RUC: A TOLL FOR WHAT?

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Introduction

In recent years, as traffic has continued to increase, traffic related problems have become severe in urban areas around the world. These problems can be summarised as traffic congestion, shortage of space for parking, traffic accidents, traffic noise and pollution, severance of social networks and unpleasant street environment, etc. There has been an increasing recognition that transport policies in urban areas need to balance demand and supply with some combination of appropriate measures in order to deal with traffic related problems. Therefore, the concept of travel demand management (TDM), which uses different mechanisms to help to attain this balance, was born.

Road User Charging (RUC) is one of the TDM measures whose theory comes from Pigou (1920)'s study of marginal cost pricing, adapted to transport by Knight (1924). It has long been on and off in the list of preferred approaches of the transport planners - however rarely that of the public nor of politicians - to solve urban traffic congestion since Vickrey (1965) in the USA and Smeed (MoT,1964) in the UK, who advocated pricing for the direct management of scarce road space as an element in urban transport policy. Although there is no such thing as an urban pricing scheme that have been implemented for the purpose of economic efficiency, there are few schemes in operation and many more has been purposed for the purpose of traffic reduction, such as in Singapore, or environmental improvements and providing revenue for transport investments, such as Bergen, Oslo and Trondheim.

The main barriers to the implementation of RUC have been identified as public and political acceptability (Ison, 2000, Jones, 1995 and 1998). There are many stakeholder groups and concerns that affect political decision making. Although there are many design parameters therefore scheme options which could suit the concerns of stakeholder groups, there is not any systematic way of scheme design that helps the professional to consider all the possible scheme options in order to accommodate the likely concerns that are raised by different stakeholder groups.

This paper discusses the elements of RUC scheme design in a new "scheme generator format" that has been developed by the author and presented in this paper by using two operational schemes: Singapore and Trondheim. In the fist part of the paper Road User Charging (RUC) is introduced as a mechanism for charging drivers for the marginal cost of driving or their use of roads in order to reduce traffic levels, therefore reducing the environmental impacts of traffic, and raising revenue for transport investments. The second part of the paper discusses a systematic way of exploring RUC scheme options shaped with various objectives and design parameters. Finally the paper introduces three operational schemes: Singapore's earlier Area Licence Scheme and later Electronic Road Pricing, and Trondheim. The paper concludes that the different scheme options should be formed to serve different scheme objectives and local needs.

1. Theory of Urban Road User Charging

Economic theory suggests that congestion pricing is the most effective way to bring about the efficient use of road capacity, to keep travel demand under control and maintain a socially efficient level of roadway use. As many, Hau (1992 and 1995) argues that all restraint measures, other than pricing, involve huge efficiency losses or overconsumption by transport of valuable societal resources. He believes that congestion is simply a problem of excess demand, and raising the price during peak hours not only allocates scarce road space to those travellers who place the greatest value on their trips, but it also saves society significant amounts of resources in obviating the establishment and maintenance of an oversized infrastructure network.

The requirement for efficient pricing is to ensure that the cost borne by the user of roads reflects the sum of the marginal costs of

a) *road infrastructure:* Road damage is basically caused by heavy vehicles as the damage to the road pavement increases to the fourth power of the axle load. Therefore road damage costs should be proportional to the damaging power. Thus almost all costs should be paid by heavy trucks.
b) *accidents:* Accident externalities arise when extra vehicles on the road increase the probability that the other road users will be involved in an accident. Accident probability depends to a large extend on distance, driving time and particularly the other traffic.
c) *congestion*: Congestion costs arise due to the fact that additional vehicles reduce the speed of the other vehicles and hence increase their journey time.
d) *environmental damage:* The road use of vehicles has various spill-over effects on the environment like:

- local: emission of CO, NC, NO2
- global: emission of CO2, CFC
- water pollution
- noise and vibrations
- land use effects (destruction of wildlife habitats and the landscape

However, drivers only perceive and respond to the average cost of a journey. RUC requires drivers to pay for the marginal cost that they impose on infrastructure provider, road users and others outside the transport system. Consequently, drivers are assumed to take more economically rational travel decisions and therefore congestion and the environmental impacts decline as traffic volumes reduce.

Over the period, the objectives of RUC have expanded by its successful implementations in Singapore, Bergen, Oslo and Trondheim. Besides economic efficiency, RUC is mainly considered to achieve three main objectives;

- Reducing traffic levels therefore congestion,
- Improving environmental quality and
- Raising revenue for transport investments

2. RUC Scheme Options

While few studies have demonstrated the technical feasibility and economic benefits of introducing RUC schemes, limited public acceptability has been shown to be one of the key factors preventing its successful implementation (London in the 1970s, Hong Kong in the 1980s and again in 2001, and Stockholm and regional proposals in the Netherlands in the 1990s). There are various concerns raised by different stakeholder groups, such as: restrictions on freedom of travel, boundary effects for residents living just outside the pricing area, equity impacts on low income groups, or the effects on commercial competitiveness of businesses based inside the charged area. Consequently, most local authorities are hesitant, fearing the political unpopularity of proposing such a scheme.

