operator.

(a) User registration and providing access to in-vehicle equipment (if needed)

The in-vehicle equipment needs to uniquely and unambiguously point to the means of payment, so at the time of issue, the equipment must be linked to the charge payer and optionally to the vehicle. This linkage may be physical, such as a simple adhesive fixing or a permanent tamper-resistant installation, and/or logical, by relating the in-vehicle equipment to the vehicle in a central system database, which is discussed in Chapter 6.

In-vehicle equipment may not always be required (e.g., as in the London Congestion Charging scheme). Some scheme operators offer a product for occasional users that requires the registration of the license plate of a vehicle against a means of payment. A road user would be encouraged to register for an occasional user scheme before traveling on the chargeable road network, but grace periods could range to as much as 5 days later. Trondheim, Norway, offered occasional users the option of paying for entry into the city using coin machines on the cordon entry roads. Such an option would only be feasible in small-scale schemes. The Stockholm, Sweden, pilot only allowed postpayment within 5 days of the vehicle passage. These and other approaches to dealing with occasional users are described in Chapter 3. The strategy for dealing with occasional users is very important. A number of potential urban charging schemes in the 1990s were shelved because no credible occasional user scheme could be established at an acceptable cost and level of complexity. This is the beauty and pragmatism of the present-day London Scheme all users of the congestion charging zone, whether occasional or regular, use the same method of registration and payment, through license plate registration and enforcement with ANPR [27, 28]. If and when the TfL migrates to some form of electronic on-board unit for regular users, the occasional users would still be able to utilize the license plate registration scheme as an alternative form of payment, since the infrastructure already exists.6

(b) Declaration of user and vehicle-related information to allow the correct charge to be determined at the point of provision of road use

The in-vehicle equipment needs to provide the means for a road user (or the entity responsible for the vehicle) to make declarations, at the point of charging, of the

[6] The London scheme is discussed in more details as a Case Study in Chapter 8.

vehicle type and other attributes to enable the correct charge to be calculated. The user's ability to influence the content of this declaration is likely to be very limited (e.g., informing of the existence of a trailer or caravan). Other attributes are either static (e.g., a vehicle's emissions class) or dynamic (e.g., entry point to closed toll road, quantity of road segments traveled, and time of day), but in most cases cannot be modified by the road user. As will be discussed in Sections 5.5 and 9.3.3, new sensing and monitoring technology may provide options for more dynamic declarations, such as using real-time environmental measurements as a basis for calculating a component of the change.

Declarations that have a direct relationship with the calculation of road usage, such as a vehicle's classification, may be subject to independent external checking. These declarations and the results of any other external checks or measurements are related to the enforcement process (see Chapter 4), rather than to the charging process.

(c) Enforcement if the correct charge cannot be applied e.g. lack of or incorrect user declarations

Ensuring compliance with the locally enacted charging policy is crucial to an effective, credible charging regime. Charging cannot exist without enforcement [54].

A vehicle's license plate must be used to enable a penalty to be issued if a user drives through a toll lane and the vehicle is not properly equipped to interact with the electronic payment system, or if the charging process fails for any other reason. If the toll lane has a barrier, the responsible person is the driver who would be required to pay by another means.

The choice between automatically triggering an enforcement process and attempting to apply a charge based on a vehicle's license plate will depend on the enforcement policy of the operator. For example, if the electronic payment system requires the vehicle's license plate to be registered, and if the license plate number is captured correctly, this would be sufficient to apply the charge. This process would cost more to the operator than would a transaction generated by in-vehicle equipment. This approach to the enforcement process forms part of the Stockholm Congestion Charging pilot scheme [72]. The alternative is to treat the lack of in vehicle equipment as an offense. This may incur a higher cost to the operator, which is offset by revenues from penalties or fines, depending on the policies of the particular jurisdiction. However, cross-border enforcement is difficult and costly, so the revenue recovered may not be as high as anticipated. A business case analysis allows enforcement policy options to be compared, although the choice will invariably depend on other factors, such as the intended purpose of the scheme (e.g., demand management or tolling). The enforcement strategy also must consider the cost of enforcement and the probability of the violation being detected and the user identified. There may be issues with the availability and accuracy of the vehicle license plate database with cross-border or cross-state operation.

