Scholars Journal of Engineering and Technology
Abbreviated Key Title: Sch J Eng Tech
ISSN 2347-9523 (Print) | ISSN 2321-435X (Online)
Journal homepage: https://saspublishers.com

OPEN ACCESS

Intelligent Real-Time Management Based on Wireless Sensor Network for Road Traffic Regulation in Downtown Bujumbura

Fiston Niyonkuru[1*], Ilundu Wail Walumbuka[2], Jérémie Ndikumagenge[3], Hassan Kibeya[3]

[1]Center of Research in Infrastructure, Environment and Technology (CRIET), University of Burundi, Bujumbura, Burundi
[2]Computer Management, Bukavu Higher Pedagogical Institute, Bukavu, Democratie Republic of the Congo
[3]University of Burundi, Bujumbura, Burundi

DOI: https://doi.org/10.36347/sjet.2025.v13i06.003 | **Received:** 18.01.2025 | **Accepted:** 21.02.2025 | **Published:** 19.06.2025

***Corresponding author:** Fiston Niyonkuru
Center of Research in Infrastructure, Environment and Technology (CRIET), University of Burundi, Bujumbura, Burundi

I. Abstract

Original Research Article

Globally, traffic management is a daily concern during peak periods. The presence of this state of affairs observed daily has a negative impact on many areas such as economy, ecology, air and noise pollution, and contributes to the multiplication of certain diseases such as headaches, acute respiratory infections, lung cancer and travel-related stress. The use of technology and real-time analysis facilitates road traffic management. The constant is that traffic jams are often the result of poorly designed priorities, even though the number of vehicles and population density is constantly increasing. Moreover, the quality and quantity of urban infrastructure is not sufficient to help meet this challenge. Ultimately, it would be desirable for decision-makers to adopt a strategy based on the use of advanced technologies or to build new infrastructure including three bridges in the northern neighborhoods and two bridges in the southern neighborhoods of the city of Bujumbura to deal with traffic congestion.

Keywords: Wireless Sensor Networks, Queuing Theory, Intelligent Transport System, Intelligent Algorithm and Method.

II. INTRODUCTION

Globally, overall, the population has been increasing for several decades. This has had an impact on people, the economy, infrastructure and the environment.

African countries are no exception to this reality, which continues to have an impact on various aspects of socio-economic and environmental life, especially in the country's large cities such as Bujumbura.

Indeed, the population growth of Burundi will continue at a steady pace, going from 11,215,580 in 2020 to 13,375,501 in 2030, an increase of 66.08% over 10 years. In the municipality of Bujumbura, the population was 692 364 inhabitants in 2020, with a scientific estimate of 825 701 inhabitants in 2030, an increase of 16.14% over 10 years [1]. Based on the estimate, it was expected that the number of cars in Sub-Saharan Africa would increase from 1,410,000 in 2023 to 1,890,000 by 2029, an increase of 6.04% [2].

As of 31 December 2022, there were 72,214 vehicles in circulation in Burundi, including 34,069 cars (47.17%), 16,479 motorcycles and tricycles (22.82%), 10,637 jeeps (14.73%) and 1,104 other vehicles (15.28%). Based on vehicle age, 19,867 (27.5%) were between 20 and 50 years old, while 31,338 (43.4%) were between 11 and 19 years old.

In addition, 8,449 (11.7%) were aged between 5 and 10 years, including 4,576 motorcycles and tricycles. However, there are 12,560 (17.4%) vehicles under 5 years of age, including 9,959 motorcycles and tricycles. Approximately 2,500 vehicles (2,111 aged 31-40, 133 aged 41-50 and 288 aged 50 and over) were between 30 and 50.

In terms of pollution, the majority of vehicles in the country are internal combustion engines, most of which are used cars, usually older, making them the main source of greenhouse gas emissions [3] [4].

III. METHOD OF DATA COLLECTION

The data used are collected by the technique of interviews with drivers, road safety officials, pedestrians and the administration of PSR (Security and Road Traffic Police) and ARB (Burundian Road Agency), as well as health workers such as respiratory physicians. In addition, we have developed a kobocollect form for use by agents of the road traffic management structure. Using computer and technical tools, we were able to identify the causes and consequences of these traffic jams. Additionally, by application, this data has allowed us to create an intelligent algorithm for managing congestion effectively.

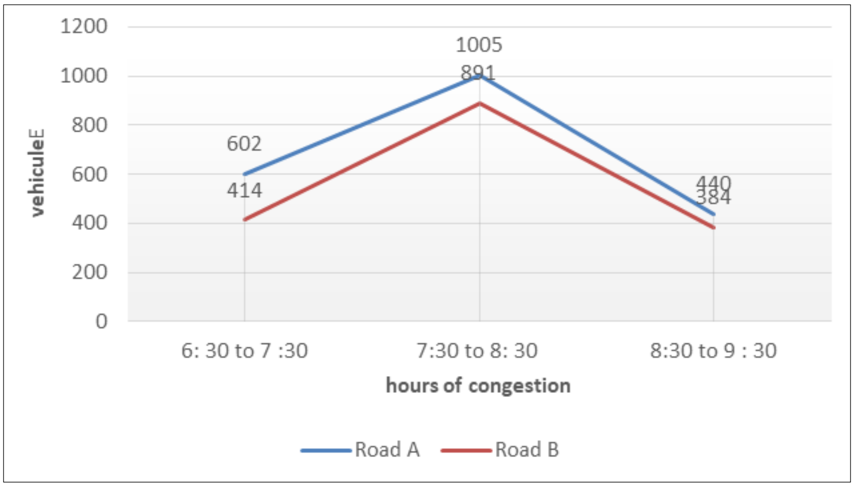
III.1 Data

In many major cities around the world, road traffic and congestion are a daily reality to such an extent that there is reason to believe that the situation will not improve in the years ahead. Traffic jams occur during peak hours, particularly morning, noon and evening. To obtain the simulation data, we conducted automatic road counting in section consists of identifying vehicles on a simple-way or double-way road axis, this count was carried out in the studied environments to know the number of vehicles on the road.

