A KILOMETRE-BASED ROAD USER CHARGE SYSTEM: PROOF OF CONCEPT STUDY

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ABSTRACT

The South African fuel levy is used to fund government's general expenditure programmes, including the construction and maintenance of roads and support of public transport. Yet, the continuing reliance of the fuel levy to generate sufficient income is questioned due to a decrease in the average amount of fuel sold per vehicle per annum. The need exists to identify, explore and test a viable and operationally feasible alternative that is not dependant on fuel sales when generating income. The paper undertook a qualitative analysis of transportation financing sources to identify and then explore a viable alternative to the fuel levy. Furthermore, the operational feasibility of the alternative was tested and evaluated through a proof of concept vehicle tracking experiment. A kilometre-based road user charge (KBRUC) system was identified as a viable alternative which addresses many of the problems associated with the fuel levy. The system could entail an on-board global positioning system (GPS) enabled device to be fitted to a road user's vehicles where vehicle movement data can be collected in order to generate a road use invoice at a set charge per kilometre travelled. The vehicle tracking experiment showed that a suggested configuration of the system is operationally feasible, in small scale, in South African. The paper concludes that further research is needed to assess the operational and technical feasibility of the system on a larger scale as well as policy, social and equity concerns.

1. INTRODUCTION

The South African fuel levy is an indirect excise[1] tax[2], paid at the pump per litre of fossil fuel sold, which contributes 5% to the national tax revenue (4th highest income stream) collected each year (National Treasury and South African Revenue Service, 2015). This represents 255 cents per litre of petrol and 240 cents per litre of diesel

[1] A tax levied on certain goods or commodities produced or sold within a country.
[2] A compulsory contribution to *government revenue*, levied by the government on worker's income and business profits, or added to the cost of some goods, services and transactions.

sold which culminated in a total of R48.5 billion collected for the 2014 / 2015 financial year (Engen, 2015; National Treasury and South African Revenue Service, 2015).

The fuel levy was introduced in 1935, with the creation of the National Road Fund, as a way to fund the construction of national roads (Van Lingen, 1960). From 1983 to 1988 only the National Road Fund was funded by a dedicated (ring-fenced[3]) fuel levy, in addition to tolls (Floor, 1984). Since 1988, the revenue collected through the fuel levy is used to fund government's general expenditure programmes, which includes the construction and maintenance of roads and support of public transport (National Treasury, 2014).

The fuel levy however is becoming unsustainable whereby on average less fuel is being sold per vehicle per annum (Van Rensburg and Krygsman, 2015b). The result is declining revenue collected per vehicle accompanied by an increase in registered vehicles and vehicle kilometres travelled. This is due to technological trends that includes more fuel efficient vehicles, the introduction of electric and hybrid vehicles and alternative fuels as well as societal trends which includes working from home and internet shopping.

Furthermore there is an argument that there is no relationship between road use and the fuel levy thus road users don't pay an appropriate fee for their actual road use. The costs that needs to be recouped include road construction and maintenance cost, congestion cost, environmental cost and social cost (Jaffe, 2015). The current fuel levy system do not cover all these costs. The fuel levy can also be seen as a regressive tax[4] as opposed to a progressive tax[5] whereby the socio-economic deprived population classes be hit hardest due to everyone paying the same. These classes is normally inclined to own and drive less fuel efficient vehicles. Relative to fuel efficiency, road construction costs has increased driven by inflation and scarcity of natural resources as well as labour cost (Jaffe, 2013b). As the situation in America, South Africa needs to spend more on roads, estimated at R100 billion road maintenance backlog (Wittman, 2010), than it generates from road charges (Jaffe, 2013a). The shortfall is normally funded from municipal rate taxes paid by local residents and transport grants (Freeman, 1982).

