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Selection of optimal electronic toll collection system for India: A subjective-fuzzy decision making approach

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ABSTRACT

Present study deals with the adoption of newer technologies for developing nations. Most of the developing countries due to lack of resources perform techno-socio-economic analyses on the already existing models of the developed ones. Such adopted technologies may not perform effectively because of unlike socio-economic factors. Hence, it becomes important to select new technologies based on appropriate and suitable criteria with respect to a particular country. In this paper, we have demonstrated selection of optimal electronic toll collection (ETC) system for India. In this context, we have considered thirteen crucial parameters for selection of appropriate ETC system. Cost is found to be the pivotal selection criterion in India. Further, fuzzy logic based MADM (multiple attribute decision making) approach is employed for selection of optimal ETC system for India. RFID-based (radio frequency identification) ETC is found to be the most suitable alternative among all considered ETC technologies. Our results are in strong agreement with the report of apex committee, appointed by "Government of India (Ministry of Road Transport & Highways)" for implementation of ETC in India.

1. Introduction

The most influential factor towards techno-socio-economic conditions of any country is the formulation of newer policies. An inappropriate decision can adversely affect the future scenarios of a nation. The major part of new policy formulation of the most of the countries is devoted to adoption of newer technologies. In this context, comprehensive investigation of all past, present and future technological, social, economical and environmental aspects is mandatory. A developed country follows the same protocol. On the other hand, third world countries (due to lack of resources) adopt the technologies which are already successfully implemented in the developed ones. It is to be noted that they ignore the key point of distinct resources, infrastructure, psychology of the people and many other socio-economic factors. Thus adoption as well as implementation of advanced technologies has become the most frightening as well as issue of prime concern in recent time. Present study addresses such an issue – "selection of an optimal electronic toll collection system for India". In last few years, an exponential increase in number of automobiles is noticed in India [1–5]. This can also be easily observed at Toll Plazas. Other important observations are contribution towards pollution and increasing road congestion. These cause time wastage, accidents and unnecessary quarrels. World Bank's report in 2009 reflects the seriousness of the issue [6]. They have reported a loss of "six billion USD" every year in India only because of road congestion and adverse environmental impact caused due to it. In order to overcome this problem either we have to widen the road network or need to adopt comparatively better tolling systems. Widening of road network is quite difficult due to constraints of space and infrastructure. Thus we are left with the only solution that is adaption of better electronic toll collection systems (ETC).

The most promising feasible ETC technologies in the world are based on (1) DSRC (dedicated short range communication) which covers barcode and RFID (radio frequency identification) [7–11], (2) video tolling that includes ANPR (automatic number plate reader) [12–15], (3) global positioning system (GPS) or geographic information system (GIS) or vehicle positioning system (VPS) and (4) infrared short range communication (ISRC) based on calm active infrared [16–21]. Barcode-based ETC has a bar-coded sticker attached to the vehicle and is read by a laser scanner when it passes through the toll plaza. It is the simplest as well as the

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oldest technology. It is widely used in various applications such as in library for managing book record, shopping plazas to take an account of sale and purchase, food industry to store food details and many more. Despite of these all it also has several drawbacks in order to be used for toll collection system such as lack of reliability (as can be easily imitated), less accuracy in bad weather, lack of flexibility, slow data read rate, less storage information and easy to be theft. Second technology is RFID-based ETC system [16,18], which has an In-vehicle unit (IVU) installed on the front windshield of the vehicle. This IVU interacts with the RFID frequency reader or antenna at toll plaza and transaction is done accordingly. It contains a cash card for payment of road tax which can either be prepaid or postpaid. It contains more information in comparison to barcode, has faster reading rate, tough to be fraudulent and also comparatively more reliable. It is also observed that sometimes it shows the problem of interference among frequency of devices (mobile phones, other IVU, walkie-talkies, FM radio or other electronic gadgets) in vicinity of the toll plaza or passing vehicles. Angle of installation and alignment plays an important role for reliability and high accuracy of these systems. Third important technology is ANPR [18,22]. It utilizes a stationary camera to record and identify the number plate of vehicles passing through toll plaza. The identified license numbers are matched in the database (connected with transport office) and toll is deducted. If the recorded number is not read properly or not found in the records, it issues an enforcement violation alarm to the alert the authorities. In this way, it simultaneously solves two objectives; identification of vehicle for deduction of toll tax and issuing/recording violation enforcement alert. The Indian government has started issuing "high security number plates", which is tough to be falsified. Thus this technology will also be helpful to detect the stolen vehicles and vehicles with fake number plates. It also has constraints of high cost and reduced accuracy under tempestuous environment conditions. Calm active infrared [23–25] is a relatively new technology. It is similar to RFID system, the only difference is that it has an active infrared unit installed on vehicle which contains all the information. In comparison to RFID, it has a faster data reading rate, reliability, accuracy, efficiency and it works well in all environment conditions. It also comes over the problem of interference. Lack of interoperability, vendor support and high cost are the roadblocks in usage of this technology. Apart from these, it is still under research and many other aspects need to be studied yet. Fifth technology in this list is VPS. VPS-technique [8,26,27] consists of worldwide satellite navigation system incorporation with a communication mechanism. It works with the help of a global positioning system (GPS) unit installed on vehicle attached to an on board unit (OBU), which stores the coordinates of the vehicle and send the transaction information to the toll authorities via GSM (global system mobile communication). This system is highly reliable, accurate and efficient. The efficiency of this system is not affected by environmental conditions. It provides a payment option only for the distance travelled and is highly flexible in generating the corresponding payment details. It can also be used by the police petrol for highway surveillance and theft prevention of automobile. The associated shortcomings for this system are its excessively high installation, running and maintenance cost, careful handling, requirement of extra power and other accessories.

