ICT and COMPRAM to Assess Road Traffic Congestion Management in Kinshasa

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Abstract: Traffic Congestion Management (TCM) in a megacity like Kinshasa, capital of the DR Congo, is a knowledge and real life problem of complex nature. Here, the authors describe the TCM problem through 9 phases of the layer 1 of the COMPRAM methodology. TCM is a worldwide complex societal problem and specifically in Kinshasa where it presents a set of characteristics such as 'chaotic' driver behaviour, road potholes and the road network physiognomy doesn't respond to the supply- versus demand-side equation. The other complex problems include the absence of road planning with consideration to demographic parameters and car ownership increase, no suitable traffic operations infrastructure and limited funds for both maintaining existing roads and building additional ones. To solve this TCM problem, the authors propose a TTCMP (Triangular Traffic Congestion Management Process) framework as an output based layer 1 of COMPRAM by identifying types and sources of congestion, followed by a TCM problem description and a set of technical elements for 'curbing' traffic congestion with an overview on a Bluetooth based technology for traffic data collection as an adapted ICT4D solution for a low-income city like Kinshasa.

Keywords: Traffic Congestion Management (TCM), layer 1 of COMPRAM, TTCMP, ICT, Bluetooth Technology for traffic data collection.

1. Introduction

Road traffic congestion management, a part of road traffic management, constitutes a real life city problem, with consequences on domains such as social, economic, environment and health. Traffic congestion impacts mobility of people and goods as well as challenges in climate issues [7] [10] [14] [15]. Traffic congestion wastes time, energy and causes pollution. European Countries, India, Brazil, Nigeria, Kenya and Tanzania [3] [4] [8] [9] [10] [14] are trying to find adapted "solutions" to curb the congestion phenomenon by a comprehensive tackling of the Traffic Congestion Management (TCM) problem and offer various road traffic management strategies and technological possibilities in accordance with road infrastructure, road demand, economic and social environment as well as related specific "road culture".

Some authors [1] [7] stress that the congestion phenomenon occurs either when the demand is greater than the supply related to road capacity or to road potholes as well as to an unusual event such an accident, which occurs, or a truck that breaks down on the road [2] [3]. In short, congestion is a product of supply and demand side factors. The determination of traffic congestion types and causes, which is a mix of measures on three sides (demand side, supply side and land use side), will guide the overall traffic congestion management process [6].

TCM consists of a wider approach to addressing the traffic congestion challenge [6]. [22] [23] [24] advocated that ICT applications known as Intelligent Transportation Systems (ITS), for transportation or traffic management but specifically for monitoring, planning, prediction, could be used as one of various strategic measures to curb the negative impact of traffic congestion and thereby increase the operational efficiency of the road network.

The congestion management process combine strategies, policies, technologies or new infrastructures building in order to mitigate recurrent and non-recurrent congestion. [3] [6] advised to tailor TCM on the road network type and local context, which is depending on general aspects as road space, economic environment, and specifically on driver behaviour, and road planning culture.

The first step for a better road traffic congestion management is the identification of causes, nature and type of congestion on the road network, which will conduct to mitigation

measures [4] [17]. Mostly in developing countries, traffic congestion has a "chaotic" nature and its management constitutes a complex reality.

Road traffic congestion management and traffic management are particular problems in the developing world due to a shortage of the following resources: funds, traffic and transportation equipment (traffic monitoring centre, appropriate traffic signals, planning space side), interdisciplinary traffic research related to the developing world (social, scientific, economic and policy research).

The causes of the road traffic congestion problem are generally driven by two factors: micro-level (traffic on the road) and macro-level (overall demand for road use). We could identify a simple or multiple types of congestion due to the interaction of two or several vehicles: bottlenecks congestion, where several vehicles are trying to pass through narrowed lanes; and "trigger neck" congestion, when an initial narrowing generates a line of vehicles interfering with a flow of vehicles not seeking to follow the jammed itinerary; and network control congestion, which is a programmed control of traffic at peak hours and inevitably delays off-peak hour traffic and congestion due to network morphology.

As stated by [3] [4], road traffic congestion management should be applied at both supply and demand sides. But [12] advises to consider also the planning side. At supply side, traffic planners, engineers and experts are considering three main pillars: the capacity of the road network, the operation of the road network (e.g. optimising signals, reduction of existing road space or new roads construction), and the supply of the road transport equation. The demand for road space side depends strongly on socio-economic and population factors, the availability of alternative means of transport, the availability of parking and the social perception of car versus public transport travel [4].