Table 1: Road A and B at the intersection of North Station (RN1) in the morning period

H.of congestion	Number of vehicles On route A for 60 min	Number of vehicles On route B for 60 min
6.30 to 7 .30 a.m	615	522
7.30 to 8 .30 a.m	767	618
8.30 to 9 .30 a.m	488	398
Total number of vehicles	1870	1538

The above table shows the number of vehicles operating for 60 minutes during peak hours from 6.30 minutes to 9.30 minutes. Looking at the number of vehicles, it can be concluded that traffic police have difficulty in managing traffic jams effectively [5].



Graph 1: Variation in the number of vehicles on the roads of the North Station road A and B in the morning

The graph above shows the variation in traffic during busy times compared to the non-congested period at the North Station intersection of the National Road1.

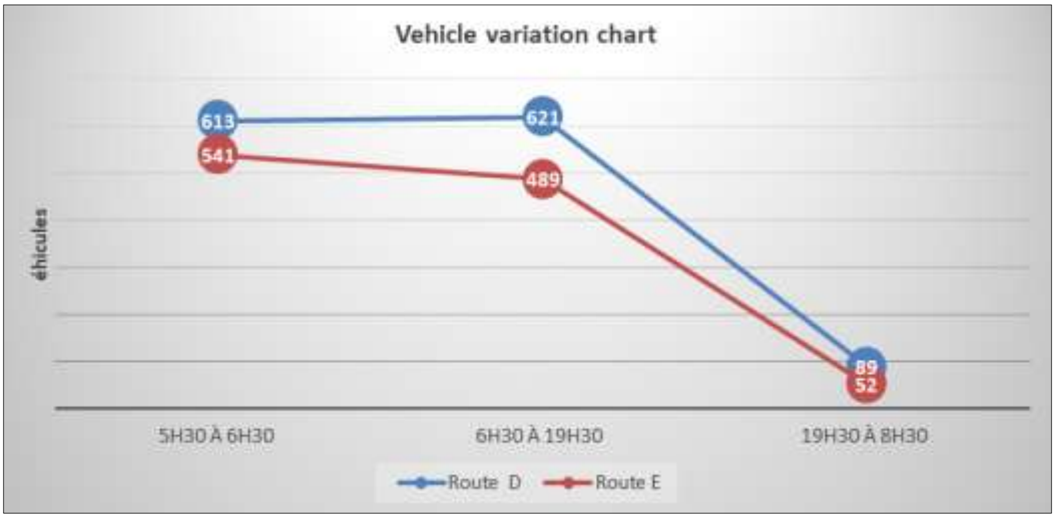
Figure 1: Types of traffic jams on the intersection of the North Station RN 1 lane A in the morning

In light of this image, we can see the position of tricycles at the northern station hearing the green light to have permission to continue the journey to the city center of Bujumbura.

Table 2: Data from D and E roads on the intersection of North Station in the evening period

H.of congestion	Number of vehicles On route D for 60 min	Number of vehicles On route E for 60 min
5 :30 to 6 :30 pm	613	541
6 :30 to 7 :30 pm	621	489
7 :30 to 8 :30 pm	89	52
Total number of vehicles	1323	1082

The above table shows the number of vehicles circulating in the 60-minute period during peak hours between 5.30 pm and 6.30 minutes pm and 7.30 minutes pm at 8.30 pm on evening. After analysing the data in this table, it can be concluded that the number of vehicles circulating at night is lower than the number of vehicles circulating in the morning. In addition, the traffic police have difficulties managing traffic jams effectively.



Graph 2: Variation in the number of vehicles on the roads of the North Station Road D and E in evening period

At the intersection of North Station on the national road 1, the graph above shows the variation in traffic during busy times compared to the non-congested period.

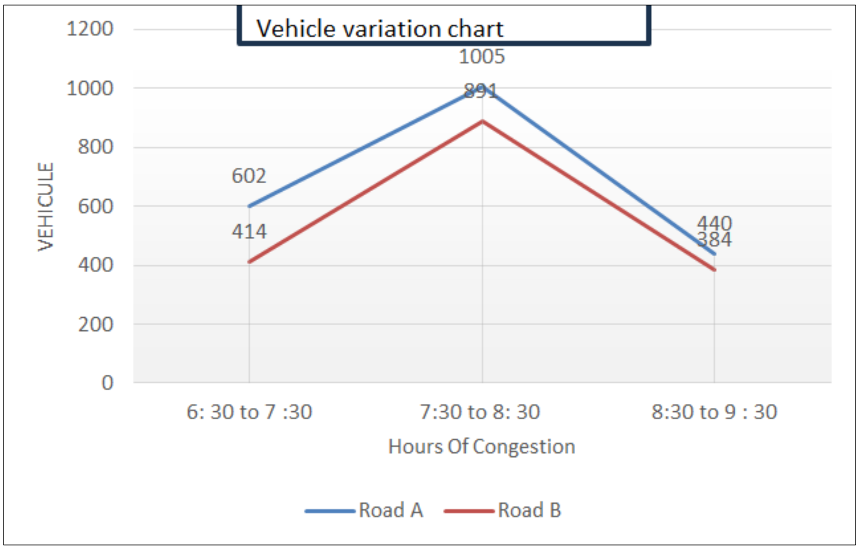
Figure 2: Traffic jam type on RN 7 Route A

Figure 2 above shows the congestion situation and its management at peak times in the study environment at North Station and the UN roundabout. The image above shows that traffic is heavy compared to existing infrastructure/road capacity. As a result, the risks of accidents and high fuel consumption become very common in these locations.

Table 3: Data from A and B roads on the intersection of United Nation roundabout (COTEBU) in the morning period

H.of congestion	Number of vehicles On route A for 60 min	Number of vehicles On route B for 60 min
6.30 to 7 .30 a.m	602	414
7.30 to 8 .30 a.m	1005	891
8.30to 9 .30 a.m	440	384
Total number of vehicles	2047	1689

The above table shows the number of vehicles on Route A in a 60 min queue interval (RN9) as well as the Numbers of vehicles in Route B in a 60 min queue interval (Av Mwamutsa) from 6.30 minutes to 7.30 minutes and 8.30 minutes to 9.30 minutes. It is at this time that the police are regularly present and vigilant to regulate traffic and prevent too many accidents.