It is clear that there are no clear trade-offs among the above mentioned technologies. Due to this, it becomes an important task to decide the best option among the existing ones. In such a state of ambiguity when one is not even able to choose the best among the existing alternative, there is no space for the question of adopting a hybrid technology. It also demotivates the policy makers to adopt newer advanced technologies. A single wrong decision can bring up loads of problems for coming generations with huge wastage of money and time. Therefore, it becomes essential to predict the best solution in terms of best alternative for such problems using a highly subjective decision making technique. Such problems can be tackled using multiple attribute decision making (MADM) techniques. A variety of methods are reported under MADM category. These methods include simple additive weighting (SAW), analytic hierarchy process (AHP) [28], graph theory and matrix approach (GTMA) [29], VlseKriterijumska Optimisacija I Kompromisno Resenje (VIKOR) [30], technique for order preference by similarity to ideal solution (TOPSIS) [31] and many others. These have been successfully applied to various fields such as manufacturing processes [32], supply chain management [33], social science decisions [34], financial decisions [35] and engineering problems [36,37]. These methods are also used by our group in last few years and found to be efficient and effective [38–47]. MADM models are used to select best alternative from the large number of alternatives for a set of selection criteria. Moreover, these also tell about the degree of closeness in terms of rank index. The above mentioned MADM approaches work on crisp values of attributes. However, in case of selection of advanced technologies, most of the attributes/parameters depend on views of various decision makers (such as user, operators, government, distributors, technical and economy experts etc.). There are no clear boundaries among the views of these decision makers. Such selection issues can be dealt with fuzzy set theory aid with MADM approaches. The aim of present work is to select the optimal ETC technology for Indian roads under fuzzy environment using fuzzy VIKOR methodology. The present study is one of the first efforts for selection of optimal ETC.

2. Selection criteria for evaluation of ETC in India

We have identified the following parameters for the selection of optimum ETC system for Indian roads. These are based on our discussion with toll authorities, operators and users (daily users as well as occasional users); and reports published by various researchers and experts [18,26,48–54] about pros and cons of various technologies.

Parameter	Description
Cost (C1)	It is the prime factor for investing in any new technology. It includes cost of installation, running and maintenance. Before adopting a newer technology countrywide it is crucial to estimate about budget and this became vital in case of third world countries. So we have to make some compromises according to our financial aids.
Reliability/accuracy (C2)	It questions the ability of system not to create any confusion regarding vehicle identity and payment options. As almost in every country different category of vehicles (e.g. two-wheelers, SUV, buses, trucks, multi-axle vehicles etc.) have to pay different amount of toll fees for the same travelled distance. So there must not be any ambiguity in vehicle detection and corresponding money deduction.
Negative environmental impact (C3)	It describes the extent to which the technology is safer for environment. The main aim of adopting an advanced technology in present case is to reduce the losses due to environmental pollution and road congestion.
Flexibility (C4)	It is to be noted that sometimes apart from the main objective the same technology may also serve in several other manners. So it is always suggested to take an account of possible future prospective with a small compromise in current assets. Utilization of ETC systems for navigation, theft prevention of automobiles and traffic surveillance are well known examples of such secondary objectives.