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SELECTION OF A SUITABLE ELECTRONIC TOLL COLLECTION SYSTEM

Thompson F. Aderonke, Aliu M. Folasade and Akinyokun K. Oluyomi
Department of Computer Science,
The Federal University of Technology,
Akure, Nigeria.
afthompson@futa.edu.ng sadealiu@gmail.com okakinyokun@futa.edu.ng

ABSTRACT: *In this work, the AHP (Analytic Hierarchy Process) is applied to select a most satisfactory ETC (Electronic toll collection) method. ETC is an applied science that permits the automation of tariff collections at toll parkways. The ETC technologies from which selection was done are based on DSRC (dedicated short-range communication) which includes barcode, quick response (QR) code and radio frequency identification (RFID). Each of these technologies was analyzed based on five criteria to optimize the selection process.*

KEYWORDS: ***AHP, ETC, Barcode, RFID, QR code, technology.***

INTRODUCTION

Infrastructure is an inclusive name for principal edifices and facilities that are vital to the growth and development of the present-day wealth of any nation (Adebusuyi, 1994). Nations that have ensured a meaningful, organized and coordinated approach in building these infrastructures have experienced significant development over the years (Beesley, 1973). Consequently, countries that have failed to ensure coordinated development of their infrastructures end up retarding their development. Toll booths are fragments of road infrastructures necessary for the maintenance of main roads in any territory. The major intent of toll booths is to help to bring about income that will assist in operating and conserving the highways effectively (Lekan, 2015). In 2012, the Nigerian government announced their plan to re-introduce toll gates on interstate roads. However, the oddities involved in the management of the toll roads have not been dealt with. The challenges of fraud, mismanagement, and irresponsibility have not been addressed. Operational and financial factors are a major challenge for many road agencies. It is therefore important to carefully consider the toll collection systems and select the most suitable one before large-scale investment to address these anomalies.
There are many ETC structures with each having its strengths and flaws. One of the most favorable ETC systems is DSRC which includes barcode and radio frequency identification (RFID) (Saurabh *et al.*, 2016). The organized implementation toll acquisition process will lessen the chain of vehicles at the toll centers.

LITERATURE REVIEW

RFID

RFID is a general phrase for recognizing technologies that make use of frequency waves to identify people or items spontaneously (Roberts, 2006). An absolute RFID structure is made of a transceiver (tag), reader/writer, antenna, and computer host. The

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transceiver, which is also referred to as the tag, is a chip that is integrated with an aerial or a receiver in a closely-packed manner. The chip has a memory and integrated circuits to obtain and transmit data to the reader (Ayoub *et al.*, 2009). These tags can be either passive or active tags. A reader is made up of an antenna that sends and receives data from the tag. The reader also has a decoder and a radio frequency (RF) module. The reader could be placed on a platform or could be a portable, handheld mobile device. The computer host holds the information systems software that acts as the intermediary between the RFID components and the end-user. The computer system converts the information acquired from the RFID system to relevant information for the client (Khadijah *et al.*, 2010).

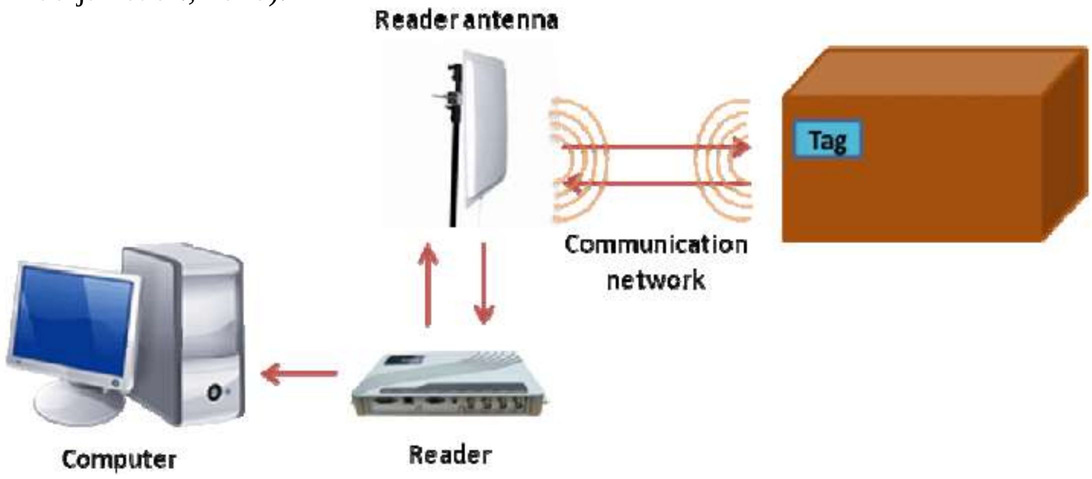

Figure 1: Working Process of RFID (Faudzi *et al.*, 2013)