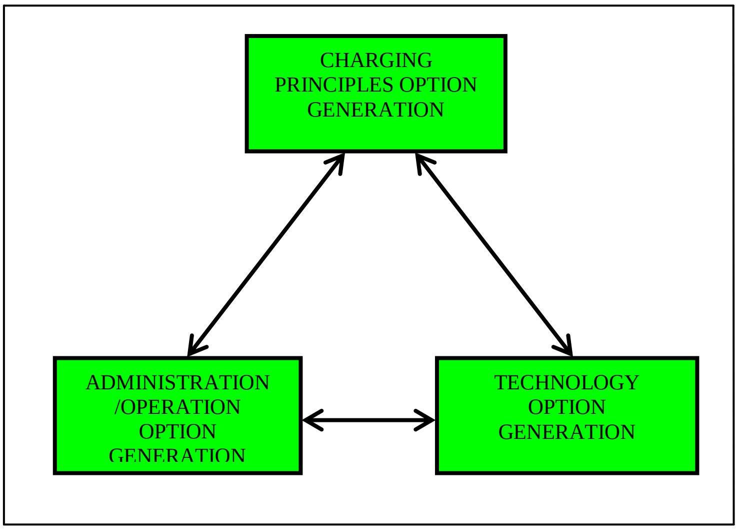
Although there are well established techniques for data collection, modelling and evaluation of RUC, the attention paid to the generation of possible RUC options has been relatively limited. In fact, there are many design parameters to consider, including: varying the area of coverage, type, time and level of charge and the technology which is used for operation and enforcement. Different combinations of the various design parameters can result in a very large number of possible schemes one of which may address the local concerns and constraints. By systematically exploring the full range of RUC options that technology now permits, it should be possible to better identify RUC options that meet stakeholder concerns while achieving strategic policy objectives.

An operational urban road user charging scheme consists of the following three elements (Kocak, 2002)

- *Charging Principles*: defines the principles of the charging, such as the area, time of day or week, type of charge, charge levels etc.
- *Administration/operation:* defines how a scheme operates in terms of registration, payment/collection of the charge and enforcement.
- *Technology* comprises the types of equipment used for the operation of a scheme.

The link between the scheme components is shown in Figure 1

Figure 1: Generic Option Generation Framework



For enabling users to generate full sets of combinations of scheme parameters in a systematic way, Zwicky's morphological approach (1969) has been adopted to each RUC scheme component, so that the design parameters and the various choices available under each parameter are set out in a matrix format. In the matrixes, each column deals with one design parameter (e.g. time of charging, type of charging) and the cells in that column represent the choices available to the policy maker with regard to that design parameter (e.g. time: weekdays and/or weekends only; all day, working hours only, am and/or pm peak only). Together, they display all the possible options.

For the purpose of this paper, the Singapore and Trondheim schemes are used as case studies, in order to present these scheme design elements for each scheme component (principles, administration/operation and technology of charging) and to present how the scheme combinations forms according to the objective(s) of urban pricing and local conditions.

3. Case Studies

In this part of the paper, the scheme components are discussed by comparing Singapore's early and current urban pricing schemes and Trondheim's current scheme.

3. 1. Principles of Charging

The first component of an operational scheme is its 'charging principles'. There are six general parameters which define the principles of charging, covering: charging area, period of time, type/basis of charging, level of charge, charging entity/unit, charge variations according to time and location, and any variations based on user categories and intensity of use. These design parameters also have a number of options covering ways in which the design might be implemented.

When designing scheme options, the starting point should be scheme Objective(s), which sets the context for design selection. For example, if the objective is to reduce traffic levels, then the charging area should cover the area where traffic reduction is required, such as the city centre, or a specific part of the network so on so for.

In May 1975 Singapore introduced world's first road user charging scheme within the central business district area (extended in 1989) in order to control car usage and increase public transport patronage. Soon after its introduction, rush-hour traffic was reduced by 45%, traffic speeds increased by 20% and accidents fell by 25% (Seik, 2000). Following the success of its 23 years operation, the scheme was revised to accommodate the modern needs of the country's transport policy in 1998. The new scheme was also the world's first example of fully electronic urban charging.