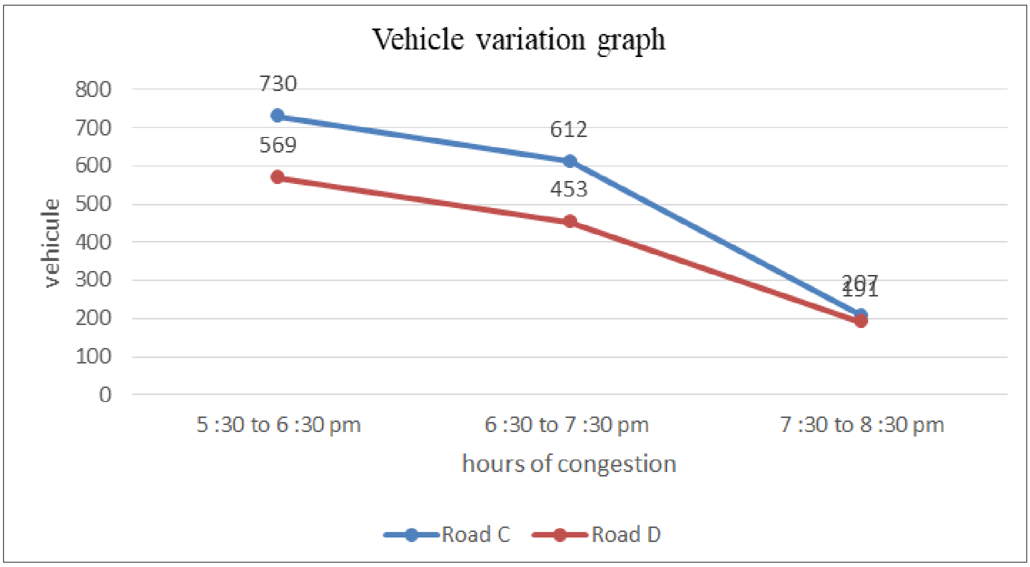
Graph 3: Variation in the number of vehicles on the roads of United Nation roundabout road A and B in the morning

This graph above shows the variation of vehicles in busy traffic times compared to the uncongested period on the United Nations intersection from 6. 30 minutes to 7.30 am and 8.30 minutes to 9.30 am.

Table 4: Data from C and D roads on the intersection of United Nation roundabout (COTEBU) in evening period

H.of congestion	Number of vehicles On route C for 60 min	Number of vehicles On route D for 60 min
5 :30 to 6 :30 pm	730	569
6 :30 to 7 :30 pm	612	453
7 :30 to 8 :30 pm	207	191
Total number of vehicles	1549	1213

The above table shows the number of vehicles on road C in a 60 minutes queue interval People's Boulevard MURUNDI as well as the number of vehicles in road D in a 60 minutes queue interval, it is to be said from 5.30 minutes to 6.30 minutes and 7.30 minutes to 8.30 minutes. After analysing the data in this table, it can be concluded that the number of vehicles circulating on road D is lower than on road C.



Graph 4: Variation in the number of vehicles on the roads of United Nation roundabout road C and D in evening period

The above graph shows the variation of traffic in busy times compared to the uncongested period on the United Nations intersection from 5.30 pm to 6.30 pm and 7.30 pm to 7.30 pm.

A participatory methodological approach was used to conduct this study, taking into account all the actors involved in the analysis of the phenomenon of traffic jams in the city of Bujumbura, particularly at the three intersections, namely the roundabout of the RN1, United Nation roundabout (RN9) and the Kanyosha Small Seminary roundabout (RN3). Different data collection methods and tools were used to achieve this objective [6] [7].

III.2 Causes of Bottling

Traffic in the city of Bujumbura is becoming increasingly intense. As a result, there are traffic jams on major highways such as the Boulevard de MWEZI GISABO connected to the Boulevard de MWAMBUTSA, the Route RN 9 dedicated to Lieutenant General Adolphe NSHIMIRIMANA, the Boulevard of the Burundian People, Boulevard dedicated to the Heroes of Democracy in Burundi President Melchior NDADAYE RN 5, to the road JENDA RN 7 and to the road RUMONGE RN 3.

It is therefore difficult to get around the city without spending a lot of time in traffic jams. There are several reasons for the traffic congestion in the city, including poor traffic organization, population increase, increase of new vehicles, etc. It is clear that Burundi currently has 15 ministries, most of which are based in the city of Bujumbura. In addition to these are the general and technical services, large companies, art galleries and the central market. Surveys carried out on key axes reveal that the bottling often begins at 6.30 minutes and ends at 8.30 minutes in the morning, a duration of 2 hours precise. In the evening, the bottling starts at 5.30 pm and ends at 8.30 pm, a precise 2-hour time.

III.3 Consequences of Traffic Congestion in the City

As TomTom puts it, “traffic jams are a calamity”. Their consequences fall into two broad categories: the country’s environment and economy. For the environment, traffic congestion significantly increases air pollution, fuel consumption and thus greenhouse gas emissions. For the economy, waste of tens of billions of francs dedicated to road redevelopment, delay of goods and administrative services [8].

III.4 Study Methods

The different methods used are theoretical, empirical and analytical. The first method allows to define decision thresholds to validate the assumptions initially made. The data collected allowed us to detect the real causes of the traffic congestion problem in the city of Bujumbura with quantified indicators of more than 65%. The second method consists of a field survey using different tools such as questionnaires, interviews and observation [9]. The third and final method is to examine the methods used to manage traffic jams on the main roads of the city of Bujumbura. These methods allowed us to verify the different effects of traffic congestion in the study environment that led us to defend our idea of modernizing this sector.

IV. MATERIALS AND METHODS

IV.1 Materials

Since the 1989, policy makers in the country have been looking for a technological solution to road traffic management, but no improvements have been made. In 2017, the government of Burundi renovated the same project, in collaboration with the Chinese company Sinohydro Tianjin, installing traffic lights at 18/45 intersections. After 8 years of installation, 10/18 are currently down due to multiple problems including the stale, bumps by awkward drivers, lack of maintenance etc.