Permitting a vehicle to register for a payment scheme after traveling on the chargeable road network could result in the deferral of enforcement processes until the registration (and payment) deadline has passed. However, a mismatch between declarations and independently measured vehicle attributes (where they directly relate to the amount of the charge) would immediately trigger the enforcement process.

Finally, the charging technology itself may support the enforcement process by providing the physical location of any in-vehicle equipment to enable it to be matched with the relevant vehicle passage at the time of charging.

(d) Collection and management of records relating to user and vehicle-related charging and enforcement events

There are different modes of charging, including cordon, area, distance-based, and time-based see Section 2.3.3. Road user charging also includes annual registration fees, fuel duty, and other charges and taxes. Some means of recording road usage is required either by means of the roadside equipment (e.g., identification of road usage on every road segment), or by the in-vehicle equipment (e.g., recording whenever a new chargeable road segment is being used). The location of the measuring process will depend on the charging policy, for example. The economics of a scheme based on a single toll plaza and 100,000 vehicles suggests that the charge will probably be assessed by the toll plaza equipment, and that vehicles will be expected to carry a simple tag. A scheme based on 500,000 vehicles and 5,200 interconnected road segments (e.g., similar to the German truck tolling scheme) suggests that the most economically favorable solution may be that the in-vehicle equipment should play a greater role in measuring the road usage. In practice, roadside infrastructure is always required, particularly for enforcement. The decision remains to be made on the level of complexity of the in-vehicle equipment and communication channel requirements to a data collection center [73]. Obviously the cost of ‘‘the many’’ OBUs against the cost of ‘‘the few’’ roadside charging points needs to be balanced.

(e) Collection and settlement of charges and penalties

Paying the charge means transferring funds from a road user’s account to the account of the road operator or some agent acting on behalf of the road operator, whether this be postpayment, immediate payment, or, in many cases, prepayment. The transfer of funds can be triggered, for an isolated scheme, simply by the collection of a record of a vehicle passage that can be related to an account. In a network of operators linked contractually, the transfer of funds may require a higher standard of proof, such as a certificate generated by a transaction with in vehicle equipment that is authenticated during the passage on the charged road network.

2.3.6 Payment Methods

A number of payment means have been formally defined in international standards, some of which apply to a particular scheme or objective.

(1) Automatic Account Identification: Post-Payment

From the 1970s up to the mid-1980s, automatic account identification (AAI) was the most widespread system, since it generally required only the use of simple read only tags and a relatively low level of sophistication in computing capability at the roadside. Such systems required communications to be established in only one direction (i.e., vehicle-to-roadside), and, in most schemes, little data is required to be transferred. This method was also widely (but incorrectly) known as AVI.

Upon interrogation, the roadside equipment records the unique account identity of the vehicle owner’s tag and the time of day that the vehicle passed through the charging site. The validation of the identity code is generally performed as an online process, but the collection and accounting of the actual revenue are off-line processes.

Threats to privacy problems may occur, due to the necessity of having a central computer record of the information regarding each vehicle’s movement and identity. However, some relationship between the user and the central system needs to be defined for the purposes of an audit trail. The record must be maintained for as long as it takes for the recovery of the outstanding charges from the user, or until it meets the requirements of the audit trial. The information may only be recorded for a few hours or days if a direct debiting facility is used. However, if postpayment billing is used, then the information must be stored for at least the period between successive bills (e.g., monthly or quarterly).

Most operators have moved away from offering the postpayment option. The operators have a clear advantage in using prepayment options, since they receive users’ money in advance of the transaction actually occurring. Prepayment also offers the operator the benefit of a simple and secure ‘‘audit trail.’’ The additional costs of recovering money from a roadside postpayment operation may be considerable.