These problems faced by the fuel levy are not isolated to South Africa alone. Various countries (America, European nations, New Zealand and Australia) are also experiencing a decline in the amount of funds that this road user charge can generate (Coyle et al, 2011; Whitty, 2007; Abou-Zeid et al, 2008). They are however actively engaged in looking at alternative means of road financing. The paper aims to

[3] Guarantee that (funds allocated for a particular purpose) will not be spend on anything else.
[4] Taking a proportionally greater amount from those on lower incomes.
[5] A tax in which the tax rate increases as the taxable amount increases.

identify, explore and test a viable and operationally feasible alternative that addresses many of the problems associated with the current South African fuel levy.

The paper is structured in five sections. Section 2 provides a qualitative analysis of transportation financing sources and identifies a KBRUC system as a viable alternative to the fuel levy. Section 3 explores the key technical components required for a KBRUC system implementation. The next section describe and discuss the findings of a vehicle tracking experiment based on a KBRUC system configuration. The paper concludes with a discussion on future research needed for the development of a South African KBRUC system.

2. ALTERNATIVE TRANSPORTATION FINANCING SOURCES

Local and international governments can collect funds for transportation infrastructure and maintenance from the following traditional sources (Dierkers and Mattingly, 2009):

Fuel taxes (1) is the most commonly used form of transport funding for infrastructure construction and maintenance. This method charges each litre of fuel sold. Some countries also adds (2) sales taxes on fuel purchases which taxes fuel distributors or suppliers. Most countries collects a form of (3) vehicle registration fees applicable to each vehicle in order to be operated on the road network. Traditional bond proceeds (4) is used where the government repay bondholders from user revenues, including taxes, vehicle-related fees, and toll receipts. Additionally tolls (5) on roads, bridges, and tunnels operated by government authorities can also be charged. Furthermore general fund expenditure (6) which can be established through income taxes, sales taxes, property taxes, and other government and provincial fees as well as other income sources (7) which includes inspection fees; driver license fees; advertising; a rental car tax; government lottery/gaming funds; oil company taxes; vehicle excise taxes; vehicle weight fees; investment income; and other licenses and permits can be used. South Africa uses all the methods in some form, with the fuel levy contributing the highest revenue (80%) from road users (Transport Committee, 2009).

Governments also use non-traditional and sometimes innovative approaches to fund transportation infrastructure and maintenance:

Grant anticipation revenue vehicles (8), are any debt financing instrument (bond, note, certificate, mortgage, or lease) that a government issues whose principal and interest are repaid primarily by future government-aid funds. Similarly private activity bonds (9) are debt financing instruments authorized for highway and intermodal transfer. Government credit assistance (10) can be used whereby the government provides provinces direct loans, loan guarantees, and lines of credit for major transportation infrastructure projects. Congestion and cordon pricing (11) is another method that is designed to shift demand to less congested areas or time periods by charging motorists for road use, or varying charges, during times of peak demand. Cordon pricing similarly charges users for entry into a congested area, such as a city centre, during some portion of the day.

Public-private partnerships (12) establish a contractual agreement between a public agency and a private sector entity to collaborate on a transportation project. Other income sources (13) related to impact fees, traffic camera fees, container fees and emission fees can also be used. Except for congestion pricing the problem with the above mentioned methods is that it stimulates bad travel habits and none of them address the problems associated with a fuel levy. They will only deliver small contributions to the fund. Also, as a tax they are not really a good notion as the purpose of a tax is to change bad behaviour to good behaviour.

Lastly kilometre-based road user charges (KBRUC) (13) directly charged vehicles for each kilometre driven. This method is deemed to be the best solution to the problems associated with the fuel levy as it won't be influenced by technological and societal trends, not dependant on fuel sales, can be a progressive tax, generate more income to keep up with road construction cost and taxes for actual road use. Furthermore it can supplement and even in the future replace the fuel levy to provide sufficient income. It is a policy sensitive alternative whereby if you change the tax, it impacts on road user's behaviour. It is in theory at least, relatively easy to implement and can inform road users of the road user costs they pay through an itemised road user charge monthly bill (Jaffe, 2015; Coyle, Robinson, Zhao, Munnich and Lari, 2011).