Kinshasa, a megacity of more than 10 million people, with a surface of 9,962 Km2 and capital of Democratic Republic of the Congo (DRC), does not escape traffic congestion and its management reality problem. TCM is a real life complex management problem and a knowledge problem in Kinshasa [2]. In order to assess TCM in Kinshasa as a complex societal problem, we have to describe it in the Kinshasa environment context and propose a first track of 'solutions' to handle it. From above mentioned consideration, TCM is a complex societal problem and can be handled with the already proven COMPRAM methodology [5] [19].

In Accordance with the COMPRAM methodology, the first outcome of handling a complex societal problem is to make a conceptual model of the problem. The conceptual model has the objective of "problem defining" through a seven-layer communication model between experts, actors and other relevant groups in order to change it. The Layer 1 of the conceptual model describes the problem throughout a 9-steps procedure in order to give a structured view of the problem; in our case study the focus is on the "TCM problem in Kinshasa".

2. Research Objectives

The overall challenge and intended results is related to a comprehensive assessment of the road traffic congestion management as a complex societal problem for Kinshasa by using the layer 1 of COMPRAM. The specific sub-objectives are then the following:

- To comprehensively describe TCM problem in/for Kinshasa
- To propose a Triangular Traffic Congestion Management Process (TTCMP) framework with a special focus on a technologically adapted solution for 'curbing' the TCM problem around ITS based Bluetooth technology for road TCM operation.

3. Research Methodology

The COMplex PRoblem hAndling Methodology (COMPRAM), which is mainly based on societal complexity theory, does offer a more structured and transparent way of optimally handling real-life and real-world complex societal problems. According to DeTombe, the inventor of the COMPRAM methodology, Handling *"means to find out what is going on, finding the causes, indicating possible interventions, implementing interventions and evaluating the process and the outcome of the problem handling process"*.

The COMPRAM methodology is multi-disciplinary, interdisciplinary and multilevel and multi actor(s) related [18]. It has been successfully used in fields such as healthcare, economics, climate change, terrorism, large city problems (as water supply problems, etc.), large technological projects, etc. [2]

The TCM problem in Kinshasa has to be seen as **a real life problem** because of *the discrepancy between actual and desired situation* and **a knowledge problem** because of *lack of knowledge*. A combined view within **a structured investigation** to increase **the knowledge of the problem** is needed and **the changing situation** aspect is also needed to address a real life traffic congestion management problem by COMPRAM methodology [5] [16].

In accordance with the COMPRAM methodology, the first outcome of handling a complex societal problem is to make **a conceptual model** of the problem. The conceptual model has the objective of problem defining through **a seven-layer communication model** between experts, actors and other relevant groups in order to change it. The Layer 1 out of 7 does essentially constitute and comprehensively present the problem description 'TCM in Kinshasa' through 9 process phases (that we have named **P1** to **P9**) [2] [5] [16].

P1 – *It describes in natural language what "Traffic Congestion Management (TCM)" is*. It focuses on giving definitions and information about traffic congestion management. Thus it is a comprehensive description of the traffic congestion management. P2 – *It explains the reasons for P1 (i.e. TCM) being a problem.* It aims to find out why traffic congestion management is a problem. P3 – *It does explain to whom it is a problem.* It aims also to find out by explaining the people or objects that the problem addresses/concerns. To whom something is a problem connects a person, a group, an organisation, or a society with the given problem. P4 – *It explains who is/are the problem owners.* Owner (s) of a problem may be human beings, an organisation, or a group who "owns" the problem. The person (group, organisation), who is aware of the problem and wants to change it into a desired situation in the interest for himself or for a group or for an organisation. P5 – *It explains who the problem's victims are.* For what kind of people does road traffic congestion management as applied in Kinshasa constitute a problem? P6 – *It explains what the effects of the problem on society are.* It is also to view, find or assess the impact and related consequences of the current road traffic congestion management problem in Kinshasa. It includes the negative impact of the problem on society or economy as well as on the environment. P7 – *It does present a short historical review.* How did traffic congestion started and what is the current status in Kinshasa? What was the traffic congestion management in the past and how is it nowadays? P8 – *It does present a comprehensive general future development or 'desired situation' if possible.* What could be a better road traffic congestion management in Kinshasa? What kind of measures will be conducted in order to enable this better future development? P9 – *It does comprehensively explain what is known so far or not and what has to be still discovered.* It includes a state-of-the-art review of traffic congestion management in Kinshasa.