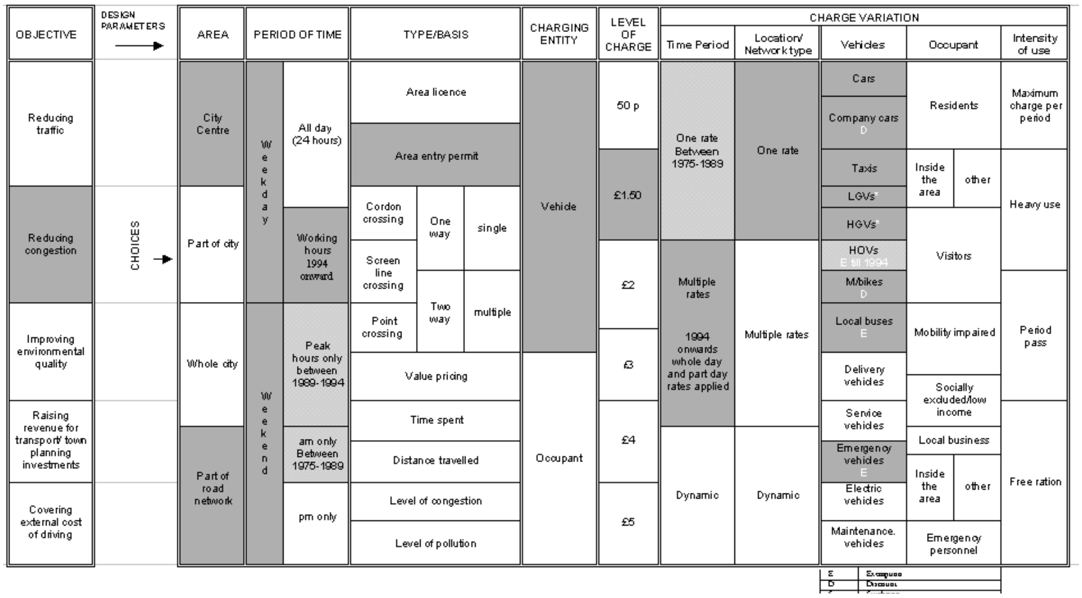
After Bergen (1986) and Oslo (1990), Trondheim is the third city where RUC was implemented in Norway, in 1991. As in the other Norwegian cities, the aim was primarily to raise revenue to fund an urban transport investment package, which was a range of improvements to the local transport system, including new road construction, improvements to facilities for pedestrians and enhanced priority and segregation for public transport (Meland, 1994). However, the fully electronic application in Trondheim provided an opportunity to apply differentiated charges to encourage a shift in traffic from morning peak to off-peak periods and so alleviate traffic congestion.

Below, the charging principles of Trondheim and Singapore schemes are discussed under each design parameter and are illustrated in the format of Charging Principles Option Generator Matrix in order to provide concise comparison.

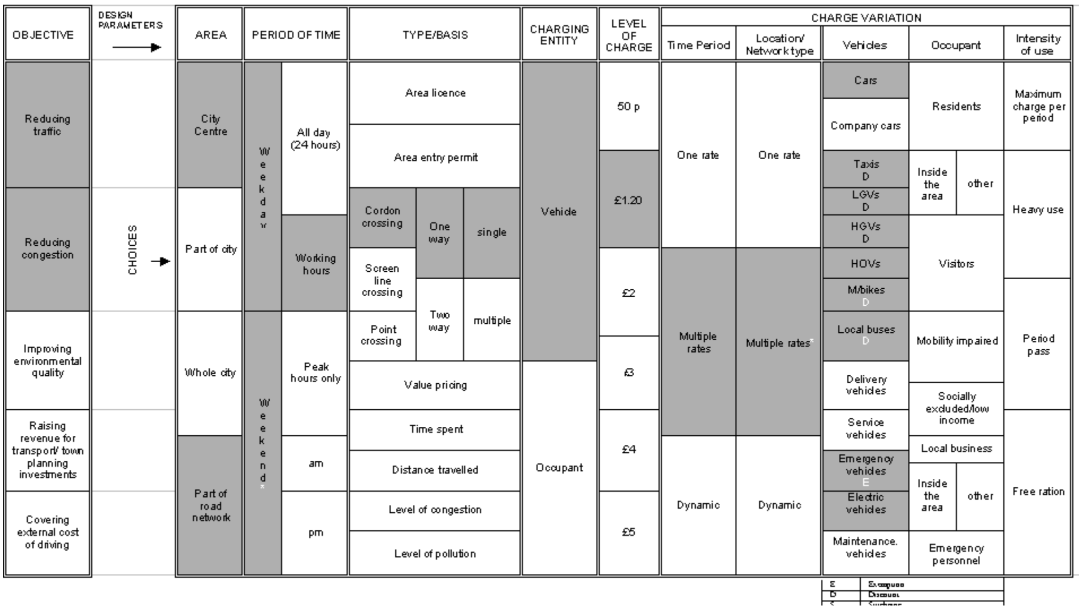
Design Parameters	3.1.1. Singapore ALS Scheme	3.1.2. Singapore ERP Scheme	3.1.3. Trondheim
objective	In May 1975 Singapore introduced world's first road user charging scheme known as Area Licence Scheme (ALS) within the central business district area in order to control car usage and increase the public transport patronage.	Singapore replaced its ALS with as known Electronic Road Pricing (EPR) in 1998 after 23 year operation. ERP to increase the effectiveness of their RUC scheme.	In 1991, Trondheim introduced Norways third road user charging scheme. Similar to the other two (Bergen and Oslo), the aim was primarily to raise revenue to fund an urban transport investment package, which was a range of improvements to the local transport system, including new road construction, improvements to facilities for pedestrians and enhanced priority and segregation for public transport the secondary aim was to apply differentiated charges to encourage a shift in traffic from morning peak to off-peak periods and so alleviate traffic congestion.