Numerous KBRUC research and pilot projects are being undertaken around the world, each with different objectives and designs (Mileage-based user fee alliance, 2015). In America 26 states are involved in pilot projects, amendment of legislation and the forming of local and international kilometre-based road user charge consortiums (The Council of State Governments, 2015). In Europe this road use revenue mechanism have been implemented in various forms for heavy trucks in countries such as Switzerland, Austria, Germany, Hungary, Slovakia the Czech Republic and Poland (Mahendra, Grant, Higgins and Bhatt, 2011). Furthermore, France, Belgium and Russia all have freight truck based systems under development. New Zealand has a similar system applying to all heavy and diesel-powered vehicles (Road User Charges Review Group, 2009). Research on a KBRUC system in developing countries is currently in its infancy and needs to be explored.

3. KEY TECHNICAL COMPONENTS OF A KILOMETRE-BASED ROAD USER CHARGE SYSTEM

Findings from international research and pilot projects show that a KBRUC system can have many configurations but must incorporate 11 key technical components. These components include (i) the purpose of the implementation, (ii) which vehicles and users to be charged, (iii) technological devices for measuring kilometres travelled, (iv) communication of the vehicle travel data, (v) the type of road to be charged, (vi) the time of day that will be charged, (vii) how much should be charged, (viii) invoice billing, (ix) enforcement of the system, (x) protection of privacy and (xi) value- added services. The following sections briefly discusses these technical components.

Firstly, a KBRUC system can have numerous purposes that warrants its implementation. It can potentially reduce traffic congestion, excessive road wear, harmful emissions and secure funds for transport infrastructure investment (Coyle *et al.*, 2011; Sorensen, Ecola and Wachs, 2012). By supporting a fee structure based on time of day and travel location, a KBRUC system can facilitate congestion pricing across all crowded segments of the road network. In the USA, the Puget Sound Regional Council conducted pilot projects to examine this concept and found it to be generally effective in reducing overall traffic, especially during peak hours (Council Puget sound regional, 2008). A neighbouring state, Minnesota, is exploring a similar concept in its ongoing KBRUC projects (Buxbaum, 2006). Furthermore heavy commercial trucks cause significantly more road damage than lighter passenger vehicles. To help reduce excessive road wear, a KBRUC system for trucks can vary based on axle weight. This will encourage truckers to adopt trailer configurations designed to reduce axle loads and to travel, where possible, on heavily engineered highways or main arterials. Charges can be set higher for more-polluting vehicles and lower for less-polluting vehicles which will create an incentive for drivers, when purchasing a new vehicle, to select models with lower emissions. This approach has been used for a truck toll in Germany, where the least-polluting vehicles pay almost 50 percent less per kilometre than the most-polluting vehicles (Forkenbrock and Kuhl, 2002).

Second, vehicle characteristics are attributes that can be used in a KBRUC system to differentiate the basic pricing structure (Hatcher, Bunch, Hardy, McGurrin and Hardesty, 2009). By charging vehicles differently by vehicle type and weight, number of axles, vehicle emissions, vehicle energy efficiency, and vehicle occupancy the revenue mechanism will facilitate a progressive tax system.

Third, numerous technologies can be used to measure vehicle kilometres travelled. Periodic odometer inspections with annual registration, can serve as a basis for determining kilometre fees owned (Sorensen, Donath and Derian, 2009; Sorensen *et al.*, 2012). Odometer readings can also be self-reported where drivers will report their current kilometres each year as part of the annual registration process (Coyle et al., 2011; Sorensen et al., 2009).