Barcode

Barcodes are made up of alternating dark and light lines of various degrees of thickness. The dark lines are broad, moderate or tiny. When taken in pairs of dark and pairs of light lines, they represent the digits 0 to 9. Each time a barcode is scanned, a calculation is carried out to ascertain that it has been scanned examined correctly. Barcodes are used in library book systems to identify both books and members. They are used in passport and ID card systems to represent the passport number or identification number (Leadbetter *et al.*, 2010). A barcode reader is needed to scan a barcode. Barcode scanners may be immovable or handy. When barcode readers are installed on the computer, they scan one item at a time and transmit the obtained data. Barcodes are simple to use, accurate, and quick (Deepashree *et al.*, 2016). Figure 2 shows the image of a barcode.

6583 3254

Figure 2: A barcode

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QR Code

The QR code has black elements (square dots) laid out in a square grid on white background, which can be read by an image capturing device such as a QR scanner. The QR code is seen as a digital image by a microchip detector and is subsequently scrutinized by a microprocessor. It is a two-dimensional barcode that can store more data than a standard barcode. It has the advantage of high storage capacity, good fault tolerance, dirt and damage resistance; and versatility (Shital *et al.*, 2014). Figure 3 shows a sample QR code.

Figure 3: A sample QR Code

Deeprashee *et al.* (2016) and Rohan *et al.* (2013) made a comparison among barcode, QR code and RFID. RFID does not require a line of sight to be read as compared to barcode and QR code. RFID stores more data. However, the barcode is cheaper and does the same work as RFID but it requires a line of sight to be read. Barcode is more precise and competent than RFID (Chawla, 2007). RFID is susceptible to diverse security and privacy threats when viewed from the systems dimension and the area of information security (Chia-hung, 2009).

AHP

AHP is a multi-criteria decision approach that translates personal appraisals of the importance of a set of factors to a set of universal scores or weights. It was initially developed by Thomas L. Saaty (Saaty, 1980). It breaks down a difficulty in a ranking of criteria and alternatives. The goal must be clear, the criteria must be well-expressed and the alternatives should be sorted out discreetly. The data may be acquired from attested values like weight and height; or individual judgment such as belief and fondness (Kardi, 2006). AHP permits some level of irregularity in judgment since people are not always stable in their choices. The scale of preferences is extracted from the concept of principal eigenvectors; and the consistency index is obtained from the principle of principal eigenvalue. AHP is based on a fixed scale that transforms subjective feelings into unbiased values and changes qualitative difficulties into numeric values.

The initial step in the AHP process is to make pair-wise comparisons (judgment matrix) between each criterion. It is as shown in equation 1.

$$A = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

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Where A = *comparison pair-wise matrix,*
w_1 = *weight of component 1,*
w_2 = *weight of component 2,*
w_n = *weight of component n.*
To ascertain the comparative values for two elements in the substructure of a matrix A, pair-wise comparisons are done based on a standard table of comparison (Ming-Chang, 2014). Table 1 shows the comparison scale.

Table 1: Scales for pair-wise comparisons

Level	**Degree of Importance**
1	Equal value
3	Modest significance of one factor over another
5	The strong or crucial importance
7	Very crucial importance
9	Utmost importance
2, 4, 6, 8	Values for unsure comparison

Bring about a normalized pair-wise matrix by adding the values in each column of the pair-wise matrix and then dividing each element in the matrix by its column total.

$$X_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (2)$$

To generate the weighted matrix, the average of the normalized matrix is calculated by dividing each row by the number of criteria used. It is given as:

$$W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n} \quad (3)$$

Furthermore, the consistency vector (λ_{max}) is computed by multiplying the pair-wise matrix by the weights vector and then dividing the sum of row entries by the correlated criterion weight.
The regularity of the judgment is checked by calculating the consistency Index (CI) as seen in equation 4.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

where n is the order of the matrix.
Finally, the consistency ratio is calculated by comparing the CI with the random index (RI). As a general rule, the judgments are consistent if CR is less than 0.1. The formula of CR is:

$$CR = \frac{CI}{RI} \quad (5)$$

where the value of RI (Random Index) is shown in the Random Index Table 2.