After analyzing these government initiatives to address these congestion problems, we decided to conduct extensive research based on the experience of countries that have faced this kind of challenge but currently have a successful model. To achieve this, countries such as Canada (Toronto), China (Beijing), South Africa (Cape Town), Spain (Madrid) and Australia used equipment such as intelligent traffic lights and dynamic algorithms.

Dynamic congestion management methods such as TRANSYT, SCOOT, SCATS and PRODYN were proposed in the 1960 to improve the fluidity of vehicle flows. These algorithms were presented to highlight the variety of these traditional methods [10]. Given the current situation of the city of Bujumbura, we have adapted a PRODYN method (Dynamic Programming) which is a decentralized system adaptive to road traffic in Bujumbura. The advantage of using this method is to optimize traffic flow online by minimizing delays in turning green or red light on for a period of 80 seconds. The frequency of phase changes and light durations is set at 5 seconds depending on the number of vehicles detected in the queue. The operation of modern fourth-generation traffic lights is based on dynamic programming to minimize delays by relying on a traffic flow model across the entire horizon. Regarding communication between control points, it is important to use wireless sensor networks to facilitate data exchange between two or more nearby control points. This dynamic programming allows for expressing the evolution of queue based on arrivals and departures on the road.

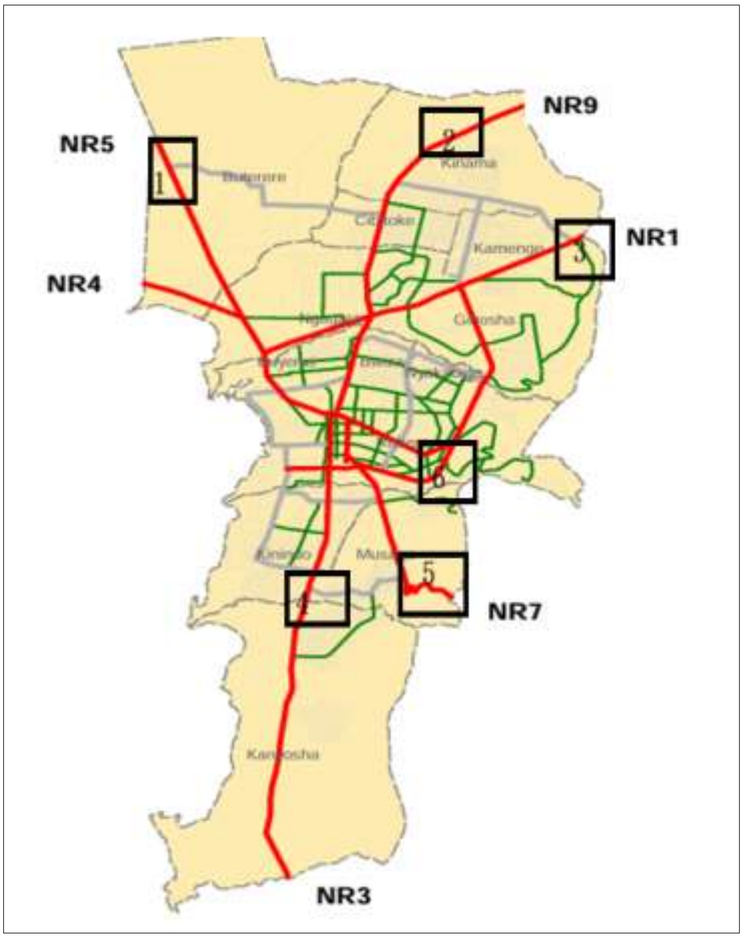


Figure 3: Road network in the city of Bujumbura

The image above shows the road network of the axes and national roads entering the city of Bujumbura. This image identifies areas where traffic lights and sensors can be installed to improve traffic management and driver detection. The most frequently mentioned national roads are RN1, RN9, RN7 and RN3 [11].

Figure 4: Condition of some of the traffic lights in Bujumbura

Through this image, one of the traffic lights is seen being struck by the clumsy driver who violated the highway code and escaped the sanctions according to law.

IV.2 Methods

The theory of queues will be applied to know the length of the queue: N(0), the waiting time of all vehicles during the cycle: WC, the waiting time of all vehicles during the red period: WR, the waiting time for all vehicles during the green period: WV and the number of vehicles in the queue: N(t). For much more complex systems, a single queue is not sufficient, so wait networks are required. A queue network is made up of several interconnected queues between which flows of vehicles flow. In an open queuing network, as shown in the figure below, vehicles arrive from outside the network, pass through the various stations and then leave the network [12].