A vehicle can also be equipped with a simple on-board device, possibly connected to the on-board diagnostics port capable of computing kilometres of travel electronically. This device will include electronic communication to transmit kilometre data without the need for periodic vehicle inspections (Coyle et al., 2011; Sorensen et al., 2012). Vehicles can also be equipped with automated vehicle identifier devices featuring radio frequency identification technology tags. These will communicate, via dedicated short-range communication technology, with gantries set up along the most heavily travelled segments of the road network (Coyle et al., 2011). A sticker-based electronic system called e-Vignette can also be used. Toll stickers are attached to vehicles denoting that they have paid the appropriate usage fee to travel on specific roadways. Furthermore the on-board unit will be equipped with cellular communications, and this will make it possible to determine, with rough accuracy, the location of travel. This configuration will thus make it possible to vary rates by vehicle characteristics, by national or provincial jurisdiction, or by smaller geographic area (Coyle et al., 2011; Sorensen et al., 2012). A more advanced option of the on-board unit will include a global positioning system receiver along with wireless communications, making it possible to determine the specific route, and potentially even the specific lane, of travel.

Rather than relying on expensive in-vehicle equipment, kilometres can be measured with a smartphone application, which provides GPS and cellular communications for measuring and reporting kilometre data (Sorensen et al., 2012). Furthermore fuel consumption can serve as the basis for estimating travel distance. All vehicles can be equipped with some form of automated vehicle identifier device. When a vehicle visits a fuel station to purchase fuel, electronic readers installed at the pump will detect vehicle ID and use this information to determine the vehicle's fuel-economy rating based on the make and model. The expected kilometres travelled can then be estimated based on the amount of fuel purchased. The corresponding charge can then be added to the fuel purchase price, while the fuel levy will be subtracted (Coyle et al., 2011).

Forth, three distinct technologies for communicating travel behaviour and billing data to the back-end system have been used. These include dedicated short-range communications (DSRC), global systems for mobile connections (GSM) and chip cards. DSRC rely on short-range microwave communications between vehicles and roadside receivers and transponders. It is commonly used to determine when vehicles enter or exit specific road segments or geographic areas. GSM is an alternative to DSRC, which can be used to communicate travel data or billing data. Although typically more costly than DSRC, GSM does not require the installation of roadside communications devices, and furthermore it permits real time communications. A chip card is a small, credit card-sized device with an embedded computer chip or memory module. The most common use of chip cards within road pricing applications is to store and transfer billing data from the on-board unit to a card reader that can relay the information to the collections agency. Card readers might be set up at fuelling stations, or alternatively they can be attached to a home computer with Internet access (Sorensen and Taylor, 2005).

Fifth, there are many instances when a location-based charge will be desirable in order to manage overall demand such as in a central business district. Location-based charging implements a charge based upon the location where a vehicle is traveling (Hatcher et al., 2009).

A sixth component is a varying rate depending upon the time of day. Time of day charging adds an additional layer to the KBRUC by fluctuating the fee rate based upon the time of day a vehicle is traveling on the roadway infrastructure. This additional layer enables a transportation agency to better manage travel demand by providing a financial incentive for someone to travel in lower demand periods.

Seventh is the rate per kilometre that should be charged. The Oregon KBRUC assessed a flat rate of 17 cents per kilometre for all travel in Oregon, while the off-peak paid a lower rate of 6 cents per kilometre for most travel, but R1.40 per kilometre when traveling in congested areas during peak hours. In the Puget sound Regional Council study depending on the time and route, the kilometre rate ranged from 0 to R5.62 per kilometre (Sorensen et al., 2012).

Eight, the system must provide mechanisms for reporting kilometres and collecting payment. Relevant issues include the frequency and method of payment along with appropriate public – and private sector roles in collecting payment and managing accounts. Payment options might include automated debit accounts, monthly billing, annual payment with registration, or even with fuel purchases.

Ninth, the system must include effective strategies for preventing or detecting efforts to evade payment fees. Although there have been numerous strategies proposed to prevent toll evasion, they can generally be grouped into two categories: (1) designing the on-board unit in such a manner as to prevent tampering or disabling and (2) observing the vehicle from fixed or mobile check points to ensure that charges are being recorded.