Figure 2 Principles of Charging Option Generation Matrix

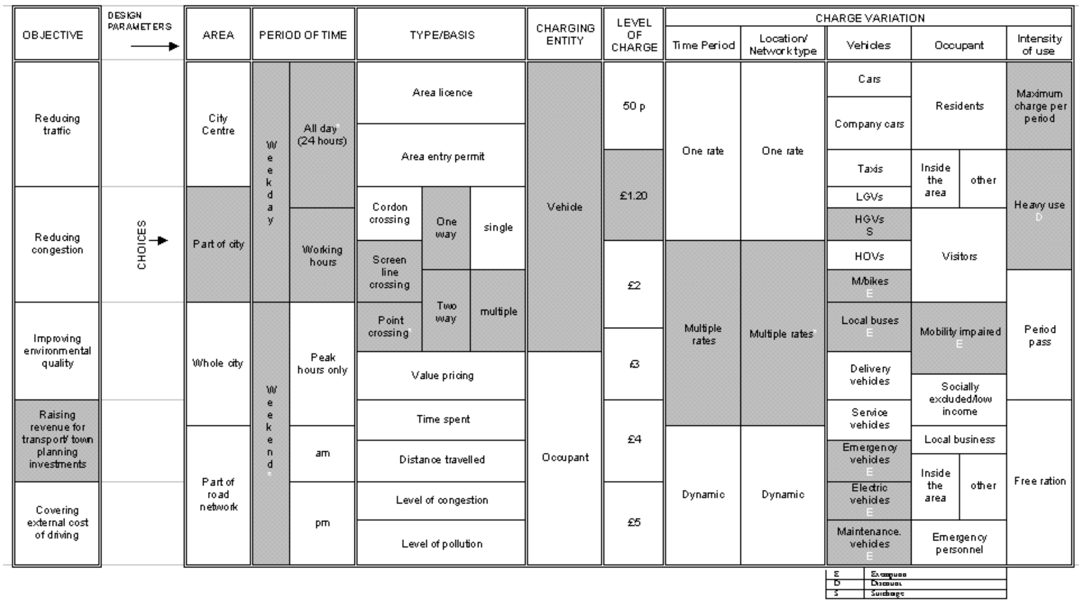
Principles of Singapore ALS Scheme Represented in Charging Principles Option Generator (* applies to RP scheme on expressways)



Principles of Singapore ERP Scheme Represented in Charging Principles Option Generator (* applies to the airport road charging scheme)



Principles of Trondheim RUC Scheme Represented in Charging Principles Option Generator (* applies to the airport road charging scheme)



Area covered for charging	The initial Singapore scheme covered the Restricted Zone (RZ) where was the most congested part of the Central Business District in 1975 (Phang, 1997). It was extended to 725 ha. in 1989. In the 1990s, following the success of the scheme, the congested sections of three major expressways were also priced that is known as Road Pricing (RP).	ERP scheme replaced the ALS scheme in RZ and RP on motorways in 1998 that is why it covered the same area and the network. However, two more expressways have been included in the scheme to date.	The initial Trondheim scheme covered the city centre and the inner and some middle residential areas as well as the airport road in 1991. However, with the revision to the scheme in 1998 it now covers most of the built area to capture as many trips as possible since the objective of the scheme was to raise revenue in equity.
Period of time for charging	The ALS was first implemented on weekdays between 7:30 am to 10:15 am (initially to 9:30 am) which was extended to include the evening peak-from 4:30 pm to 6:30 pm in 1989. In January 1994, the scheme was extended to cover the whole working day (weekdays only) from 7:30 am to 6:30 pm. and 7:30 am to 3:00 on Saturdays (to 2:00 pm in 1995).	ERP currently operates between 7:30 am and 7:00 pm on weekdays for RZ and 7:30 am and 9:30 am for expressways.	Charging hours were initially from 6 a.m. to 5 p.m. on weekdays (Monday to Friday) With the revision, it was extended to 6 p.m. for the toll ring. No charge has been applied in the evenings or at the weekends. 24-hour charges only apply to the airport road throughout the week.
Type/basis of charging	The first RUC scheme ,which is known as Area Licensing Scheme, operationally was an entry permit scheme since the license (daily or monthly-peak or off peak licences)had to be displayed at the entry points only (22 in 1975-extended to 33 in 1989), on the windscreen. With the same area licence for a day, vehicles could make multiple trips daily into the area. Vehicles were also allowed to travel free of charge (without a licence) within the restricted area during the charging hours.	Singapore replaced its simplistic entry permit operation with a cordon crossing/ pricing operation in 1998 since it became too complicated to operate for modern needs and requirements. In this scheme, charges are based on usage so those who contribute more to congestion, pay more and those who use the roads less frequently or who travel during non-ERP hours will enjoy more road tax rebates.	When the scheme was first introduced in 1991, it was a simple inbound cordon with 11-toll gates. This was integrated with charging on the airport road which was introduced a year before the toll ring opened. In 1998 the simple cordon scheme was revised and a zonal-like charging scheme came into operation, by using several screen lines throughout the city. Since this revision both way charges apply in some entry points. The reason for the revision was to raise more revenue that was needed to fulfil the transport investment plans and, to provide a more spatially equitable scheme.

