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Analyze the Impact of ITS in Improving the Efficiency of Road Tax and Fee Collection Use of Digital Technologies in the City of Bujumbura

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Abstract

Road transport is currently one of the most important sectors affecting sustainable development and the improvement of the population's standard of living. In some sub-Saharan African countries, including Burundi, the transport structure is vulnerable, under attack, or even damaged or destroyed. This is prompting decision-makers to look for every possible way to enable dynamic management of the road system, as well as the collection of tax revenues attributable to this sector. To reach this stage, we postulate that the introduction of the Intelligent Transport System (ITS) into the road tax and fee collection process would make a significant contribution (road safety, zero cash on silk Safety Officers, payment of a fine, eradication of road corruption etc.) to the digitization of the various transport sectors. As far as the city of Bujumbura is concerned (our field of intervention), the applicability of the present System could thus meet the expectations of the decision-maker, certain drivers and, by the same token, contribute to the promotion of Digital Technology in Burundi.

Keywords

Intelligent Transport System, Infra-Red Sensor Network, OCR Algorithm, Vision Systems, Multi-Agent System

1. Introduction

The implementation of the Intelligent Transport System (ITS) incorporating specific functionalities aims to model the existing method of collecting road charges and taxes [1].

Not all member countries of the Northern Corridor are exempt, as road safety has become a major challenge despite considerable efforts to develop and improve transport infrastructures. In 2021, Burundi reported a total of 1,056 accidents along Northern Corridor roads, while Kenya reported 987 accidents and Rwanda 447 accidents over the same period [2]. The main causes are speeding, loss of vehicle control, careless overtaking, road conditions and road corruption [3] [4].

Burundi has a road network of over 11,000 km. According to the Burundi Roads Agency (ARB), this comprises 4456 km of classified roads and 6150 km of unclassified roads. With 47 km of road per 100 km^2, second only to Rwanda as the country with the best road infrastructure in Africa. According to the Association of African Road Managers and Partners (AGEPAR), the average road density in Sub-Saharan Africa is 7 km per 100 km^2. This compares with 12 km per 100 km^2 in Latin America and 18 km per 100 km^2 in Asia.

In terms of mathematical modeling, the decision-making system acts in line with countries already implemented in Sub-Saharan Africa such as Kenya, Rwanda, South Africa, etc. This decision-making system aims to use tools such as the OCR algorithm, python language, openCv, infra-red sensor, road vision system and queuing theory. All these tools will contribute to the implementation of this innovation in Burundi.

The aim of this study is to scientifically analyze the impact of using the Intelligent Transport System (ITS) in Burundi, with a view to raising awareness among decision-makers of the need to use the latter for several purposes: collecting road taxes, limiting the number of road incidents, apprehending users who do not respect the highway code, increasing revenue in the public treasury, etc.

2. Tools, Materials and Methods

2.1. Tools

Implementing this system requires tools such as the OCR algorithm, the Python language, the openCv library, the road vision system and queueing theory. In addition to the aforementioned tools, others such as the matplotlib library, numpy and pandas are also required, all of which will help us achieve our work objective.