Tenth, a KBRUC system must protect the privacy and security of personal travel and billing data. Four approaches to privacy is possible: relying on metering options that provide no information about the location of travel, relying on a trusted third party to protect and secure private data, designing the technology with a built-in privacy safeguards, and establishing privacy legislation that clearly distinguishes between permissible and impermissible uses or personal travel data. To strengthen privacy protection, several of these can be applied jointly.

And finally, a KBRUC system must include value added services. In-vehicle metering equipment can be configured to allow for automated payment of parking charges, eliminating the need to pay at parking meters. Drivers can pay for the actual time that they occupied the space. On toll roads where, in-vehicle metering equipment can support automated toll payments, eliminating the need to stop at the tollbooth and have cash in hand. The in-vehicle equipment can share many features associated with personal navigation devices, such as real-time routing assistance based on current traffic conditions or identification of nearby points of interest. In-vehicle devices can provide satellite radio or serve as a Wi-Fi node for passengers. This can lead to a broad range of in vehicle wireless applications such as parking location and reservation services.

A KBRUC system configuration needs to be tested for the South African environment in order to assess the technical components presented. This will facilitate future research on the economic and perceptive issues of such a system. The following section briefly outlines a small scale proof of concept experiment evaluating the technical components of a KBRUC system configuration in South Africa.

4. IMPLEMENTING A KILOMETRE-BASED ROAD USER CHARGE SYSTEM CONFIGURATION

A KBRUC system configuration (see figure 1) was tested using one vehicle, in a small scale proof of concept study in November 2015, comprising of selected key technical components. The configuration was designed in order to charge all self-propelled vehicles for the infrastructure cost they incurred on the road system. A removable GPS unit, with GSM technology was fitted to the vehicle and tracking was undertaken for a period of one week collecting vehicle movement data comprising of x- and y-coordinate pairs on all roads every 30 seconds throughout the day. The use of the system was enforced by assessing the vehicle's odometer reading throughout the tracking period. The vehicle movement data was sent to a third party vehicle tracking company's server and reported via their secure web-based interface. A back-end system extracted various datasets from the web-based interface in order to compile a billing invoice to be forwarded to the vehicle owner depicting the road use charge owed. A value added service was also provided by showing information related to the vehicle movement which might facilitate a change in travel behaviour.