Most operators have moved away from offering the post-payment option as the advantage to them of pre-payment, whereby the operators receive users' money in advance of the transaction actually occurring is clear. Pre-payment also offers the operator the benefit of a simple and secure "audit trail." Furthermore, the additional costs of recovering monies from a road-side post-payment operation are not inconsiderable.

(2) Automatic Account Identification (AAI): Pre-Payment

Prepaid AAI is the method of road use revenue charging and collection that is favored in most current automatic tolling and cordon-pricing schemes. The data acquired from the tag or OBU is usually validated in real time, which allows a check that the user’s in-vehicle device is legitimate, and that the user’s account has adequate credit and is not blacklisted for any reason.

The financial transaction takes place immediately after validation of the identification code, by deducting the appropriate charge from the vehicle owner's account that is held with the toll authority. The transaction may be performed by means of electronic funds transfer, which ensures the security of the information. Once the transaction has been completed, the information gathered could be destroyed. The vehicle owner should have access to a record of recent transactions carried out with his or her in-vehicle device, in case it is necessary to contest the validity of the transaction charges. With read-write tags or automatic debiting transponders, only the user could actually request as a preference that this data be written into the device's memory for later access. The only record of the transaction in almost all current schemes is held by the operating authority, with access available to the user on demand. Few, if any, on-board units record the transactions as an independent record and audit trial. However, in past demonstration projects, such as the Cambridge congestion metering trial, up to 50 of the most recent transactions were recorded on the user-held smart card that was inserted into the OBU. This option may again be offered, as acceptance of an electronic or a printed receipt is almost universally provided as a record of credit card or Internet transactions [24, 51] and so the smart card log would replace the need for paper records.

(3) Subscription Account Based Upon Identification

Subscription involves the advance purchase of a ‘‘service right.’’ This may be either the right for the user to pass a specified number of times without incurring any further charges (a concept similar to the Paris and Brussels underground networks' CARNET), or the right to use the road network an unlimited number of times within a given time period, like a season ticket (a concept similar to a London Underground TravelCard).

Subscription with identification is usually (but not exclusively) associated with the fixed-number-of-journeys principle. The information regarding the number of journeys that remains on a user's tag is usually held at the roadside. This information is checked and adjusted, in real time, with each passage through the toll site by the user.[7]

(4) Anonymous Subscription Account

Anonymous prepayment subscription is generally operated on the same basis as a travel card (i.e., permission to use the road network as often as desired for a predetermined period of time). The time of day may also be differentiated in terms of an ‘‘off-peak’’ and a more expensive ‘‘peak’’ or ‘‘all-day’’ road use subscription. The subscription may also be arranged in terms of access allowed into differently priced zones.

The Spanish Association of Toll Road Operators (ASETA) established this system in the early 1990s with a read-and-write tag system. Certain data is written onto the transponder, which, upon interrogation, indicates that the tag is programmed with a code that indicates a right to use the roadspace without incurring an additional

[7] Further discussion on how such information is held and made available to the user is provided in chapter 6.

charge during the specified period, while still maintaining tag and use anonymity. Similar schemes have been successfully tried using colored stickers and vignettes, such as in Bergen, Norway [16, 43].

(5) Automatic Debiting – on-board electronic credit (Anonymous)

Automatic debiting tags and OBUs are emerging as a new generation of devices for automatic tolling and road user charging. The device allows for flexible onboard processing of data, and the facility to store user-held credit that has been purchased in advance from an operating authority. This credit may be stored directly in a secure memory area of the tag or OBU, or, more conveniently, in a portable value-card or smart card connected to them.

The ability to electronically store credit in the in-vehicle device allows for great flexibility in the charging of a variable fee (e.g., dependent on time of day, vehicle class, traffic conditions) for the use of the road, and the ability to inform the driver of the charges he or she is incurring. A flexible charge could be made using a tag system, but it would be difficult for the user to keep track of incurred charges. This is important not just for point-charging, but also if a vehicle-metering system is to be used. The main benefit of holding the credit on-board is that the transaction with the roadside can be achieved without the need for the identity of the user to be conveyed to the roadside system (under correct operating conditions). This will overcome the most serious of the concerns associated with current road use revenue collection systems—the threat to privacy, which may not be an issue when users choose to ‘‘opt in’’ to an optional e-tolling scheme, but may be if a road user charging scheme is mandatory.