Level of charge	The standard charge was $3 (Singaporean) dollars for a daily licence and $2 (Singaporean) for a part day/inner-peak licence.	In ERP scheme rates are set based on the passenger car unit. Basic rate for private /company cars is currently $2 (Singaporean) per crossing between 8-9 am.	The standard charge for cars is NOK 15 (approx. £1.20) per crossing.
Charging entity/unit	Charges only applied to vehicles without regard to its occupants.	Charges only applied to vehicles without regard to its occupants.	Charges/discounts/exemption only apply to vehicles. Occupants of the vehicles are not dealt in the system except mobility impaired drivers whose vehicles have a different status.
Charge Variations	For the first days of the scheme charge only applied to private cars and company cars (fee doubled in 1976) the then taxis included (in 1976) however cars and taxis with at least four persons were exempt from the scheme till 1989. Commercial vehicles and motorcycles (one third of the standard fee) were also included in 1989. Scheduled buses, police vehicles and emergency were exempted from the scheme from the beginning. In 1994, whole day and part day licence were introduced with the longer operation hours for different vehicles classes which made the system complicated. The charge did not vary according to entry point.	Prices differ according to vehicle class. Currently, ERP scheme has differentiated charges on cars, taxis, LGVs, HGVs, buses, motorcycles. The exempted vehicles are kept the same (fire engines, ambulances and police cars) as in ALS. In ERP, different crossing charges applies for different time periods for example before, after and between peak hours fees are slightly lower than peak hour rates. Lower rates applies to under utilised gantries in ERP scheme.	Charges vary according to time period (only for subscribers). Spatially differentiated charges are only applied at the toll plazas on the airport road. Charges also vary according to the vehicle type, with the standard charge of NOK 15 (approx. £1.20) for cars and double for HGVs from 6 am to 10 am; reduced charges are applied after 10 am for subscribers, since another objective of the scheme was to relieve traffic volumes in the morning peak. Exempt vehicles include motorcycles, public transport buses, emergency and maintenance vehicles. The only user group exempted in the scheme is mobility-impaired drivers, who register their vehicle. Charges also vary according to the intensity of use, and there is a cap on the maximum charge per unit time. Charges are limited to a maximum of 1 crossing per hour and 60 crossings per month (initially it was 75). There are different levels of discount for buying more units up front

Sources: Meland, 1994, Troendelag Bomveiselskap AS, 1998, Chin, 1996, Phang 1997 and Foo,1997 and Seik, 2000 se also http://traffic.smart.lta.gov.sg/erprates.htm,

3.2. Administration/Operation and Technology of Charging

The second component of the scheme design is the *administration/operation* of charging that is designed on the basis of the charging principles (outlined above). There are five broad design parameters that define different ways of handling the operation of an RUC scheme, again set in a matrix format to show the large number of possible administration/operation scheme options as below:

1. Authorisation/registration of the user
2. Identification of liability to a charge and determination of level of charge,
3. Payment/collection of charge,
4. Validation control,
5. Enforcement /issuing penalties.

The last but not least scheme design component is the *charging technology*. A matrix generator is designed to identify the available technologies for adapting different RUC charging principles and the various administration/operation options. In practice, technologies tend to form ‘clusters’ around complementary components that together fulfil specific system requirements. In the past, most RUC option design has been technology-led and constrained; in particular, the original paper-based scheme introduced in Singapore (and proposed in the seventies for London) severely limited scheme options.

However, the technology for implementing RUC has been improving and expanding in recent years, so that it can now offer tailor-made technology clusters to meet local needs and constraints. Nevertheless, some technology clusters are more suited to certain types of RUC charging and administration/operation design options than others. The RUC technology cluster option generator provides direct links to the other two matrices to reflect these compatibility. It covers all the main technologies under three broad headings that describe the location of the equipment: on vehicle, roadside and back office equipment/functions.

As the technology of charging is the type of equipment comprising the administration and operation of charging thus they are highly correlated. For better presentation of these interrelationship, the technology of charging is covered under the administration/operation of charging parameters. However, in the design process, first administration/operation of charging is designed by making decisions in choices available for the required design parameters and then the appropriate technology clusters are designed for the operation. Figure 3 and 4 presents the case study schemes in administration/operation and technology generator matrixes.