For the application of layer 1 of the COMPRAM methodology to the assessment of the road traffic congestion management problem in Kinshasa, observation, thinking, reading and discussions have been used to get appropriate reliable data and information on the TCM problem in Kinshasa.

Furthermore, a description of a technologically feasible 'solution' has been proposed as one brick amongst of several aspects related to TCM's future development in a sense of contributing to 'curbing' the road traffic congestion management phenomena. A technological prototype has been developed which involves the following technology bricks: Arduino, and Bluetooth technology using ZigBee communication.

4. Application of layer 1 of COMPRAM for Road Traffic Congestion Management (TCM) in Kinshasa

4.1. Characteristics of the TCM problem in Kinshasa

The TCM problem in Kinshasa has various aspects and characteristics. The mechanism used for TCM in Kinshasa is very weak, mostly inexistent and not optimal. That is why one does observe at different locations severe recurrent and non-recurrent congestions in the city of Kinshasa.

When we follow the thinking process coupled with observations, we discover that traffic congestion occurs in Kinshasa mostly due to both the 'chaotic' driver behaviour (undisciplined) and poor roadway conditions as mostly strewn with potholes. This situation explains others such as non-uniform roadway features in terms of carriageway and shoulder width, encroachment of road, poor lane discipline, improper bus stop locations and design, uncontrolled on-street parking, growth of private vehicle usage and the non-availability of funds for additional roadway infrastructures, a rapid increase of urban population, and the chronically low capacity of the available current transportation infrastructures.

TCM tools are not well arranged in Kinshasa. Worthwhile Intelligent Transportation System (ITS) technology, traffic signals and markings are less visible or inexistent. Only at few intersections, one can find CCTV cameras and traffic policeman who are trying to regulate traffic for local congestion avoidance. The absence of parking stations, traffic management centres and traffic control centres does reinforce the TCM problem. Road potholes play also partly in this problem, as they reduce road capacity. Recently, both the central and the local/provincial Congolese governments have started promoting public transportation by creating public transport companies like "Tansport au Congo" (Transco), and "Transport de Kinshasa" (Transkin) with respectively 500 and 250 buses; but these two fleets are very insignificant in face of 10 million people in Kinshasa with high travel/mobility needs over a large city. The absence of alternative traffic infrastructures such as urban and suburban railways with respect to the related state-of-the-art in order contribute to the fluidity of the road network traffic in Kinshasa does critically amplify the complexity of the TCM problem in Kinshasa.

From the above description or reality, it evident that TCM in Kinshasa is a complex societal problem with an interdisciplinary nature due to various and combined factors like road potholes, driver behaviour, supply-side versus demand-side equation, road network physiognomy, road planning, demographic parameters, car ownership increase, absence of traffic monitoring centres and limited funds for maintaining and improving road infrastructures. Somehow and somewhere, one or a combination of these factors is creating different types of congestion situations at different locations at different times.

The equation "road supply-side" versus "demand-side" ought to be reviewed to assess if the Kinshasa road network is able to respond to the demand of various competing users of the road network. The road network physiognomy of Kinshasa has not changed significantly since the 1960's period; at that time the population was about of 400,000 people and the Kinshasa city is around 10,000,000 people nowadays. The Kinshasa area surface has changed from 6,800 up to 43,414 ha [20] [21]. [19] argued that the urbanisation takes mostly place in South and South-west parts of Kinshasa (see Figure 1).

Figure 1: A global view of the Kinshasa's main road network

Thus, city urbanisation versus road planning policy and strategy should cope with demography and transport means. Since 2012, we also observe in the last years an increase car ownership in the city of Kinshasa, imported used cars came mostly from Asia, Japan and China. Traffic congestion is becoming more and more present. Traffic congestions events located in Kinshasa city centre are coming also from activities concentrated in the downtown against a relatively poor road capacity offer. The concentration of main activities in the downtown (North) does increase the congestion problem. All big companies and state administrations are concentrated in downtown. The rapid urbanisation combined with the huge demand play another partition of the traffic congestion and management problem. Another sensible situation is the reality of road potholes. Road potholes in Kinshasa have microscopic and macroscopic impacts on the traffic dynamics and affect variables such as speed, flow, density and lead mostly to road congestion.