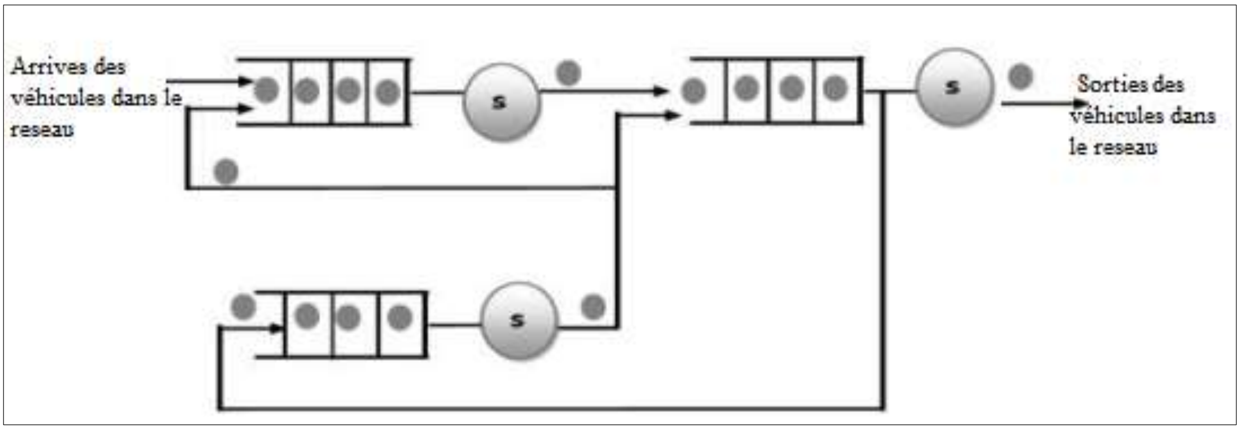


Figure 5: Mathematical model based on queuing theory

The theory of queues is based on several theoretical concepts, including: Kendall notation, which can be summarized as a sequence of A/B/C/K/N/D. symbols where: A: represents the probability law of the arrival process; B: represents the service process; C: number of servers; K: system capacity (queue + servers); N: vehicle size; D: service discipline. Little's law is the only condition for a stable system. L = W* λ, L: is the average number of vehicles; W: is the average time spent in the system; λ: is the average flow rate of a stable system. A system is said to be stable if and only if the fraction of the rate of arrival by the service rate is less than 1, i.e.: λ=μ < 1. Markovian queues are those for which inter-arrival and service times are exponential; a M/M/1 queue is a system formed by a queue of infinite capacity and a single server. Vehicles arrive in the system according to a Poisson process of rate λ, where λ is the inter-arrival time, and A(t) is a random variable with an exponential distribution of parameter λ. The service time is distributed according to an exponential law of parameters μ, where μ is the average size of a packet [13], [14].

$$P_k(t) = \frac{(\lambda t)^k}{k!} e^{-\lambda t}$$

With Pk(t): probability of having k conductors arrived during t. **1**

$$A(t) = 1 - e^{-\lambda t} \quad (2)$$

A(t): Probability of arrival during t. The service order is FIFO or even LIFO, from a queue M/M/1. The total wait time for all vehicles is very important in traffic theory, because it allows us to assess the volume of congestion. The mathematical equation gives us the following results:

Where W is the total waiting time of vehicles at intersection X; d is the waiting time of a vehicle.
Then : E [W] = E[d]. E [A(k)]
The average waiting time during a cycle.

$$E(WR) = E[\int_0^R (N(0) + A(t))dt] = RE[N(0)] + \frac{\lambda R2}{2} \quad (3)$$

$$E(WV) = E[\int_0^C N(t)dt] = \frac{\lambda pR}{2(1-\lambda p)2} + \frac{p(2\lambda RE[N(0)] + (\lambda R)2 + \lambda R}{2(1-\lambda p)} \quad (4)$$

$$E(WC) = E(WR) + E(WV) = \frac{\lambda R}{2(1-\lambda p)} (R + \frac{2E[N(0)]}{\lambda} + p(1 + \frac{1}{1-\lambda p}) \quad (5)$$

Hence, the average waiting time for a vehicle per cycle is

$$E[d] = \frac{\lambda R}{2(1-\rho)}(R + \frac{2E[N(0)]}{\lambda} + p(1 + 1 -1 \rho)) \quad (6)$$

Either: A(t): the number of vehicles arriving in the system within the interval [0, t], this interval begins with the beginning of the red period A(t) P(λ). N (0): the length of the queue at t = 0 (that is, at the beginning of the red period). WC: The waiting time for all vehicles during the cycle. WR: The waiting time for all vehicles during the red period. WV: The waiting time for all vehicles during the green period. N(t): The number of vehicles in the queue at time "t", with each driver taking a period of time "p" to cross the intersection. In this case, the green period (V) is assumed to consist of "m" departures, each with a length of "p".

IV. 3 Traffic Volume

Referring to the 3 figure, most of the National roads entering the city of Bujumbura are composed of the capacity of a 1*1 lane road (sf) is considered to be 1000 vehicles/hour/lane/sense (uvp). The other roads are composed by the motorway whose capacity of a 2*2 lane road is considered to be 2000 vehicles/hour/lane/sense (uvp) [12].

❖ ***For N-1 lane roads :***

Sf = 2000.N-1*($\frac{V}{C}$) $f_w.f_{HV}.f_A$ **7**

With reference to figure 3, most of the national roads entering the city of Bujumbura are composed by 1*1 lane road (sf) whose capacity is considered to be 1000 vehicles/hour/lane/direction (uvp). The other roads are composed by the motorway whose 2*2 lane capacity is considered to be 2000 vehicles/hour/lane/direction (uvp).

❖ ***For N lane roads :***

Sf = 1000.N.(V/C) *$f_w.f_{HV}.f_A$ **8**

Where: Sfi: capacity at service level **i**; N-1: number of lanes; (v/c)**i**: volume/capacity ratio for service level **i**; f_w: reduction factor as a function of road width; f_{HV}: reduction factor as a function of the percentage of heavy goods; f_A: reduction factor depending on the environment. The capacity of a 1*1 lane road was calculated using N-1= 2, f_{HV} = 0.5.

❖ **General Wording for Two-Lane Roads**

Capacity calculations are based on one of the peak hours (morning, noon and evening) under ideal conditions. This ideal hourly capacity is then adjusted according to a number of factors to determine the actual capacity of the medium in question. Hourly capacity under ideal conditions has been estimated at 1025 uvp/hour in Burundi. The formula for calculating capacity under real conditions, derived from HCM, is as follows: Sf = 682* f_d* f_w Where: Sf: hourly capacity v/c: volume/capacity fd: capacity reduction factor for directional imbalance f_w: Reduction factor for narrow lanes and sidewalks.

❖ **Report $\frac{C}{V}$**

For near saturation traffic conditions, i.e., the lowest service level, the following v/c ratios can be used: In flat terrain: 0.9, in hilly terrain: 0.9 when the proportion of the line where overtaking is impossible and less than 50%; 0.8 when this proportion is greater than 50% (or 0.85 on average). - In the mountains: 0.8 when the proportion of linear where it is impossible to exceed and less than 50%; 0.7 when this proportion is greater than 50% (that is 0.75 on average).