The price to pay for this anonymity is added complexity of the software (and to some extent the hardware) required at both the roadside and in the vehicle’s transponder. Nevertheless, it can protect the system from fraud and other misuse, which is a particular concern where actual electronic credit is being passed over the communications link from the vehicle to the roadside charging station.

2.4 New Methods of Charging

2.4.1 Business Considerations

Less than 20 years ago, there were no automated systems for the collection of road user charging fees and tolls. If a road authority wished to collect fees for road use and tolls, then it required a largely manual process, in which the vehicle stops and the driver hands cash to an operator. The most advanced systems of the day were automated coin machines or magnetic cards that were inserted into a card reading device. Microelectronics had not yet really entered the transport domain, and the main form of communications between a vehicle and a roadside system was probably inductive loop-initiated communications, or citizens band (CB) radio.[8] The first transponders were developed for the transport sector in the mid-1980s to track

[8] Twenty years hence, it is difficult to convey the message of how low-tech road to vehicle communication was when the concept of electronic tolling began to be considered.

railway vehicles, buses, freight containers, and for other rudimentary vehicle tracking and identification applications [5, 46]. Some of these systems used bar codes that were either optically or magnetically read, while others used radio frequency, and were coined RFID systems. These operated at different frequencies in different parts of the world. In the United States, 400 MHz and 902–928 MHz were used (902–928 was not used in Europe) in Japan, 2.45 GHz and 13.5 MHz were used and in Europe, a range of frequencies were used, including most of the above, as well as 5.8 GHz and millimeter-wave systems in the 60-GHz region. Most of these systems read a small amount of data from the vehicle-mounted transponder to identify the vehicle (or the load).

These early technologies did show the toll collection industry the possibilities that future technological developments could offer. The first two systems that demonstrated this tolling and road use charging were the Hong Kong ERP trial in 1983–1985 [74], which used inductive loop communications from a buried loop in the road to an in-vehicle transponder on the underside of the vehicle and in 1987, when the Ålesund toll road in Norway was the first to be implemented at a toll site, and illustrated to operators from around the world that some automation of the toll collection process was possible, and that the benefits were apparent and quantifiable.

Operators of toll roads saw great advantages in electronic means of payment. They noted that it speeds up the toll collection process and reduces some of the major disadvantages of toll collection facilities, such as the congestion generated at peak periods of use, the noise and air pollution, and the delays that drivers experience [75].

Here is where the technology requirements for tolling and road user charges begin to diversify. The toll plaza has a fairly controlled and in most cases monoplane operation, while the urban or wide area road user charging scenario must move away from the toll plaza concept, since such structures are impediments to traffic flow and are unacceptable in most environments. We are left with the requirements for toll road facilities where automated lanes are fitted to existing toll plazas to offer options other than manual or subscription payment, and more free-flow systems for road user charging and congestion charging, in urban areas where building a toll plaza is not possible. The mechanism for charging is often similar, but the differences in operation between monolane systems and those that must support free-flow multilane operation can be significant [76].

2.4.2 Mono-Lane Operation

Manual toll collection has always been regarded as inefficient, due to the need for vehicles to stop, causing congestion and creating unnecessary noise and air pollution. The area (and cost) of land needed for a conventional toll plaza is great, with at least three manual lanes of toll collection equipment required for each lane of highway feeding into the toll plaza. This land is not readily available when building new roads, and is not available when toll collection or road use pricing is to be introduced on existing road infrastructure.