4.2. TCM problem 'owners and victims'

According to Detombe and the complexity problem methodology, we are concerned about "to whom" it is a problem, "the victims" or "the owners" of the problem [16]. The "to whom" TCM is a problem concerning various people's categories with different "power" to the traffic congestion problem and management from its existence and its "changing". We have two categories of people: the ones who are acting as managers of traffic congestion, and those people who are suffering from poor traffic congestion management as road users.

As already stated, the TCM problem in Kinshasa is a complex societal problem. Road users as "victims" (car drivers, pedestrians, students, and workers), traffic planners, traffic engineers, traffic police, etc. are concerned in a way or another with the traffic congestion and TCM problem. The government is also a big player through a variety of organisms, e.g. with transportation and finance ministries and with specialized services or companies such as PCR, Office des Routes, FONER, OVD, CNPR, ACGT. It also constitutes a management layer in the TCM problem and in delivering road traffic management satisfying services.

The problem owner is a special actor or group, who initiates the problem handling process [18]. The problem owner must have legal or social rights or societal power to handle the problem, otherwise the other actors will not cooperate or will ignore the outcome of the problem handling process and the problem cannot be changed.

Based on the information provided above, when applied to the Kinshasa case study, a list of 'owners' and 'victims' of TCM is provided (see Table 1). In the "TCM in Kinshasa", the problem owners should be the federal government (including premier minister), the governor of the Kinshasa province or its specialized agencies such as the provincial transportation ministry. Other actors ought to be federal and local services in charge of civil works, traffic police, city planners, researchers, etc.

Table 1: Problem owners and victims of TCM in Kinshasa

Problem Owners, as actors of the traffic congestion management	Mission
Federal government representative as premier minister cabinet or the cabinet of governor of Kinshasa	Legal or social rights to handle the problem, otherwise the other actors will not cooperate or will ignore the outcome of the problem handling process.
National or local Ministries in charge of Transportation and Finances	
Owner as other actors	**Mission**
Office des Routes*	It is the DR Congolese Agency for intercity road maintenance)
FONER* (Fonds National d'Entretien Routier)	It is the DR Congolese Agency in charge of intercity toll collection
OVD* (Office de Voirie et Drainage)	It is the DR Congolese Agency in charge of inner-city road maintenance
ACGT* (Agence Congolaise des Grands Travaux)	It is the DR Congolese Agency in charge of managing large road and transportation related infrastructure projects
PCR* (Police de Circulation Routière)	It is the traffic police in charge of traffic related legal enforcement
Problem 'Victims' of traffic congestion management	**Mission**
Road users	This group includes: cars and truck drivers, motorcycle drivers, and even pedestrian as all of these person do daily experience the recurring congestions

4.3. 'Desired situation' or Future development related to TCM in Kinshasa

The effects of the TCM problem on society are impacting various variables such as travel time, speed, fuel consumption, and vehicle depreciation acceleration in road strewed by potholes, etc. Here, the future development is about the 'desired situation', which means a series of technical elements (See Figure 3) for 'curbing' and improving TCM with an incidence on road traffic management.

5. Technology description

Bluetooth technology for traffic data collection, traffic monitoring and prediction in short for traffic management is a worldwide research concern [13] [26] [27].

In TCM, a congestion detection algorithm is important with an ITS infrastructure as advocated by [11] [12] [13] [14]. Fixed and mobile sensors [8] [11] [12] [13] [14] [15] such as RFID, Wi-Fi, GPS, Bluetooth, camera, microphone, Internet of Things (IoT), agents etc. are used for road traffic monitoring, intelligent management, traffic measurement systems (density, flow) and road traffic information supervision.

5.1. Cost-effective Technology for traffic data collection and congestion detection in Kinshasa

Kinshasa's land is scarce and densely populated [19] [20] [21]. The traditional solution of building more and wider roads for traffic congestion management is not a unique, optimal and viable long-term solution [25]. Another consideration is Kinshasa as a developing country often suffers from very limited resources such as funds, experts, infrastructures, etc. From these consideration, we've oriented the research towards ITS Infrastructure better a cost-effective ITS solution as TCM approaches to be implemented in Kinshasa. Here, one of the ways is wireless technology. The advantage of wireless technology is that there is no need for breaking roads during the deployment of the technology and deployment time is reasonable compare to road building for example. So an adaptation and innovation of ITS techniques is useful in this case around Bluetooth and ZigBee technologies.