V. Sensor Network in Traffic Control

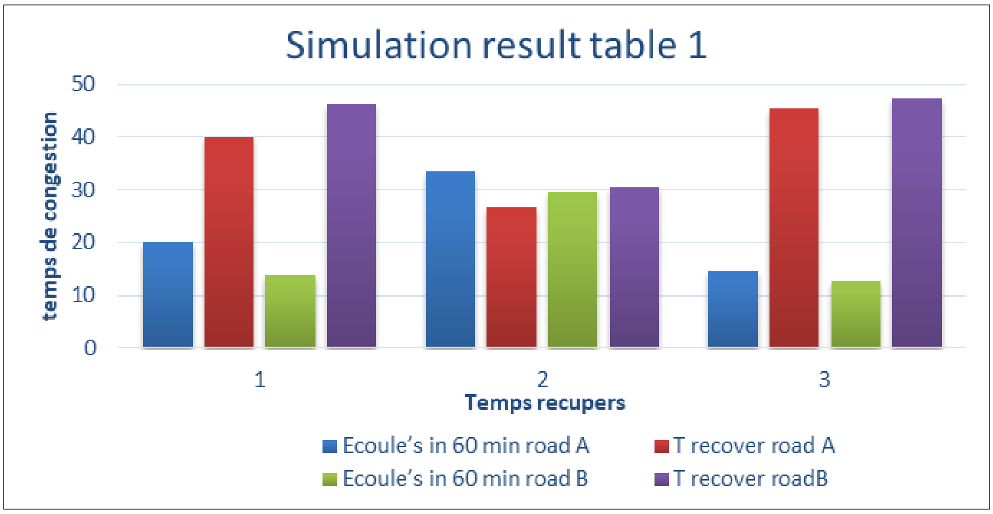
Wireless sensor networks are electronic devices designed to measure a physical quantity of the environment in which they are deployed and send these measurements to an information system. Wireless sensor networks belong to the family of ad hoc mobile networks (MANET) and consist of a large number of sensors whose capacity and energy are generally limited. The sensors are made up of the following units: Acquisition unit; Computing unit; Communication unit; Energy unit. In many cases, the sensors are dispersed in low energy environments and are equipped with a non-rechargeable and non-renewable battery [15]. In our applicable study, we used the RCSF to transmit real-time data from one intersection checkpoint to another, to the central server. This information will be used to guide the decision making [16].

V.1 Data Transmission

Real-time data transmission plays a crucial role in congestion management. Thanks to the wireless sensor network, we were able to optimize data transmission via the multi-path routing protocol. This is effective for managing multiple paths to the central server. Node 1 sends the data collected to node 2 or multiple nodes to establish the shortest path. Outside of this protocol, the additional protocol is used. These routing protocols are query-based. Query-based routing propagates the requests from the base station. The base station sends requests for certain information from network nodes, which are responsible for detecting and collecting data. In addition, they link these requests and if there is a match with the requested data, node 1 starts sending the data to the checkpoint. Each control point will have a sensor node attached to facilitate routing between the control point and another. The focus is on the 24.125Ghz satellite communication band which facilitates direct access to the central server [17] [18].

VI. RESULTS AND DISCUSSION

The city of Bujumbura, economic capital of Burundi, is made up of 5 main roads. It is constantly confronted with the recurring problem of traffic jams.



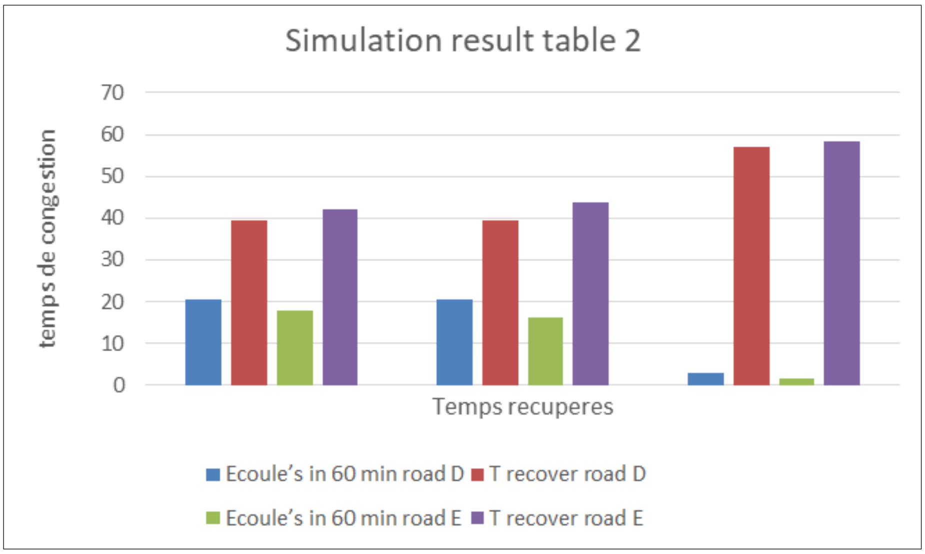
Graph 5: Simulation results from table 1

This top graph shows the simulation results obtained using the SUMO simulator for the variables in Table1. Information on Routes A and B at the Gare du Nord intersection during morning rush hour reveals that for 60 minutes, road safety officers are busy regulating 1,025 vehicles. Using the same parameters, the system is able to regulate in 34 minutes and 1 seconds, with a recovery time of 55 minutes and 8 seconds including a recovery rate of lost time of 75.85% [19] [20].

Table 5: Comparative result of time lost in queue and time recovered.

Total number of vehicles in Road A	Average waiting time in UV/min in Road A	Time recovered with the system in Road A	Total number of vehicles in Road B	Average waiting time in UV/min in Road B	Time recovered with system in Road B
615	20,47	39,52	522	17,38	43,01
767	25,5	34,45	618	20,57	39,42
488	16,25	44,04	398	13,25	47,04

The table above shows the time required for the regulation of vehicles entering the study environment at the intersection of the North Station in the early morning. In addition, our simulation allows readers/decision-makers to have an idea of the time lost on the queue as well as the time recovered in a clear and accessible way.