Table 2: Random Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

If $CI \leq 0.1$, then the judgment is acceptable, else the judgment should be re-assessed.

RELATED WORKS

Xinpei *et al.* (2007) examined eco-campus using fuzzy AHP but the method of evaluation used to acquire fuzzy integration factors was based on assumption. Fang et al. (2010) applied AHP and Fuzzy Comprehensive Evaluation (FCE) to measure the harmonious relationship between humans and water to recommend the decision-making standard for the water resources management of their region. Jin-qui *et al.* (2014) made use of AHP and FCE to discover the best coaches from several sports and to grade these excellent coaches. Saurabh *et al.* (2014) also presented a subjective-fuzzy decision-making approach to determine the choicest ETC system for India. Thirteen pivotal factors were surveyed for the selection of a proper ETC system. It was discovered that cost was the most crucial yardstick for the selection in India. Furthermore, Zhou *et al.* (2017) presented a ubiquitous approach for usability assessment by combining AHP and the FCE. Waris *et al.* (2019) used AHP to develop a multi-criteria substructure for the durable acquisition of construction appliances in Malaysia. AHP method helps in making decisions based on several criteria.

METHODOLOGY

The toll collection system was analyzed based on five criteria (Reliability, Security of data, Cost, Maturity and Implementation) and three alternatives (RFID, Barcode and QR code). This information is arranged in a hierarchical tree as shown in figure 4.

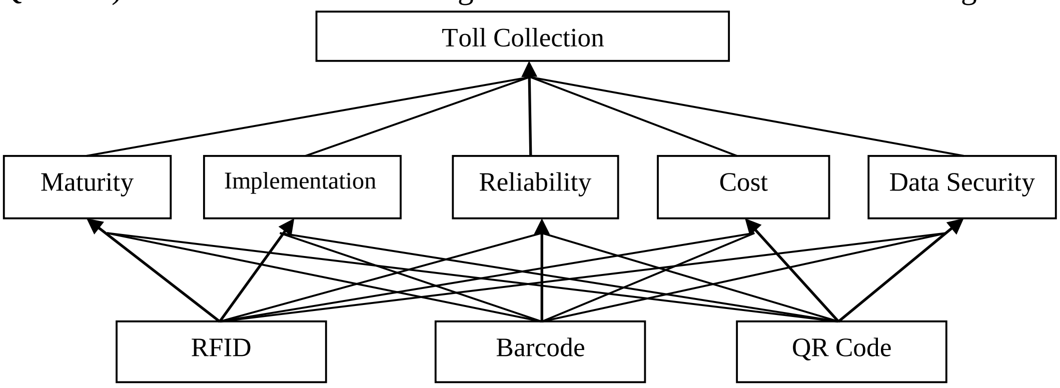

Figure 4: Hierarchical Structure for Toll Collection Method

Decision Factors

A. **Reliability (C1):** This refers to the ability of the system to work as expected without creating any delay or confusion.
B. **Data Security (C2):** This is the ability of the system to protect customers' data without posing any malicious threat.
C. **Cost (C3):** It is the major factor to consider when putting money in new technology. It includes the cost of acquisition, implementation and maintenance. It is important to evaluate the financial implication before embracing recently-acquired technology
D. **Maturity (C4):** One should make sure that the technology is well known for its positive as well as negative aspects. If the benefits and shortcomings are not

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properly weighed, it may later lead to a total break-down of the entire system, which will eventually result in a waste of time and resources.

E. **Implementation (C5):** This determines the workability or the practicability of the technology based on the country's financial strength and level of development. It will be tragic to force a new technology on the citizens if the system has not been investigated.

RESULTS

In this work, the judgment matrix is determined by an expert decision based on related research. The implementation was done using Yaahp, software for AHP. Yaahp provides help to model construction; calculation and analysis for the decision-making process using AHP. The judgment matrices are shown.