Figure 3 Administration/Operation of Charging Option Generation Matrix

Administration of Singapore ALS Scheme Represented in Administration Option Generator (* applies to manual lanes)

DESIGN PARAMETERS →	Authorisation/ Registration		Identification of liability / Determination of level of charge						Payment/collection of charge			Validation control		Enforcement/issuing Penalties	
CHOICES →	Vehicle	Occupant	Time	Area/ Location	Vehicle	Occupant	Intensity of use	Trip characteristics	Account	Cash transaction	Individual payment	Vehicle	Occupant	Criminal offence Civil offence	
	Pre-travel		Pre-determined/fixed						Pre-payment			Full coverage	Partial	Vehicle owner	Vehicle occupant
	During travel		Real time						During travel			Real time		Real time	
	Post travel		Post event						Post-travel			Post event		Post event	

Administration of Singapore EPR Scheme Represented in Administration Option Generator (* applies to manual lanes)

DESIGN PARAMETERS →	Authorisation/ Registration		Identification of liability / Determination of level of charge						Payment/collection of charge			Validation control		Enforcement/issuing Penalties	
CHOICES →	Vehicle	Occupant	Time	Area/ Location	Vehicle	Occupant	Intensity of use	Trip characteristics	Account	Cash transaction	Individual payment	Vehicle	Occupant	Criminal offence Civil offence	
	Pre-travel		Pre-determined/fixed						Pre-payment			Full coverage	Partial	Vehicle owner	Vehicle occupant
	During travel		Real time						During travel			Real time		Real time	
	Post travel		Post event						Post-travel			Post event		Post event	

Administration of Trondheim Scheme Represented in Administration Option Generator (* applies to manual lanes)

DESIGN PARAMETERS →	Authorisation/ Registration		Identification of liability / Determination of level of charge						Payment/collection of charge			Validation control		Enforcement/issuing Penalties	
CHOICES →	Vehicle	Occupant	Time	Area/ Location	Vehicle	Occupant	Intensity of use	Trip characteristics	Account	Cash transaction	Individual payment	Vehicle	Occupant	Criminal offence Civil offence	
	Pre-travel		Pre-determined/fixed						Pre-payment			Full coverage	Partial	Vehicle owner	Vehicle occupant
	During travel		Real time						During travel			Real time		Real time	
	Post travel		Post event						Post-travel			Post event		Post event	

design parameter	3.2.1. Singapore ALS	3.2.2. Singapore ERP	3.2.3. Trondheim
Authorisation /registration of charging	Singapore ALS accepted vehicles as the users of the scheme. Drivers registered their vehicle to the scheme as they bought the color coded licences on which has their vehicle number plate for the period of use (daily or monthly- peak or off peak licences) in advance from post offices, petrol stations, area license sale booths (located on the approach roads) or convenience stores prior to the entry so that every vehicle had a valid licence on their windscreen are authorised to enter the RZ.	Vehicles are registered with their vehicle registration details and given a unique in-vehicle unit (IU). The IUs are also color coded for different types of vehicle classes as charges vary among different vehicle classes which are cars, taxis, motorcycles, LGVs, small buses, HGVs, large buses and emergency vehicles. Its installation takes about half an hour and the best position is the middle lower edge of the windscreen. IU has a slot for a smartcard called CashCard which is issued by a consortium of local banks is used for the authorisation of the use/travel. Any registered vehicles with IU but without a CashCard or in-credit CashCard are not authorised by the system at the gantries and treated as a violator.	Vehicles are registered with their registration numbers as the users of the scheme. The registration is carried out pre-travel, by the installation of an in-vehicle transponder, which is currently a read-only tag. However, for authorisation of use, vehicles have to have a valid subscription which involves a contract with the toll company and records are kept in the user ID database. Manual lanes with coin machines and, at the key sites toll collectors, provide authorisation for the visitors and occasional users which are not pre-registered in the system. Although no post registration/ authorisation facility is available, in the case of insufficient payment by the subscribers, or inability to pay in the manual lanes (there is a post payment button which provides a receipt and information for post payment), payment can be made after the travel. The proof of payment has to be sent to the Toll Company in three working days to avoid paying a fine (300 ~ £25).