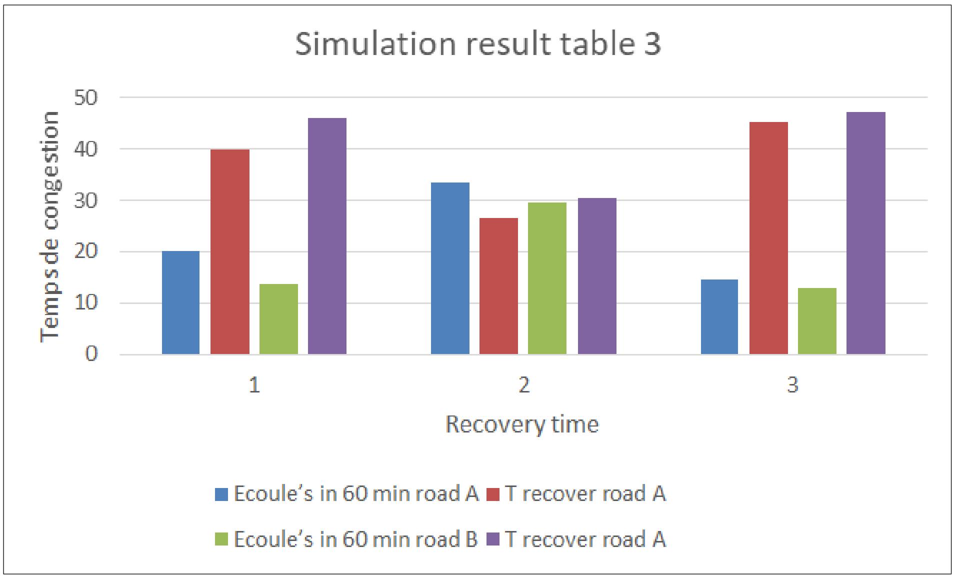
Graph 6: Simulation results from table 2

This graph shows the simulation results obtained using the SUMO simulator in Table 2 of variables. Information on Routes D and E at the North Station intersection during peak evening hours reveals that for 60 minutes, road safety officers are concerned with regulating 984 vehicles in the period from 5.30 minutes to 7:30 minutes. Using the same parameters, the system is able to regulate in 32 minutes and 7 seconds, with a recovery time of 57 minutes 2 seconds including a recovery rate of lost time of 69.09%.

Table 6: Comparative result of time lost in queue and time recovered.

Total number of vehicles in Road D	Average waiting time in UV/min in Road D	Time recovered with the system in Road D	Total number of vehicles in Road E	Average waiting time in UV/min in Road E	Time recovered with system in Road E
613	20,41	39,58	541	18,01	42,08
621	21,07	39,32	489	16,28	44,01
89	5,06	57,03	52	3,03	58,26

The results given by our simulation, allow readers/ decision-makers to have an idea about the time lost on the queue as well as the time recovered in a clear and accessible way. The table above shows the time required to regulate vehicles entering the study environment at the intersection of the North Station in the early evening.



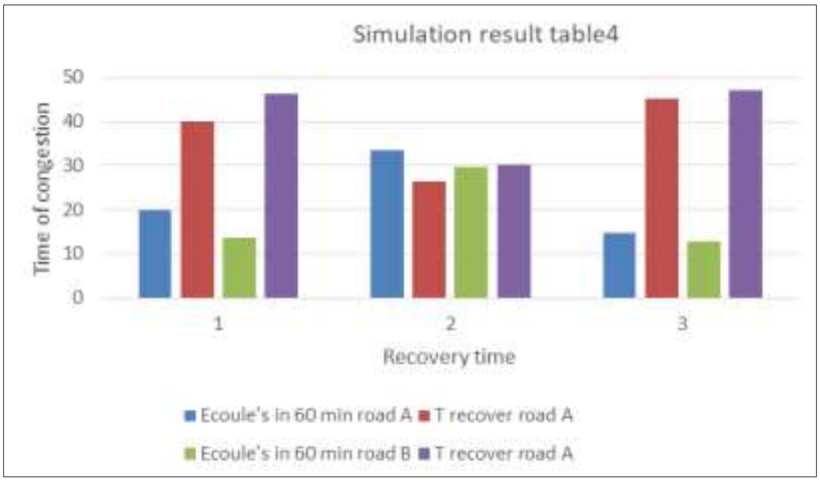
Graph 7: Simulation results from table 3.

The above graph shows the simulation results obtained using the SUMO simulator for the variables in table 3. Information on track A and B of the United Nations intersection during morning rush hour, from 6.30 minutes to 7.30 minutes, reveal that for 60 minutes, road safety officers are responsible for regulating 1138 vehicles. Using the same parameters, the system is able to regulate in 37 minutes 8 seconds with a recovery time of 52 minutes 10 seconds, including a lost time recovery rate of 72.633%.

Table 8: Comparative result of time lost in queue and time recovered.

Total number of vehicles in Road A	Average waiting time in UV/min in Road A	Time recovered with the system in Road A	Total number of vehicles in Road B	Average waiting time in UV/min in Road B	Time recovered with system in Road B
602	20,04	40,05	414	14,08	46,21
1005	33,46	26,53	891	30,07	30,32
440	15,05	45,34	384	13,08	47,21

The above table helped us understand the time required to regulate vehicles entering the study environment at the UN intersection in the morning. In addition, our simulation allows the reader/decision-makers to better understand the time lost in the queue as well as the time recovered in a clear and accessible way.



Graph 8: Simulation results from table 4

The above graph shows simulation results obtained using SUMO simulator for variables in table 4. Information on United Nations Intersection/Intersection Roads C and D during afternoon rush hour from 5.30 minutes to 6.30 p.m, show that for 60 minutes, road safety officers are concerned with regulating 1,126 vehicles. Using the same parameters, the system was able to give access to green lights for 28 minutes 9 seconds, with a recovery time of 37 minutes1 seconds, including a percentage rate of recovery of lost time of 67.22%.