2.2. Materials and Methods

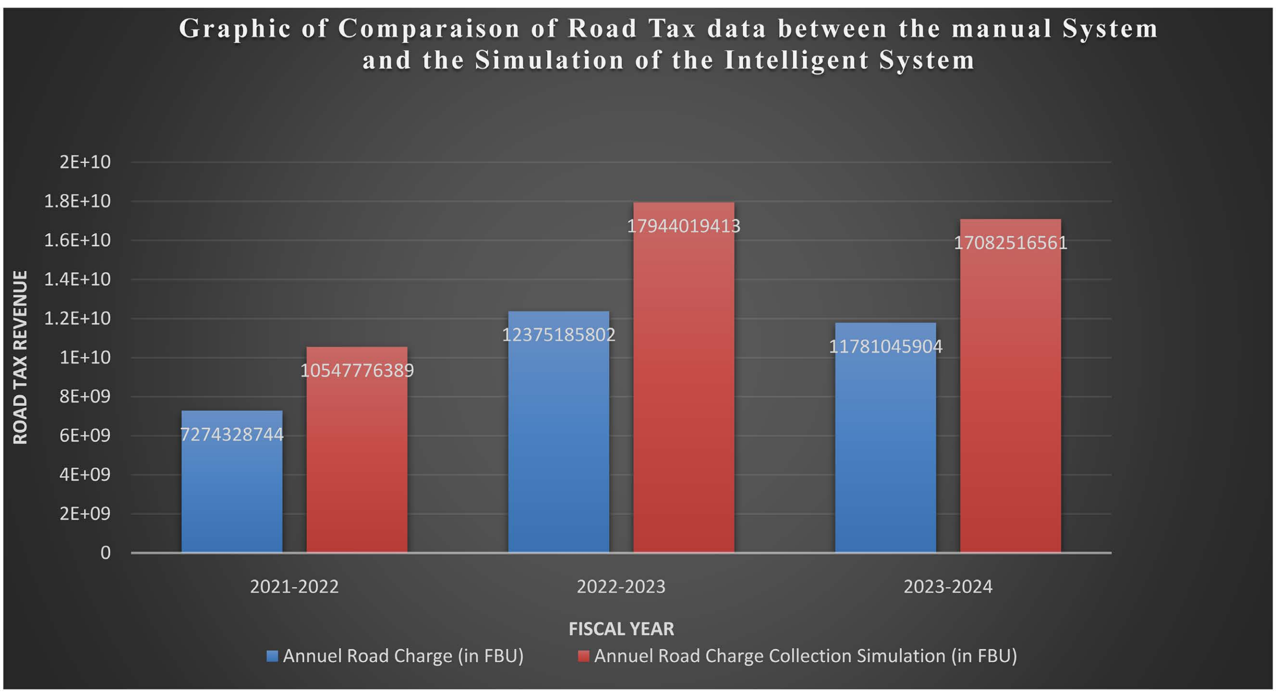
Speeding is detected by infrared sensors operating on the laser principle. This mechanism automatically takes photos of the vehicles. This photo is then encrypted and sent automatically to the server [5].

The character scanned by the OCR algorithm will be used to identify the owners of the offending vehicle, based on an Application Programming Interface (API) linking the server and the public institution in charge of registration [6]. The system will automatically classify the type of offence, the height of the fine, the time/date and location of the offence. At the end of each day, the ITS will send the vehicle owner a notification message including the offence committed, the height of the fine, the time limit for payment of the fine, as well as an indication of the additional fine if the payment deadline is exceeded.