Identification of the liability to a charge and determination of the level of charge	As the charged and the exempt vehicles advertised at the entry points and the sale outlets, owners of the vehicles were responsible to get a valid licence for their use before they enter the RZ.	Due to charge levels varying according to the time of day, type of vehicle and gantry point, the technology is designed to identify whether the vehicle is liable to pay a charge and, if so, to determine the level of charge at that time. There are two gantries at each cordon point. As a vehicle approaches the first gantry, it is detected by the first antenna. A ground level control box co-ordinates the whole process. It communicates with the IU of the vehicle via the first antenna to, firstly, check for the presence of a CashCard; secondly, to check for the balance in CashCard; and thirdly, to execute debiting instructions to the IU if everything is in order. A "vehicle presence detector" (using an optical line sensor) mounted on the second gantry visually identifies the type of vehicle and pinpoints its location. At the same time, the second antenna, which is also mounted on the second gantry, communicates with the IU and acts as a confirmation device.	Due to charge levels varying according to the time of day, type of vehicle and intensity of the use, the technology is designed to identify whether the vehicle is liable to pay a charge and, if so, to determine the level of charge at that time. At the Q-FREE lanes where subscribed vehicles with electronic tags drive through, there is an automatic vehicle identification (AVI) system, using loops set into the road surface, which sense the vehicle (and its type e.g. car, HGV, bus, however this function is not used in the scheme) using magnetic induction. Thereafter the presence of the vehicle and the time of day information is passed on to the lane controller. A 856 MHz frequency (it is being converted to 5.8 GHz) antenna reads the tag, and the identification of the subscriber and the details of subscription/payment are also passed on to the lane controller. The lane controller is a computer with a charging algorithm which consists of the registration/subscription data, the payment data, and information on the settings for the charging structure. The lane controller identifies if the vehicle is liable to a charge (e.g. motorcycles and public transport buses are exempt) and the level of charge, using the information gained from the tag ID and the AVI. Since the communication is just one way between the tag and the antenna, the driver can not be informed of the charge level; however, charge levels are well advertised and already known by the users. In the manual payment lanes, the driver manually chooses the vehicle category from the toll coin machine, which sets the level of charge according to the time of day and the chosen vehicle category.

Payment/collection of charge:	Vehicle owners paid the charge according to their needs (daily/monthly whole day or part day licence) at the sale points so that the money is collected before the entry made.	There is only one way that the users pay for the fee which is to buy a smart card called CashCard at the banks, post offices and petrol station and insert it in their IU. The stored value varies from $20 to $500 and can be topped up at automatic teller machines. There is no discount given for high credit in the CashCard. While a vehicle going through the gantries, control box determines the correct deduction for the type of vehicle and instructs the IU to display its new CashCard balance.	There are two methods of subscription payment which are pre or post. With pre-payment, the subscriber pays an advance sum of NOK 500, 2500 or 5000. Charges for each crossing are then deducted from this sum. The largest amount gives the biggest discount. With post payment, the subscriber has an agreement for direct debit from his/her bank account; the bank statement shows the amount debited for use of network at the end of each month. There are also lower discounts available for the post-payment option. After the level of charge is determined for the vehicle at the toll plaza (based on its type and time of day), the lane controller checks the intensity of use and deducts the correct amount or bills the subscriber unless the tag indicates that the vehicle is exempt. There are also two individual payment methods available for occasional users and visitors. Each toll plaza has a manual lane where the payment is made by coins in specially provided coin machines. At the coin machines a "pay later" button is provided; the user enters the vehicle registration number and takes a receipt to pay the charge in 3 days otherwise it is categorised as a violator by the system. There are also three plazas with attendants at where the vehicles stop and the attendants collects the charge. However, there are no discounts applied to these methods of payments.
Validation control	Wardens at the entry points check the moving traffic if there is a valid licence on the windscreen of the vehicles according to their vehicle type and time of entry and day.	With information from the second antenna and vehicle presence detector, a control box confirms or verifies, firstly, the presence of a valid CashCard and IU; secondly, the availablility of sufficient credit in the CashCard; and thirdly, the correct deduction for the type of vehicle going through the gantry. If the transaction is valid and accepted, the control box will instruct the IU to display its new CashCard balance.	There is a spot check covering the individual (cash or credit card) payments at the unattended automatic pay machines. The validation control is carried out in real time and covers 100% of the passing vehicles at the electronic toll lanes. The lane controller checks the validity of the tag, and whether there is a sufficient credit in the account to deduct the payment or there is authorisation for post payment. Since the tags are read only, coloured lights at the side of the road are used to inform the user about their current status, a green light indicates that there is sufficient credit remaining, a white light indicates that subscription renewal is due and an amber bar indicates that the crossing is not approved.

Enforcement and issuing penalties	Enforcement was only at the entry points. Any vehicles failed to display a valid licence, their number plate registration number were recorded by the wardens without stopping the vehicles and thereafter they were sent a notice of summons within two weeks to pay a fine for entering the RZ without a valid licence. If any vehicles did not have a valid licence managed to sneak into RZ in the moving traffic without being caught there were no other means of enforcement to catch them.	If a CashCard has been inserted but there is no transaction or an invalid transaction, an error message is sent to IU to display with a beep sound. If any system error or violation is detected, the camera mounted on the first gantry takes the picture of back of the vehicle. Information about errors and violations is sent to central computer system via telephone cables by the control box at each lane at each cordon crossing points. The central computer churns out reports of offences and system errors and send them to the vehicle owners. Presently, those caught without an IU have to pay a fine of $70 while those without a CashCard or insufficient balance will have to pay $10 plus the un-deducted charge involved.	For each vehicle that passes, the AVI also activates a video, which is also connected to the lane controller. This provided a number plate image of the vehicle which can be used in the case of a violation. If passage is not validated for some reason, (such as no tag, invalid tag or insufficient credit, etc.) then the captured image is kept in the system on which the reason, time and location are recorded. If the passing is later validated then the image is deleted. The pictures are manually checked in the toll centre/office and if necessary a fine is issued to the user. Due to the detection difficulty of a motorcycle's presence (when the loops are shared with a bigger body of vehicle) and no number plate in the front motorcycles for picture taking, they are exempted in the scheme.