Table 9: Comparative result of time lost in queue and time recovered

Total number of vehicles in Road C	Average waiting time in UV/min in Road C	Time recovered with the system in Road C	Total number of vehicles in Road D	Average waiting time in UV/min in Road D	Time recovered with system in Road D
730	24,30	36,09	569	19,04	41,05
612	20,37	40,02	453	15,08	45,01
207	7,09	53,10	191	6,36	54,03

The above table was used to understand the time required to regulate vehicles entering the study environment at the UN intersection during the afternoon period. In addition, our simulation allows the reader/decision-makers to better understand the time lost in the queue as well as the time recovered.

VII. A Few Suggestions

In view of our previous forecast results, we suggest that policy makers take action based on new information and communication technologies with a focus on intelligent transport systems (sensors, radars, intelligent traffic lights, checkpoint) to address problems related to road congestion in Bujumbura. The strategy of introducing fourth-generation traffic lights that adapt to congestion would be a major asset. In addition, the establishment of a road traffic management center (CERT) that would work with the highway police and the implementation of overlapping roads would allow to have a good performance. Finally, it would be essential to build another complementary road into the city of Bujumbura next to the three existing main roads, but also a junction on the Ntahangwa rivers connecting the districts of Kigobe and Nyakabiga II, Ntahangwa connecting the Ngagara and Buyenzi neighbourhoods.

CONCLUSION

Congestion of urban road traffic is one of the social and economic problems the development of the country that must be resolved to support the evolution of the country in general and society in particular. The appropriate solution is to find an intelligent algorithm implemented in the traffic light control point and a method mathematical (queuing theory) to deal with existing problems. The objective of our study is to contribute in solving congestion problems during peak hours in order to make road traffic more fluid. To do this, we used a wireless sensor network approach and an intelligent traffic light management algorithm.

These wireless sensor networks facilitate communication between the different control points identified in our system. In this article, we first reviewed the key aspects of wireless sensor networks. We then showed the advantage of this equipment in helping to solve congestion problems in the city of Bujumbura.

We finally focused our study on road traffic management, where we presented the different management tools and concluded with recommendations to decision makers.

BIBLIOGRAPHIE

1. UNFPA, «Rapportdes projections 200/2030,» unfpa, 2008.
2. Africa-automotive-industry, Analyse de la taille et de la part du marché automobile en Afrique – Tendances de croissance et prévisions (2024 – 2029), africa-automotive-industry, 2024
3. H. K. Niyonkuru Fiston, «gestion intelligente temps reel des feux de circulation « cas de centre-ville bujumbura »,» chez *mémoire*, Bujumbura, Universite du Burundi/Campus Kiriri/aculté des sciences de l’ingénieur (fsi) /en Genie Informatique, 2021, pp. 31,32,40.
4. I. C. e. t. Ministere de transport, «Exposé Sur La Mobilité en République du Burundi,» chez *Conference Mondiale Sur les Deux Roues Et Trois Electrique*, bangkok Thailand, 9-12 octobre 2023.
5. P. e. T. M. d. T. P. e. d. l. d. B. Ministere des Transport, «L' Etude Urgente Sur Le Transport Urbain A Bujumbura en Republique Du Burundi,» Agence Japonaise de cooperation Internationale, Japan Enginnering Consultants, Bujumbura burundi, Fevrier 2008.
6. D. I. H. K. NIYONKURU Fiston, «Gestion Intelligente temps Reel des feux de circulation, cas de Centre de Ville de Bujumbura,» Bujumbura-Burundi, Universite du Burundi/Campus Kiriri, Faculte des sciences de l'Ingenierie (fsi), 2021, pp. 10,15,52.
7. S. FAYE, «Controle et Gestion du trafic Routie urbain par un reseau de capteur sans fil,» chez *memoire*, Paris, École doctorale Informatique, Télécommunications et Électronique (Paris), 2014, pp. 40, 100,59.
8. J. A. A. N. Rufin Akiyo, «Emboueillage dans la ville de l'Afrique de l'ouest et ses Probmes:cas de la ville de Cotonou au Benin,» *AFRICAN SOCIOLOGICAL* , vol. 20, n° %11, pp. 95, 97,98, 2016.
9. J. ABDO, «Construire de nouvelles infrastructures routières la solution à la congestion,» 2011.
10. Mammar, «Systemes de Transport Intelligent, Modelisation, Information,» *Hermes Sciences,* vol. 23, pp. 24,12,15,9, 2007.
11. www.iwacu-burundi.org, «Etude urgente sur la transport urbain à Bujumbura dans le Republique du Burundi Realiser pat l'Agence Japonaise de coopération Internationale,» ISTEEBU, Bujumbura, 2007.
12. R. V. R. A. A. C. A. Abdillah Attoumani, «Transport et Circulation Routiere un regarder sur la ville d'Antonnarivo,» *Ingenierie et Géoscience, ESPA,,* vol. 45, pp. 6,8,12, 2018.
13. D. A. Alloua Imane, «Gestion de Trafic Urbain à base de Réseau des Capteurs sans fils,» Universite Antananarivo, 2012.
14. K. Haddid Kahina, «Modernisation et Simulation du Trafic Routiere à l'aide des Réseaux de capteurs sans fils,» Universite Antananarivo, juin 2013.
15. ABDO, «Construire des nouvelles insfractures routières la Solution à la Gestion du Traffic,» Decembre 2011.
16. K. K. HADDADI Kahina, « Modelling and simulation of road traffic using wireless sensor networks,» June 2013.
17. M. B. O. Rafik, «Agregation des données et Securite des reseaux de capteurs sans fils,» chez *Système et Reseaux de Telecommunication*, Algerie, Ministère de l’Enseignement Supérieur et de la Recherche Scientifique , 2014, pp. 24,56,10.
18. S. Faye, «Control and management of urban road traffic using a wireless sensor network. Infrastructures de transport,» *Télécom Paris Tech,* vol. 10, n° %155, pp. 7,8,9, 2016.
19. N. L. Imane, «Analyse Graphique pour la surveillance dans un réseau de capteurs sans fils (RCSF) Simulateur : OMNET++,» Ministère de l’Enseignement Supérieur de la Recherche Scientifique, Algerie, 2012.
20. S. S. NOR Imane, «Developpemrnt d'une application de detection et reconnaisance de plaque d'immatriculation,» Universite Abou Berk Belkaid, Algerie, 2017.