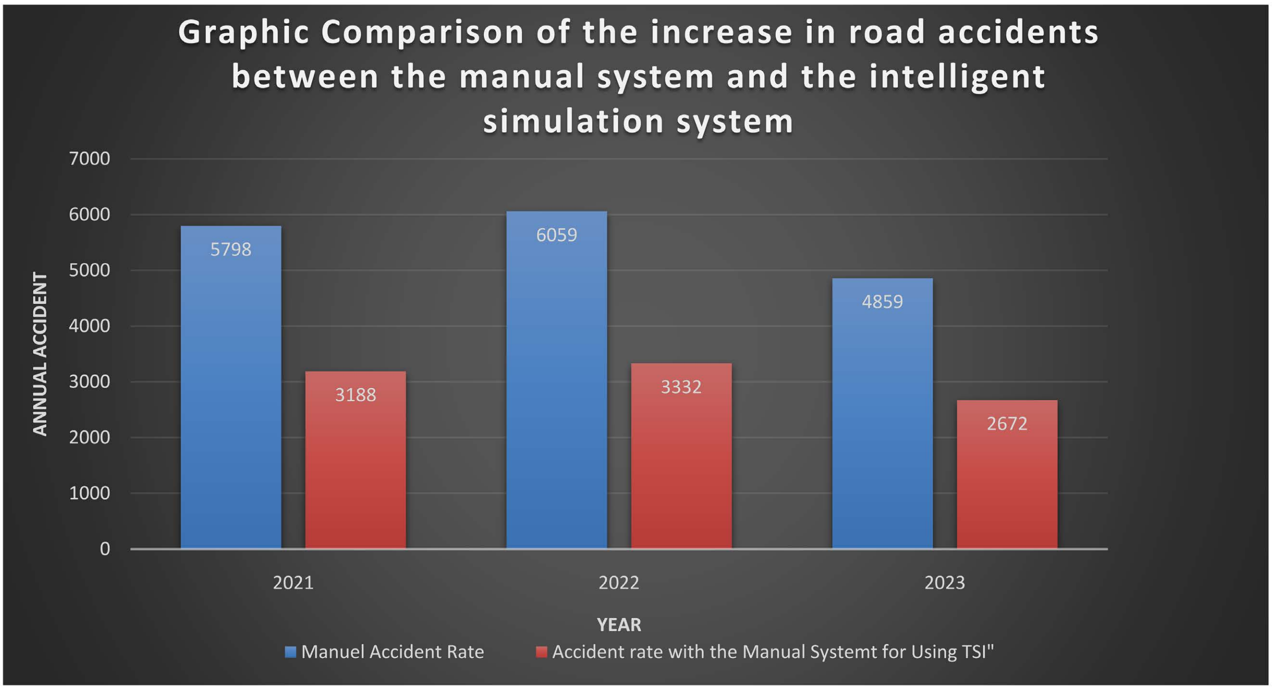
From a methodological point of view, we will use data collected in institutions such as the Driving and Road Safety Police (DR&SP), the Burundi Revenue Authority (BRA), the Burundi Transport Association (BUTRA) and the Burundi Road Agency (BRA). The data obtained from these state institutions will help us to establish a comparison between the taxes collected over the last three years via the quasi-manual system. To achieve this, we intend to simulate the results of traditionally collected taxes using the new Intelligent System. Under this system, all offending drivers will be billed according to the offence committed, while weekly and monthly reports, together with a trend graph showing the reduction in traffic offences and the increase in revenue for the public purse, will demonstrate the relevance of this system [7] [8].

Graphic 1 compares the use of manual and intelligent systems for collecting road fees. The results show the relevance of the intelligent transport system in Burundi over the last three fiscal years covered by our research.

Graphic 2 also shows the comparison between the use of the manual and intelligent systems in reducing road accidents. The simulation carried out using the intelligent system compared with the manual system shows a clear improvement in accident reduction over the last three years of the study.



Graphic 1. Comparison of road tax data between the manual system and the simulation of the intelligent system.



Graphic 2. Comparison of the increase in road accidents between the manual system and the intelligent simulation system.

3. Wireless Sensor Network Model and Control System

3.1. Wireless Sensor Network Model

The wireless sensor network is one of the technologies applied in ITS. It enables the exchange of data between several control points, while routing the data analyzed by the intelligent algorithm and image processing algorithm to the remote main server [9]. In turn, the control point facilitates the monitoring of nearby intersections.

3.1.1. Intelligent Transport System (ITS)

The Intelligent Transport System is one of the most widely deployed and developed systems in certain cities in African countries that are relatively advanced in terms of transport technology (Kigali, Kinshasa, Libreville, Yaoundé, etc.) [10] [11]. This system is a modern means of information transmission, communication, recording and control, including via the Internet, which are used to increase the level of security, stability, efficiency and improvement of the system for collecting taxes and other charges. The intelligence mechanism in the transport sector is a solution based on New Information and Communication Technologies (NICT). This technology can be used to solve problems linked to road insecurity [12].

To achieve this [13], the ITS subsystem should include modules for data reception, processing and decision-making based on data received in the server.

As a result, ITS can be applied to every mode of transport. The main thrust of this innovation is the integration of existing technologies to increase efficiency, resilience and reliability. Intelligent Transport Systems such as traffic management software and security cameras react in real time, helping to protect transport systems and infrastructure from all types of threat [14] [15].