The concept of collecting user fees from a vehicle's driver without the need for the driver to slow down, stop, or perform any actions (other than driving) at the point of collection, is not new. Until a few years ago most automatic tolling systems had one or more lanes of a toll plaza equipped with automatic reading equipment, enabling drivers to pass through the toll lane at a reduced speed, without stopping, and without the need for the driver to hand over coins, cash, or a card. There was a real need for some form of automation of the toll collection process, and where such systems have been installed they have generally been met with a high level of acceptance from both the driver and the toll site operator. Many of these systems now exist across Europe and the United States. Early systems used extremely short range communications between the in-vehicle tag and the roadside reading device.
Communications technologies included inductive, low-frequency radio, and optical or magnetic barcode systems. These early systems were limited to a very short communications range, which required the passage speed of vehicles to be very slow, or in some cases, even required the vehicle to stop [8, 11]. Many systems of this type are still in use with operators, generally using radio or microwave frequencies for communications, and allowing vehicle passage speeds of up to 60 km/h. Examples of such tags can be found at the Mersey Tunnels, Severn Bridges, and Tyne crossings in the United Kingdom. The limitation of these systems are largely due to the fact that the toll collection procedure still requires barriers (as with the other collection lanes) and must adhere to the traffic management scheme prevalent at the collection site.

The other shortcoming of these early toll systems was that they were limited to conveying only a fixed identification code to the roadside system. A generalized schematic of such a system is shown in Figure 2.14. This fixed code relates to an account that the vehicle's owner has set up with the collection agency. These systems are known as read-only or AVI systems. However, many monolane systems now also use read-and-write capable transponders, which widen the options for payment and functionality. Systems developed for the monolane market are generally not suitable for use in a free-flow, multilane road use charging context [77, 78].

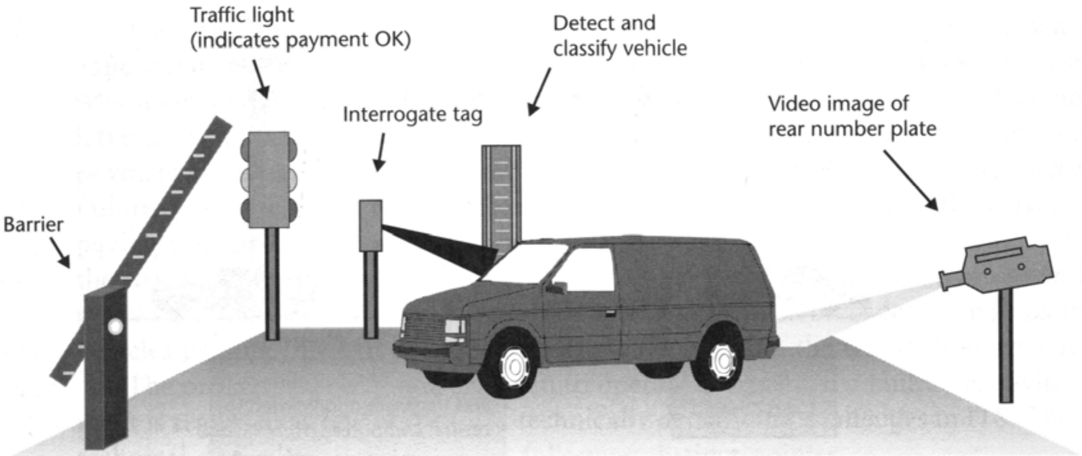

Fig 2.14 AVI System Generalised Architecture for Mono-Lane Operation

2.4.3 Multi-Lane Systems

(a) General System Design

Toll roads that were not specifically designed for multilane toll collection create a number of difficulties. First, the physical area required for a conventional stop-and-pay manual toll plaza or drive-through single lane AVI system is not available. Second, the number of entry and exit points on the road where tolling is applied retrospectively are generally much higher on a road specifically designed to permit the collection of tolls. Finally, the technical and procedural problems of how to electronically detect vehicles at the toll site, levy the correct toll electronically, and, where necessary, perform real-time enforcement of noncompliant vehicles without restricting the traffic flow, must be solved. This is the so-called multilane problem.

It should be reiterated that the multilane problem is a problem associated with certain technical systems. Systems that use short-range DSRC tags and transponders must address the multilane problem. The charging, classification and enforcement processes are all related to knowing with which vehicle the gantry system is in contact, and that any noncompliant vehicles can be identified and located.