Sources: Meland, 1994, Troendelag Bomveiselskap AS, 1998, Chin, 1996, Phang 1997 and Foo,1997 and Seik, 2000 se also http://traffic.smart.lta.gov.sg/erprates.htm,

4. Conclusions

While the concept of RUC attracts the attention of many transport professionals, in terms of traffic reduction, environmental improvements and revenue raising, in general it is not a popular measure, among the public, businesses and politicians. It is clear from the literature that a package approach – combining RUC with a range of supporting or complementary measures that could be funded from the net revenue – is necessary in order to raise acceptability to the levels required to take political action. However, there is another area that has not been explored: that is, how to maximise the acceptability of RUC as an element of a package, by developing options that draw on the full range of potential design combinations.

This paper discussed the scheme design elements for each scheme component; principles, administration/operation and technology of charging in a systematic way that can also guide the scheme design. The case studies used here illustrate how options for each scheme parameter differs in order to achieve the objective(s) of urban pricing under different local needs and conditions. The comparison shows that the more comprehensive the principles of charging, the more complicated the administration/operation and more advanced technology are required, and vice versa.

Figure 4 Technology of Charging Clusters Option Generation Matrix

Technology of Singapore ALS Scheme Represented in Technology Clusters Option Generator

ON VEHICLE		ROAD SIDE		BACK OFFICE
Paper		Wardens/police		User registration database
Number plate		Cameras		Installation centres
Electronic number plate		Automatic vehicle identification (AVI)	Laser scanners	Call centres
			Reader loops	
Barcode			Infrared reader	Retail offices
			Radio-frequency antennas	
Transponder	Read-only tag	Automatic vehicle classification (AVC)	Inductive loops	Internet
			Treadles	
	Read-write tag		Weigh in-motion	Account payment system
			Light beams	
	Smart card		Light curtains	Charging algorithm
			Scanning devices	
	Electronic cash card		Video image processing	National Vehicle registration database
		Lane + plaza controller		
GPS/ VPS/GSM		Attendant gates		Manual image checking
Time/distance meter		Cash/coin machines or automatic pay machines		Optical character reader
Congestion/pollution detector		Congestion/pollution detector		Issuing penalty notices
Mobile communication		Charging information signs		Court action

Technology of Singapore ERP Scheme Represented in Technology Clusters Option Generator

ON VEHICLE		ROAD SIDE		BACK OFFICE
Paper		Wardens/police		User registration database
Number plate		Cameras		Installation centres
Electronic number plate		Automatic vehicle identification (AVI)	Laser scanners	Call centres
			Reader loops	
Barcode			Infrared reader	Retail offices
			Radio-frequency antennas	
Transponder	Read-only tag	Automatic vehicle classification (AVC)	Inductive loops	Internet
			Treadles	
	Read-write tag		Weigh in-motion	Account payment system
			Light beams	
	Smart card		Light curtains	Charging algorithm
			Scanning devices	
	Electronic cash card		Video image processing	National Vehicle registration database
		Lane + plaza controller		
GPS/ VPS/GSM		Attendant gates		Manual image checking
Time/distance meter		Cash/coin machines or automatic pay machines		Optical character reader
Congestion/pollution detector		Congestion/pollution detector		Issuing penalty notices
Mobile communication		Charging information signs		Court action

Technology of Trondheim Scheme Represented in Technology Clusters Option Generator

ON VEHICLE		ROAD SIDE		BACK OFFICE
Paper		Wardens/police		User registration database
Number plate		Cameras		Installation centres
Electronic number plate		Automatic vehicle identification (AVI)	Laser scanners	Call centres
			Reader loops	
Barcode			Infrared reader	Retail offices
			Radio-frequency antennas	
Transponder	Read-only tag	Automatic vehicle classification (AVC)	Inductive loops	Internet
			Treadles	
	Read-write tag		Weigh in-motion	Account payment system
			Light beams	
	Smart card		Light curtains	Charging algorithm
			Scanning devices	
	Electronic cash card		Video image processing	National Vehicle registration database
		Lane + plaza controller		
GPS/ VPS/GSM		Attendant gates		Manual image checking
Time/distance meter		Cash/coin machines or automatic pay machines		Optical character reader
Congestion/pollution detector		Congestion/pollution detector		Issuing penalty notices
Mobile communication		Charging information signs		Court action

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