3.1.2. OCR Algorithm

Optical Character Recognition (OCR) is a method for converting digital images into electronic text. In our academic work, OCR will help the PR&SR to make a trust of the used for license plate detection. During plate detection, this algorithm forms a rectangle around the plate characters as reference points for extraction [16].

3.2. Control System

Speed detection will be carried out using infrared sensors installed on poles at each identified intersection. The sensor takes a photo of the offending vehicles, which is then encrypted by an algorithm (OCR) and automatically sent to the National Center for Traffic Regulation Studies (NCTRS) server for identification. The data obtained, including information on the discernment of the license plate number, the critical speed reached, and the exact time and place at which the violation was committed, will be recorded [17]. Technically, the detector (transmitter) transmits a signal to the control point (receiver), located at identified intersection. Technically, the transmitter's movement must be divided into two parts: the radial movement towards the receiver, which will be affected by the Doppler effect, and the orthogonal movement, which will remain constant [18].

This is the case with speed cameras. Placed at an angle of 450˚ to the direction of the road, it transmits electromagnetic waves of frequency F in the direction of the vehicle.

$$F = f + \Delta f \tag{1}$$

the simple Doppler effect is:

$$\Delta f = f_R - f_E \tag{2}$$

While the vehicle is in motion, it will receive waves of a specific frequency f' and send them back to the radar.

For a double Doppler effect

$$\Delta f = 2f \cdot V \cdot Cos(\theta) / C \tag{3}$$

Of which: V: vehicle speed, C: celerity (speed of light or electromagnetic waves), fr: reception frequency, fe: transmission frequency of which:

$$\Delta f = f \cdot V / C \tag{4}$$

The infra-red sensor continuously emits two frequencies at a constant speed more or less equal to the celerity; the latter is transmitted at different angles. When a vehicle is hit by the first frequency, the vehicle will reflect this wave at time t_1, and the space between this point of reflection and the light source will be calculated as follows:

$$E_1 = t_1 \cdot C \tag{5}$$

The moving vehicle is struck by the second frequency at a new point at time t_2. The space between this point and the light source is calculated as

$$E_2 = t_2 \cdot C \quad (6)$$

In addition, the sub-threshold Moving Velocity is calculated as follows:

$$V_m = (e_1 - e_2)/(t_1 - t_2) \text{ where } e = e_1 - e_2 \text{ and } t = t_1 - t_2 \quad (7)$$ [19]

If the mobile's speed Vm exceeds the set threshold, an impulse will automatically be sent to a camera installed on the pole near the control point; this enables image detection of the license plate that has exceeded the required speed in the threshold environment, as shown in **Figure 1** below:

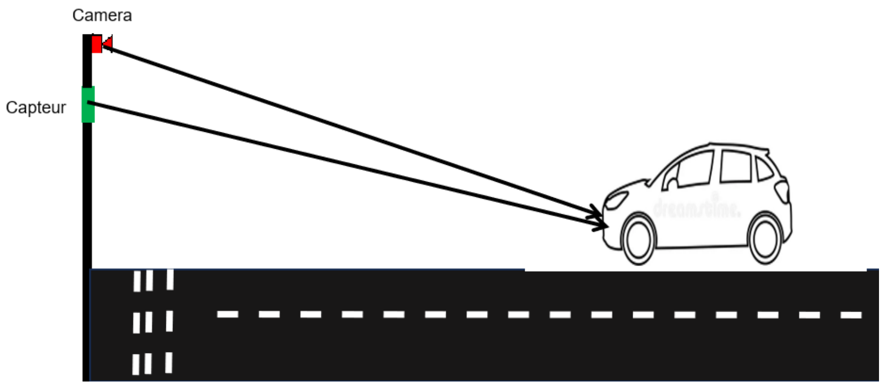


Figure 1. Infra-red wave triggering system.