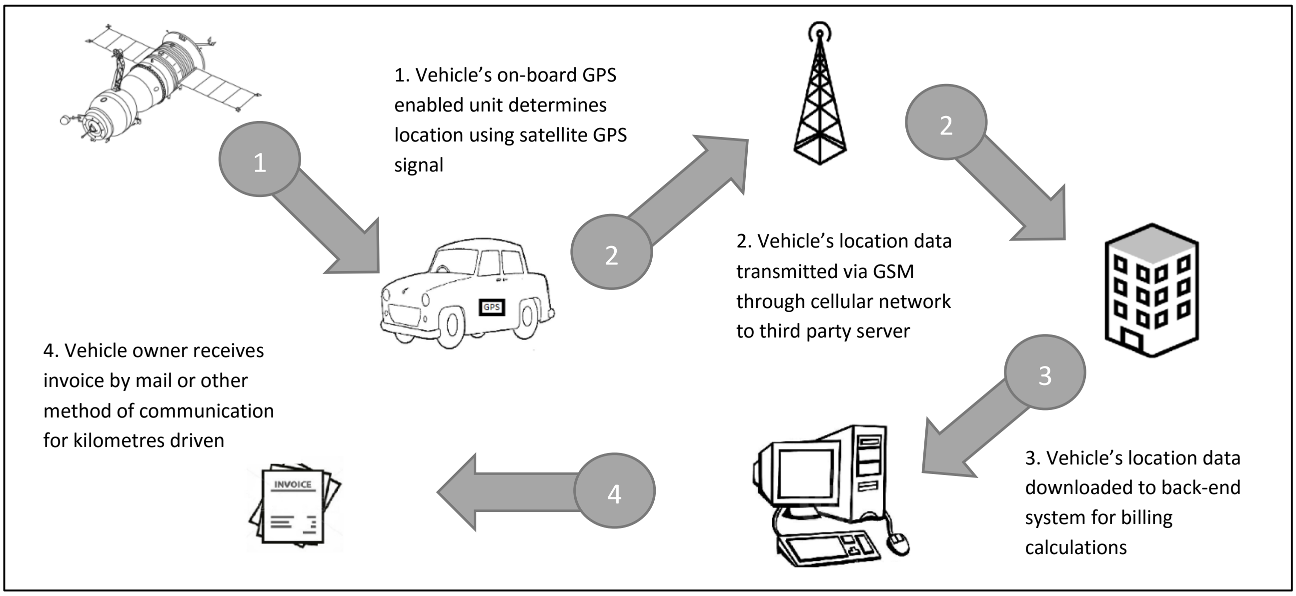

Figure 1: Kilometre-based road user charge configuration (Van Rensburg and Krygsman, 2015b)

The road use charge for the tracked vehicle was calculated at 21.45 cents per kilometre by means of dividing the estimated annual maintenance-, administration-, street cleansing-, street lighting- and capital cost incurred by the vehicle class it belongs to by the vehicle class's estimated annual kilometres travelled (Freeman, 1982). The calculation assumed a total infrastructure expenditure of R54.6 billion[6] for all vehicle classes and then allocated the cost to each vehicle class in terms of the above mentioned cost components. Added to this calculated road use charge is an operating cost of 5% for the KBRUC system to be implemented resulting in a charge of 23.10 cents per kilometre.

The invoice was compiled with a similar look and feel as the municipal account invoice of the City of Cape Town (Figure 2). The KBRUC owed was calculated by multiplying the KBRUC rate per kilometre by the amount of kilometres travelled. The invoice also incorporated a rebate for the fuel levy already paid. The fuel levy rebate was calculated by multiplying the average fuel consumption per kilometre of the vehicle by the amount of kilometres travelled and fuel levy rate. The fuel levy rebate amount was then subtracted from the total KBRUC owed by the participant to show the additional road user charge owed. Additional information related to travel behaviour and vehicle operating cost was included as a value-added service. The vehicle operating cost was calculated by means of the AA rates for vehicle usage.

Figure 2 show that the vehicle was operated for almost 10 hours, driving 332.64 kilometres while undertaking 31 trips at an average speed of 37 kilometres per hour. Distance travelled data obtained from the odometer readings was compared to the distance calculated from the x- and y-coordinate pairs. The deviation was less than

[6] Estimated income generated through the fuel levy in 2015

1% (2 kilometres). The vehicle used R222.55 worth of fuel, while accumulating a vehicle operating cost of R359.25 over this period. The total KBRUC was calculated at R76.84 for the 332.64 kilometres driven at a set rate of 23.10 cents per kilometre. The fuel levy already paid was calculated at R45.80 for using 17.96 litres of fuel at a fuel levy rate of R2.55 per litre (Engen, 2015). This resulted in the participant owing an additional amount of R31.03 for road use.

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UNIVERSITEIT STELLENBOSCH

Stellenbosch University
Private bag X1
Matieland
7602

Account number	***000001***
Reference number	***000001***

Road User Charge Invoice

Tel: '+27 21 808 2879
Fax: '+27 21 808 3406
E-mail: javrens@sun.ac.za
Correspondence: Researcher
Private bag X1
Matieland, 7602
Web address: www.sun.ac.za

Name	Participant 1
Address	Bosman Street
Suburb	Stellenbosch
Postal code	Private Bag X1, Matieland 7602, South Africa