Wide area systems that use GNSS, GSM, or some form of in-vehicle metering do not have the same requirement for charging. However, when the checking and the enforcement of these systems are performed, it is necessary to be able to identify and locate the position of the vehicle on the road for enforcement purposes thus, free-flow multilane solutions are required for these processes [12, 28, 70]. A typical short-range tag multilane layout is illustrated in Figure 2.15.

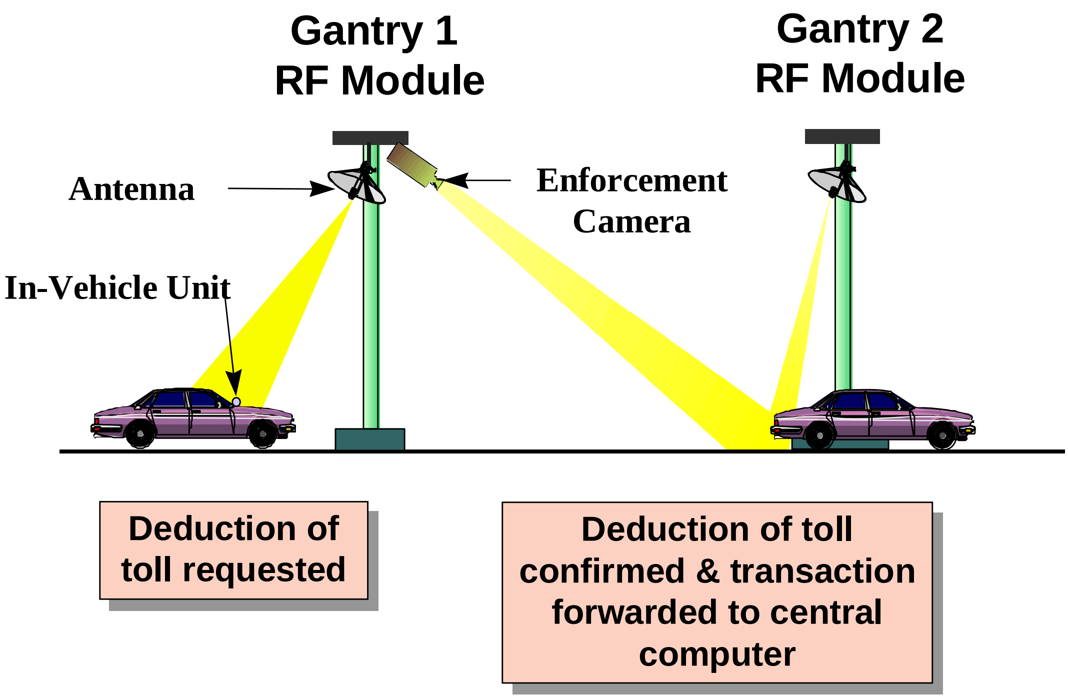

Fig 2.15 Typical Arrangement for Multilane Road-User Charging

This solution may seem cumbersome but it is necessary in many cases. The challenge is to design a reliable system that could use a single gantry. The challenge is also to achieve this in two distinct scenarios: on high-speed roads with high vehicle speeds, and on urban roads where there may be congestion and consequently many vehicle transponders within the range of a single roadside transceiver [79].

In between multilane and monolane operations, vehicles operate in a free-flow situation, but with the requirement that they stay in their lane when passing through an automated road charging point. This is often called quasimultilane operation. These three scenarios are illustrated in Figure 2.16.