The system explored here is based on a traffic congestion detection by deploying a network of Bluetooth probe devices (see Figure 2) that scans other Bluetooth-enabled devices (especially mobile phones of travellers: pedestrian and people in cars) within its radio proximity with ZigBee communication. The sensor networks does know the geographical coordinates of all sensor nodes and the distances that separate them from each other.

It uses an electronic identifier called Media Access Control address or simply MAC address as an electronic name, so any electronic terminal having a MAC address can, when it is in Bluetooth mode, keep track of a correspondent during a data communication. MAC address of mobile phone and the time at which is discovered by Bluetooth probe devices constitute elementary data to be stored in a database. Knowing the distance that separate every couple Bluetooth probe devices on road network, average travel time of mobile phone is deducted and traffic state is determined for a specific period. With this approach, the MAC address is used as a basic element in ITS to obtain real-time information on road traffic congestion. Thus, the data retrieved ought to be stored and used for congestion detection analysis.
Details of results obtained after implementing and testing this system on roads in Kinshasa will be published in a future paper work.

As the technology is cost-effective for a low-income country ($879 for 3 probe devices) but schema of obtaining accurate data is a real challenge. This begins by putting in place a filtering algorithm for identifying mobile phones in cars to pedestrian's one. One solution is to 'stick' mobile phones to cars. A challenge that one would face is interference avoidance because Bluetooth and ZigBee are emitting in the same frequency band 2.4 GHz (2.4-2.48 GHz). Adaptive Frequency Hopping (AFH) algorithm is used to dynamically activate channels for interference communication avoidance. So the characteristics of equipment must support AFH protocol.

An intelligent data mining algorithm is also required for extracting accurate traffic data and traffic pattern recognition (congestion, semi-congested, free flow states). Furthermore, the design of platform for information dissemination (Internet, radio, T.V., SMS, etc.) should be designed for travel people decision.

Figure 2: Picture of Bluetooth probe designed

6. Industrial Significance and Eventual Benefits

ITS solution around Bluetooth system deploy in Kinshasa will certainly have societal and economic benefits. Road users (cars, motorcyclists and pedestrians) will be informed on congestion section and will make decision according with known traffic map situation. Social cost linked to congestion will decrease delays and uncertainly in traffic, pollution and will increase mobility. With this system, transport economic ideas like congestion pricing, parking cost could emerged for identified congested zones (downtown).

7. Recommendations

7.1. Policy towards TCM Problem in Kinshasa

The TCM problem for Kinshasa has to be tailored on key elements related to transport demand management, transport supply management and land use management, in an integrated approach (see Figure 3).

On the demand side, we consider socio-economic and population factors, awareness on congestion management through training towards reducing chaotic driver behaviour, empowering traffic police service, driver's associations to understand traffic management and traffic congestion management challenges. On the supply side, actions such as road capacity improvement through release capacity or new infrastructure building is recommended. Other measures are policy improvement in road maintenance by early involving all actors, invest

more in public transportation and traffic operation, promote a multi-modal system of transport such as in inner- and inter-urban rail system and promote road pricing policy for TCM. On the land sue side, an effective urban planning policy is recommended.

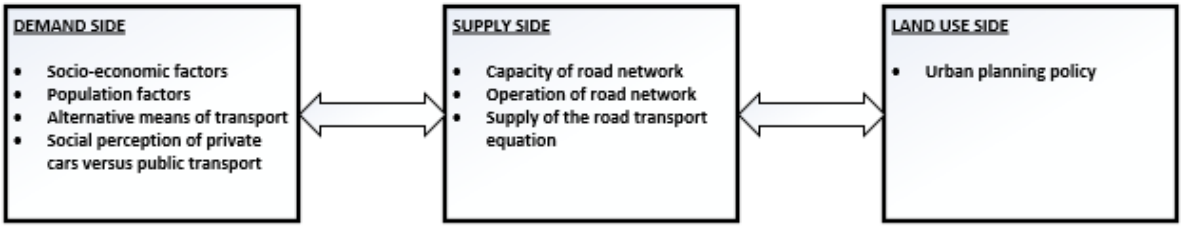

Figure 3. TCM splatted on demand, supply and land use side

7.2. Triangular Traffic Congestion Management Process (TTCMP) in/for Kinshasa

In the layer 1 of COMPRAM, the 'desired situation' is to be mentioned for the description of the problem handling goal. Here, the Triangular Traffic Congestion Management Process (TTCMP) is proposed as a framework for problem circumscription and "solution" finding in/for Kinshasa.