Toll Collection

$$C = \begin{bmatrix} 1 & 3 & \frac{1}{6} & 5 & \frac{1}{2} \\ \frac{1}{3} & 1 & \frac{1}{7} & 2 & \frac{1}{5} \\ 6 & 7 & 1 & 7 & 5 \\ \frac{1}{5} & \frac{1}{2} & \frac{1}{7} & 1 & \frac{1}{3} \\ 2 & 5 & \frac{1}{5} & 3 & 1 \end{bmatrix}$$

λ_{max} =5.3639 CR = 0.0812

Reliability

$$C_1 = \begin{bmatrix} 1 & 3 & 7 \\ \frac{1}{3} & 1 & 5 \\ \frac{1}{7} & \frac{1}{5} & 1 \end{bmatrix}$$

λ_{max} = 3.0649 CR = 0.0624

Data Security

$$C_2 = \begin{bmatrix} 1 & \frac{1}{3} & 5 \\ 3 & 1 & 7 \\ \frac{1}{5} & \frac{1}{7} & 1 \end{bmatrix}$$

λ_{max} = 3.0649 CR = 0.0624

Cost

$$C_3 = \begin{bmatrix} 1 & \frac{1}{7} & \frac{1}{6} \\ 7 & 1 & 3 \\ 6 & \frac{1}{3} & 1 \end{bmatrix}$$

λ_{max} = 3.0999 CR = 0.0961

Maturity

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$$C_4 = \begin{bmatrix} 1 & \frac{1}{8} & \frac{1}{3} \\ 8 & 1 & 7 \\ 3 & \frac{1}{7} & 1 \end{bmatrix}$$

λ_{max} = 3.1004 CR = 0.0966

Implementation

$$C_5 = \begin{bmatrix} 1 & \frac{1}{7} & \frac{1}{3} \\ 7 & 1 & 5 \\ 3 & \frac{1}{5} & 1 \end{bmatrix}$$

λ_{max} = 3.1013 CR = 0.0974

The judgments are consistent since the values of CR are less than 0.1. Table 3 shows the overall weights for the toll selection.

Table 3: Final Weights for Toll Collection

Element	**Weight**
Alternatives	
Barcode	0.6275
RFID	0.2723
QR Code	0.1002
The Criterion Layer	
Data Security	0.5709
Maturity	0.1877
Reliability	0.1365
Cost	0.0588
Implementation	0.0460
Combined Consistency: 0.0724	

DISCUSSION

The result indicates Barcode as the highest-ranking toll collection technology with a percentage of 62.75%. The result also shows that data security is the most pivotal criterion with a percentage of 57.09%. Figure 5 shows the graphical representation of the toll collection weights.

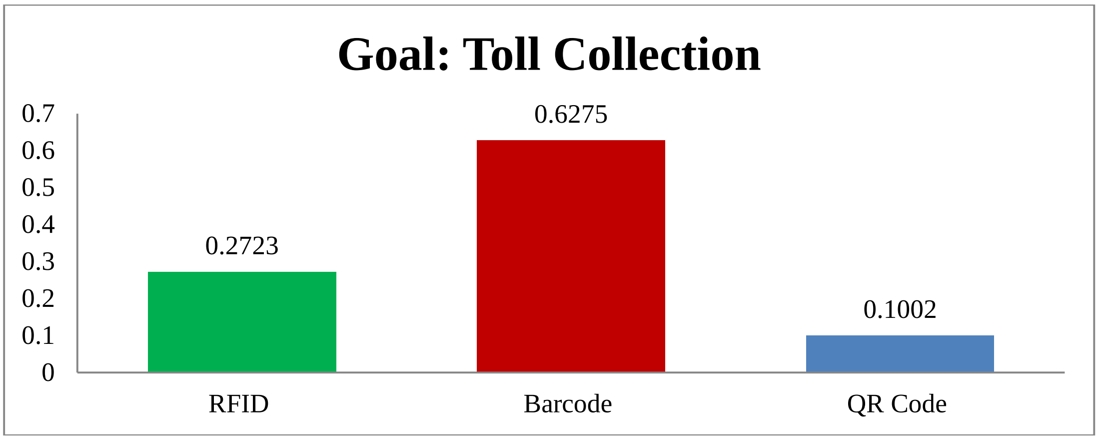

Figure 5: Graph showing Toll Collection Weights

CONCLUSION

This work proposes the use of AHP to decide on the most suitable toll collection technology. The work was structured into a hierarchy based on five criteria and three alternatives. Data security was found to be the most important criterion for the selection of the toll collection technology, while barcode technology emerged as the most appropriate technology. The result can provide an intelligent guide for the selection of an ETC method for use in Nigeria. Our future work will combine Fuzzy Comprehensive Evaluation (FCE) with AHP to capture some uncertainties.

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