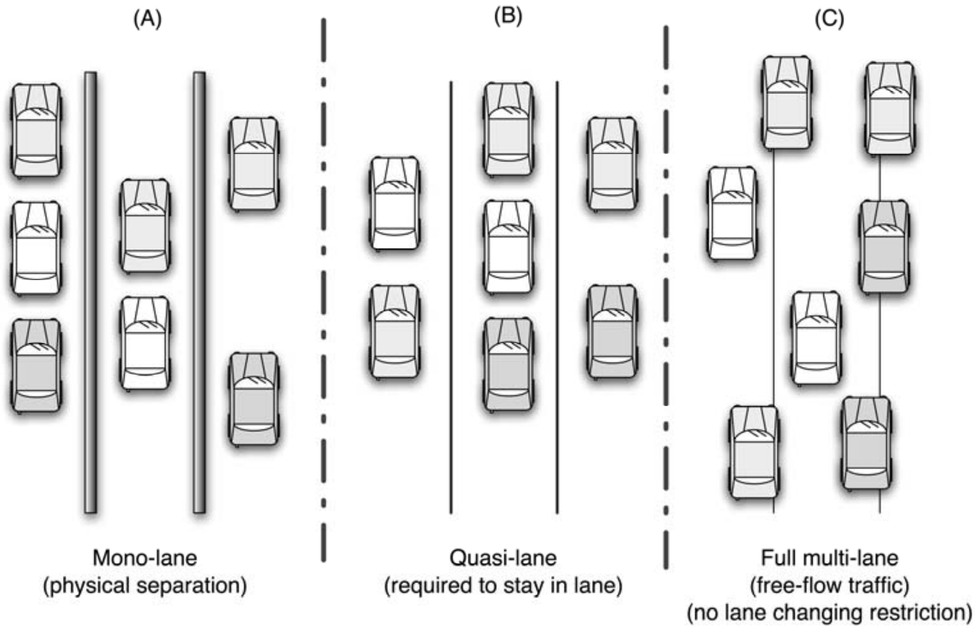

Fig 2.16 Multi-lane Free Flow: Operational Scenarios

(b) Challenges

Vehicles are allowed to pass through the toll site or road user charging site in multilane free-flow situations, without any additional restrictions on speed or lane discipline, other than those required for normal driving behavior. This means that vehicles are not restricted from passing or changing lanes at the toll site, but they are free to move as they would in normal traffic on a multilane highway.

This poses two problems for a multilane debiting and enforcement system. The first problem is communication between the vehicle's tag or OBU and the roadside tolling system, and the second is enforcement [80].

The communication problem arises because of the need to have an orderly dialogue with several vehicles transponders simultaneously, when more than one vehicle may be in the communication zone at any one time. This means that the system must maintain a secure logical communication link with each transponder for the period of time necessary for the debiting transaction to be completed.

The enforcement problem is determining which vehicle has not performed a valid payment and recording the details of the vehicle. There can be two reasons why a vehicle has not performed a valid transaction: (1) when a vehicle does not have a tag or OBU and (2) when a vehicle does have a tag or OBU, but the payment transaction has not been performed correctly, either due to some system failure or an attempt to defraud the system. The spatial position of all the correctly paying tags or OBUs must be known to some reasonable degree of accuracy by the roadside system, in order for the system to perform a correlation (match) with the vehicle detection and classification (VDC) system, which must detect and classify vehicles passing through the toll site independently from the transaction system.

The problem of designing a system to operate correctly in a multilane environment is regarded as one of the most technically demanding challenges in ITS. These technical difficulties are due to the following distinct points:

1. For DSRC-based toll systems (or DSRC-based enforcement points in a GNSS or other wide area scheme), the time constraints imposed on the system due to the short communications window in which the debiting transaction may take place (typically 100 ms) at high vehicle speeds [81]
2. The need for the roadside system to communicate with, and perform a correct transaction with, all the equipped vehicles in the communications zone
3. The requirement for the system to detect and classify all vehicles passing through the communications zone
4. The need to determine which vehicles have correctly performed a transaction
5. The identification of nonpayers
6. The identification of unequipped vehicles
7. Recording the identity of nonpaying vehicles for enforcement purposes.

For systems that use wide area communications, such as the global positioning system (GNSS)-based Toll Collect System for lorry road user charging in Germany, the requirement to carry out the above steps (except step 1) is still valid. However, the point where these steps are performed may be distributed and not at the actual point where the transaction takes place [82]. There will still be some need for onstreet multilane enforcement functionality to check that vehicles are correctly paying their charges, even if the charging is performed without the need for a multilane arrangement like that required for DSRC (transponder-based systems). The specific solutions will depend on the system configuration, charging policy, or enforcement regime [83, 84].