Note that calculating/measuring speed, distance and time is essential for understanding and quantifying transport movements.

$$\text{Speed } (S) = \frac{D}{T}, \text{ Distance}(D) = V \cdot T \text{ and Time}(T) = \frac{D}{V}.$$

To find the average speed of a moving object between two given instants of time, we use the following formula:

$$V_m = \frac{\text{Change in position}}{\text{Change in time}}$$

In this case, the change in position is the difference between the position at time T_2 (x at T_2) and the position at time T_1 (x at T_1). The time change is simply the difference between instants T_2 and T_1. So the formula becomes:

$$V_m = \frac{XaT_2 - XaT_1}{T_2 - T_1}$$

In the scientific expression given for velocity $V = \sqrt{(5x + 36)}$, we first need to find the position values at T_1 and T_2 using the given time values (T_1 = 2 seconds and T_2 = 10 seconds). Once we've obtained the position values, we'll be able to use the formula above to calculate the average speed of the mobile between instants T_1 and T_2. The average speed of the mobile between instants T and T + Dt is equal to the ratio $(\Delta X)/\Delta T$, hence the instantaneous speed at instant T, noted

$v(T)$, as the limit of this ratio when the real result Dt.

$$V(T) = \lim \frac{x(t+\Delta T) - x(t)}{\Delta T} \text{ si } \Delta T \to 0$$

Hence $V(T)$ by definition, the derivative of the function X and Y gives: $F = R \to R$, *i.e.* a real-valued function of the variable X. The function F is said to be derivable in a if the ratio $\frac{f(x) - f(a)}{x-a}$ admits a finite limit.