Account summary as at	***2015-11-30***	**Due date**	***2015-12-28***
For vehicle:	***CY 123456***		
Previous account balance			*R -*
Less payments			*R -*
(a)	*R -*		*R -*
Current amount due (b)	***2015-12-28***		***R 31,03***
	Total (a) + (b)		***R 31,03***
Total (a) + (b) above	*R 31,03*		
Total liability	***R 31,03***		

Travelling information

Distance travelled (km)	332,64	Amount of trips	31
Time spend travelling	9:39:56		
Ave speed (km/h)	37,36		

Travelling cost

Vehicle running cost	R 359,25	Fuel cost	R 222,55
Vehicle fixed cost	R 934,71		
Total vehicle cost	R 1 293,96		

Please note:
(1) Billed for use of National, Provinsial and Municipal Roads
(2) Billed according to distance travelled
(3) Billed according to time of day travelled
(4) Interest will be charged on all amounts still outstanding after due date
(5) You may not withhold payment, even if you have submitted a query concerning this payment

Pay points: Stellenbosch University cash offices or the vendors below

ABSA Bank	PayCity	Checkers	SPAR
Shoprite	WOOLWORTHS	Pick n pay	Post office

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Account details as at			***2015-11-30***		**Account number**		***000001***	
Charge	**- Period**		***2015-11-11***	**to**	***2015-11-19***	***8***		
332,6365996	km	x	*0,231*				***R***	***76,84***
Fuel levy rebate	**- Period**		***2015-11-11***	**to**	***2015-11-19***	***8***		
17,96237638	litres*	x	*2,55*				***R***	***-45,80***
							R	***31,03***

* Kia Rio, 2015 model, uses on average 5,4 litres per 100 kilometres = 0,054 litre per kilometre
0,054 litre x 332,6366 kilometres = 17,9623764 litres

Current account: Total due - ***R 31,03***

Figure 2: Kilometre-based road user charge invoice (Automobile Assosiation, 2015; City of Cape Town, 2015)

5. CONCLUSIONS AND FINDINGS

The paper aimed to identify, explore and test a viable and operationally feasible alternative to the South African fuel levy. It is contended that the fuel levy is becoming unsustainable which consequently cannot secure sufficient income to fund government's general expenditure programmes which includes the construction and maintenance of roads and support of public transport.

It is recommended through a qualitative analysis of alternative transportation financing sources that South Africa investigate the possibility of supplementing or replacing the current fuel levy with a KBRUC system. This method can ensure a viable alternative that is not influenced by technological and societal trends or dependant on fuel sales as it directly charge road use by monitoring the actual time and distance of vehicle travel and then charging appropriately for that use. Furthermore the system could equip vehicles to allow for future initiatives such as congestion pricing as well as increased efficiency of the toll collection process (Fichtner and Riggleman, 2007).

A KBRUC system was found to have many configurations comprising of various key technical components that needs to be taken into consideration. These components include the purpose of the implementation, which vehicles and users to be charged, technological devices for measuring kilometres travelled, communication of the vehicle travel data, the type of road to be charged, the time of day that will be charged, how much should be charged, invoice billing, enforcement of the system, protection of privacy and value- added services.

A vehicle tracking experiment has shown that a suggested configuration of the system is operationally feasible on a small scale in South Africa. A removable on-board GPS unit with GSM technology was acquired from a third party tracking company. Installation was quick and the service was easy to use. Information pertaining to the vehicle's movement was secure and only available to the participant and researcher via a web-based interface. Vehicle travel data was readily available in the correct format for analysis and a road user invoice can be constructed with ease charging the vehicle owner for the distance travelled at a set rate per kilometre.

Future research is needed to assess the operational and technical feasibility of a KBRUC system on a larger scale as scaling issues is critical to the implementation of such a system. Additionally policy, social and equity concerns still needs to be investigated and addressed. This includes properly setting fee levels as well as to understand road user's responses to the acceptability and experience of using such a system.

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