2.5 Complementary Systems

2.5.1 Vehicle Classification

As illustrated in the previous section, one of the ways to detect a violation is to check that the toll or fee being paid by a vehicle is the correct amount for that vehicle class.

There must be an automatic vehicle classification scheme that can discriminate between vehicles of predetermined classes on a multilane highway in real time [27, 28].

Automatic vehicle classification is performed by measuring some parameters of the vehicle and comparing them to parameters stored in a database that defines the classes in use.

No common, clearly defined classes of vehicles exist for automatic toll collection systems. Some current implementations have as few as 6 classes, while some European operators document 32 different classes. The cost of a system that can accurately discriminate between 32 different classes of vehicles would put it beyond the means of most operators of multilane systems. Experienced operators suggest that a pragmatic approach to classification should be taken, since there is a great deal of trade-off between accuracy, cost, and complexity of the system.

The classification process is also complicated by the wide variety of vehicle designs, which gives rise to marked differences between vehicles within the same class and to similarities between vehicles of different classes. A wide range of vehicle dimensions exists, which must be collected and interpreted to correctly classify the vehicles. This is difficult to achieve with some vehicles, particularly two-wheel vehicles, due to their relatively small size.

Many new techniques for online vehicle detection and classification have been demonstrated and deployed in the past few years. Although remote classification measurements may be used, many toll operators rely on the vehicle's transponder declaring the class of the vehicle when it is in communication with the roadside system. The automated classification systems are used as a backup and a threat to operators and individuals who choose to defraud the system. Chapter 5 focuses on the details of vehicle detection and classification.

2.5.2 Enforcement

To enforce an automatic road use pricing scheme, noncompliant vehicles must be detected and their identities recorded to provide evidence valid for prosecution [53, 56]. All vehicles are currently required by law to clearly display a license plate on the front and rear of the vehicle, in most European countries, and in most of the United States, with the exception of motorcycles that are required to display only a rear license plate. Recording of the license plate number provides a means of uniquely identifying noncompliant vehicles. Other information, such as the make, model, and color of the vehicle, may support prosecution of noncompliant vehicles and prevent the unjust prosecution of compliant drivers, particularly if drivers have falsified their license plates to avoid identification.

Simply manually noting the license plate details is one means of enforcing a road pricing system, although it is impractical for a heavily used widespread system. Some form of photographic method is necessary to maintain an efficient and effective enforcement procedure recourse to automatic recording equipment [57].

Two variants of automatic recording equipment currently available, based on photographic and video cameras, are used to provide pictures of license plates, which are then read manually off-line. ANPR systems are also available that may be considered for either online or off-line processing of license plates.

In the online case, the system is located at the roadside and the license plate numbers of noncompliant vehicles are recorded as the vehicles are detected. In the off-line case, the system is located in a central control station, and replaces manual reading of images captured by photographic or video cameras [63].

The reading of vehicle license plates by automatic methods involves image processing techniques for vehicle-presence detection, the accurate location of the license plate in the image, the processing of the license plate image to isolate the characters from the background, and the identification of the characters. High quality, high-contrast images are required for accurate reading [85].

Video and photographic techniques to detect and locate license plates, record the images, and read the characters online are among the most rapidly changing fields in ITS [86]. Many vendors are offering innovative and high-performance solutions, motivated by the success of the ANPR technologies utilized as the primary form of charging and enforcement in the London Congestion Charging Scheme. Enforcement technology options are the focus of Chapter 4.

2.6 Summary

This chapter has introduced the concept of road user charging and tolling, and the technical issues and options associated with the implementation of such policies. The choices presented in terms of technology and operational modes of the charging system are complicated by the policy-orientated goals that the systems must meet. The following four chapters consider each of the key elements of the system in more detail, and the design options, trade-offs, and choices are then discussed.

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