Due to the 'specific character' of congestion, the TTCMP for each country or specific areas constitutes a mean to firstly identify types and sources of traffic congestion in order to secondly discover the TCM problem for thirdly finding or implementing technical elements for the TCM 'desired situation' (see Figure 4).

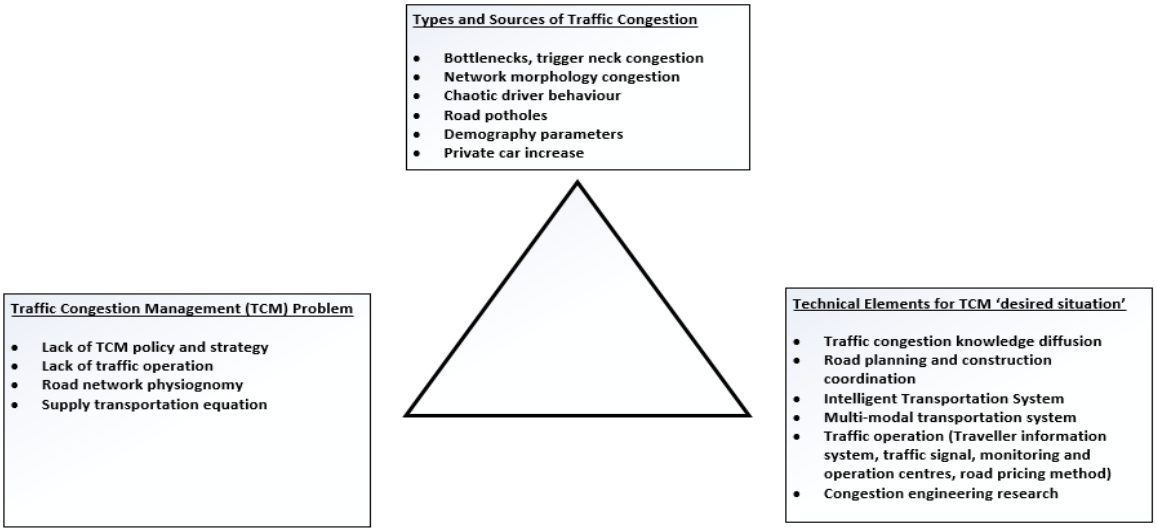

Figure 4: Triangular Traffic Congestion Management Process (TTCMP) in/for Kinshasa

8. Conclusions and future work

Traffic Congestion Management (TCM) in a megacity like Kinshasa, capital of the DRC, is a knowledge and real-life problem of complex nature. Before proposing a comprehensive 'solution' or an intervention to handle the TCM problem, we describe in this paper the TCM problem through 9 phases as a step to the definition of the problem as advised by the COMPRAM methodology throughout the layer 1 of the conceptual model.

TCM as a worldwide complex societal problem and specifically in Kinshasa presents characteristics such 'chaotic' driver behaviour, road potholes, a road network physiognomy that doesn't respond to the supply- versus demand-side equation, the absence of road planning with demographic parameters and car ownership increase consideration, the absence of suitable traffic operation measures and limited funds for either improving road infrastructure or increasing road capacity.

Furthermore, a TTCMP (Triangular Traffic Congestion Management Process) framework is proposed as an output to the TCM problem in Kinshasa based on layer 1 of COMPRAM by identifying types, sources of congestion followed by a selection of a TCM problem and

technical elements towards ‘curbing’ traffic congestion with a special focus on Bluetooth technology.

As future work, the consideration and core challenges will be concentrated on a full deployment of Bluetooth probes with Arduino or Raspberry technology at many intersections across the large urban intersection of Kinshasa for discovering Bluetooth devices MAC address and timestamps for traffic counting purposes. Another challenge will be a cost analysis through a comprehensive cost-benefit analysis consideration. The data mining challenges will then also be considerable and will require a whole new big data approach, but will also become an invaluable input in an ITS platform. Other measures to TCM problem could be road pricing measures, which will also certainly positively contribute to reduce the congestion problem in Kinshasa.

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