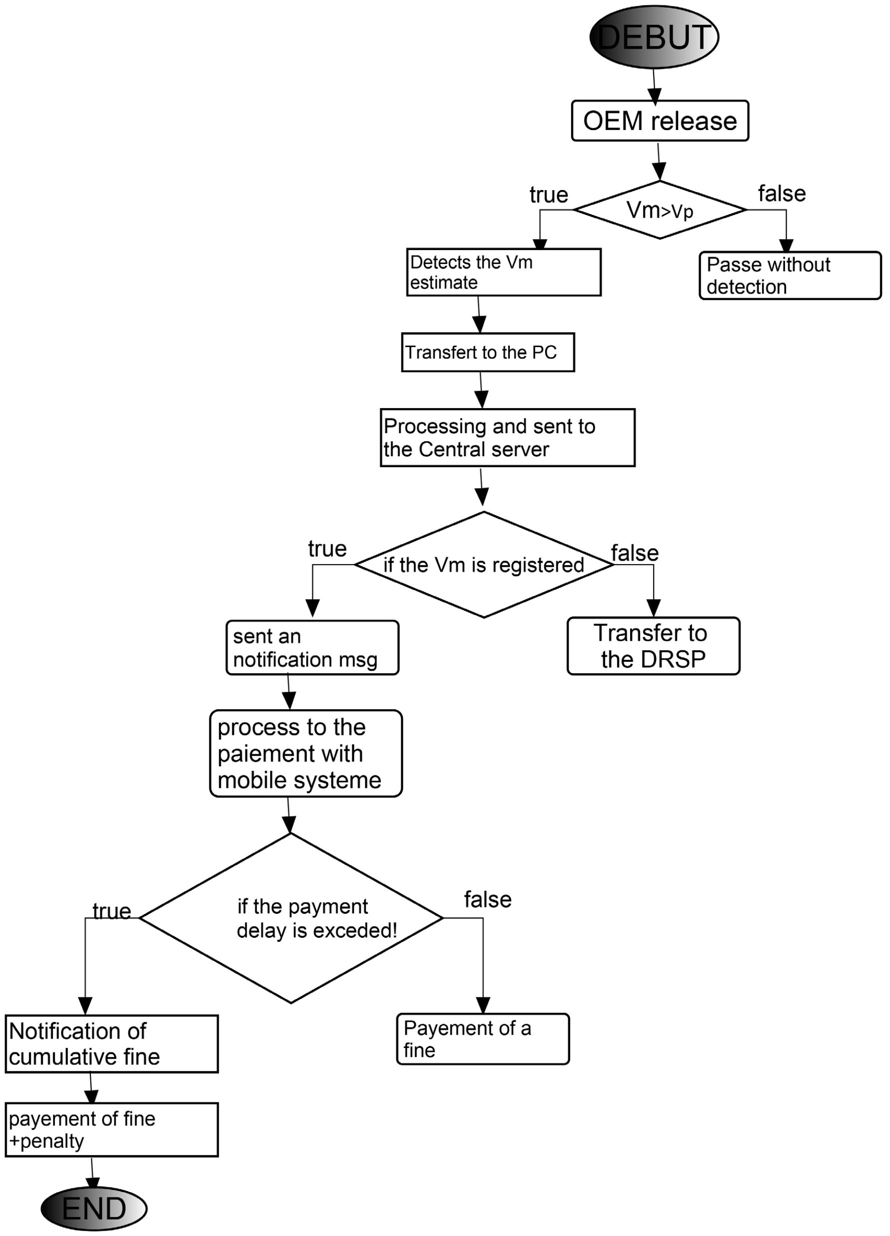


Figure 2. The number plate detection algorithm.

Figure 2 above, clearly explains how the intelligent system will trigger infra-red waves to detect the number plate in order to clarify the category of offence, the height of the fine as well as the time/date and place of the offence. This algorithm will play a critical role in the ITS, notifying the vehicle owner of the offences committed throughout the day, the level of the fine and the deadline for payment. After deadline, the system will be able to automatically accumulate the additional penalty [20].

3.2.1. Transmission of Data

When it comes to transmitting information to the central server, the fiber-optic network facilitates optical data arriving at the server in real time. When it comes to storage, all you need to do is rent a high-speed bandwidth dedicated to your system. The aim here is to avoid response latency [21].

3.2.2. Data Gathering Technique

The data collection technique consisted of a questionnaire containing one or more categories; this served as a guide for interviews conducted in the study area. Questions were put mainly to agents of the PR&SR, ATRABU, OBR, ARB, and to drivers, as well as to users taken individually to get out a given character. These questions provided us with information on: the type of road accidents, the major causes of accidents, the most common location, the number of accidents recorded, the type of equipment used, the types of fines, the fine payment system, the number of roads damaged by vehicles, the road or boulevard permitted for heavy goods vehicles, and the annual rate of fines. All these questions helped us to find out more about how, when and where the fee collection system works, as well as the number of incidents recorded by PR&SR, not forgetting the annual assessment of the road fee collection rate [22].

4. Results

We will present our results by comparing data reports from the last three years with the use of an existing manual system and the results of ITS simulations. We believe that this study will give decision-makers an idea of the losses/fraud that exist in the system for collecting road taxes and charges.

In addition, our ITS simulation results will make it possible to ensure road safety by placing greater emphasis on the detection of number plates, traffic offences (speeding, fraud in connection with the collection of road taxes and charges, unauthorized parking and no-passing, etc.), in order to reduce the rate of fatal road traffic accidents on the one hand, but also to increase revenue to the public purse on the other. It should be noted that this system will enable the creation of a database of all vehicles entering/exiting the city of Bujumbura.

5. Conclusions

The main aim of this article is to present an in-depth study of the existing system for collecting road taxes and charges in the city of Bujumbura. The aim of our research is firstly to carry out a statistical analysis of the rate of collection of road taxes and charges in the city of Bujumbura and the rate of fatal accidents caused by non-compliance with the legal texts governing road safety, and secondly to analyze the simulation results generated by the proposed mathematical formula.

In order to achieve our objective, we proposed a solution based on the use of an Intelligent Transport System based on speed detection with an image-taking device operating under the Doppler effect for smooth network operation. In addition, we have added a wireless communication system, linked to the Control Points as well as the National Center for Traffic Regulation Studies (NCTRS) which will be under the control of the Driving and Road Safety Police (DR&SP), This article makes an unprecedented special mention of Burundi in general and the city of Bujumbura in particular. Indeed, the main contribution of this study is to revitalize road safety, promote the digitalization of the country's public services and promote an intelligent, clean city.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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