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Dynamic Management of Traffic Congestion – Case Study in Developing Countries

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Abstract In a context of globalization where economic transactions are consumed at a very high pace, being able to rapidly move from a place to another is key in our society. This is especially true in developing countries where technology is not very developed. People need face-to-face meeting to conclude deals or consume activities. However, the reality today is that the increasing in economic transactions has developed and worsen the situation of traffic congestion. Existing roads are not enough, and governments are struggling to solve the problem with limited budgets. In this paper, we propose a simple and cost-effective approach to track, anticipate and mitigate traffic congestion. The approach is based on two indicators called Warning Limit and Inhibit Limit. Warning Limit is a limit above which traffic congestion is most likely to happen, and Inhibit Limit is the limit above which congestion is in place or can no more be avoided. A survey has also been realized and results are combined to Warning Limit and Inhibit Limit to help local authorities take the right decision at the right time.

Keywords Traffic congestion, Optimization, Control, Transportation

1. Introduction

Traffic congestion is a fact, a worldwide known situation or problem. All countries and cities around the world are either impacted or have already faced this problem. Depending on the region in the world, the situation can be acceptable or just a nightmare.

In modern or developed countries, situation seems to be tolerable because of the various alternatives (infrastructure, security, public transportation, etc.) offered to people by local authorities. However, in developing countries like in the Republic Democratic of Congo (Kinshasa), the situation is a real nightmare with significant impact on the local economy. People cannot safely move from a point to another, they cannot plan the arrival time on a meeting for example, and even sometimes, it is just impossible to know how many activities can be managed in a single day. For some citizens, life itself becomes in danger as it is very difficult to reach downtown to seek something to eat or feed the family. Since the COVID-19, the situation has even worsen due to the fact that the government restricts the number of passengers on buses or taxis, and people prefer to use their own cars, leading to an increased number of vehicles on the road and thus increased traffic congestion [1] [2].

[3] presents traffic congestion as a sign of prosperity arguing that a wider variety of social interactions and economic transactions can be consumed. This is true until a certain level. When people can no more move, when they systematically panic with the idea of taking the road, when they need to drive in the night to be on time at the office, traffic congestion is no more a sign of prosperity. It's a barrier to the economy development [4].

Many studies have been conducted with the aim of solving or reducing the impact of traffic congestion. A variety of strategies to deal with congestion have been developed. These strategies have been gathered into three main groups by [5]:

1. Adding more capacity for highway, transit and railroads;
2. Operating existing capacity more efficiently; and
3. Encouraging travelers to use the system in less congestion-producing ways.

In developing countries, it's observed that effort is mainly put on the first group of strategies, i.e. increasing the road capacity [6] [7] [8]. Local realities such as security, poverty, driving habits, or social issues are not considered [9]. Moreover, many studies only look at static analysis and do not consider the variability or dynamic aspect of the traffic [10]. Consequences are such that proposed solutions [6] are seen inefficient when coming to real implementation.

In this study, we focus on the second group strategy, i.e. operating existing capacity more effectively while considering the dynamic aspect of traffic. We propose a novel approach to anticipate and reduce the impact of traffic congestion without significant investment. The approach consists of determining two key parameters called Warning Limit (WL) and Inhibit Limit (IL) [11]. These two

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parameters were introduced in [12] for sampling approaches in semiconductor manufacturing. WL is a limit above which traffic congestion is most likely to happen, and IL is the limit above which congestion is in place or can no more be avoided.

The study has been performed in the town of Kinshasa in the Democratic Republic of Congo. A specific intersection called “Station Maccampagne” has been chosen because of its reputation of facing one of the biggest traffic jam in the city. Data have been collected using tally counters, every day between 4:00PM and 6:00PM, and during a period of one month. In parallel of collecting data for WL and IL determination, we have performed a survey to understand which kind of actions could be put in place when WL is exceeded to avoid reaching IL.

Results indicate that traffic congestion and its impacts can be reduced without significant investment in road development.

The paper is structured as follows. Section 2 summarizes a literature review on traffic congestion with a focus on developing countries. The problem is described in Section 3. In Section 4, the survey and data collection approach are presented. Section 5 presents WL and IL determination using experimental data. Analysis and discussions are also performed in this section. Section 6 concludes the paper and gives perspectives for further research.

2. Literature Review

Traffic congestion can be defined as a state of traffic flow when the travel demand exceeds the road capacity [11]. This is not recent in our organizations [14] [15] [16] [17] [18]. Since the advent of the petrol-powered motor vehicle at the beginning of the 20th century, traffic congestion had been pointed out as a problem to fix [19]. This is mainly because of the direct impact on the economy of countries [20] [21] and consequences on social cohesion [22].

Through years, traffic congestion has become an entire research problem. Many researches have been conducted to understand the root causes of traffic congestion and propose solutions. Two main groups of researches or approaches can be defined: Static and dynamic. Static approaches consist of collecting data, performing surveys, or using known information to analyze a situation and propose solution to reduce impact of traffic congestion on the society. Dynamic approaches consider real-time measurements, detection, communication, information provision, or control to anticipate and prevent traffic congestion.

Static approaches have been widely used by organizations and governments. [5] published a report in the United States in 2004. The report identifies six sources of congestion distributed as follows: Bottleneck (40%), traffic incidents (25%), work zones (10%), bad weather (15%), poor signal timing (5%), special events / others (5%). Recommendation is to pay attention on the available funds when selecting a strategy over another.

[8] performed a comparative analysis of traffic problems faced in Pakistan and Indian. He concludes that the main problem is the government who doesn’t decide quickly and do not take appropriate decisions in favor of country’s economic development. [23] performed a study in Peru and concludes that the usage of private cars is the main cause of traffic congestion. [7] performed a survey in Nigeria to track causes, effects and remedies to traffic congestion. Inadequate road capacity appears to be the most significant cause of traffic congestion. [24] analyzed traffic congestion in Ghana and found that bad attitude of drivers is the main cause of congestion. [25] performed an empirical assessment of traffic congestion in Central London, UK. They found that about 15% of the observed congestion in the region is due to nonrecurrent factors such as accidents, roadwork, special events, and strikes. [26] analyzed traffic congestion in Kabul. Lack of infrastructure, improper human behavior, and demographic problem appear to be the top three causes of congestion. [27] discussed a system approach to solving traffic problems in large cities in Russia. Their study indicate that transport problems are mainly caused by insufficient throughput transport capacity of the road network and traffic rules violation.

All researches introduced above indicate that causes of traffic congestion vary between towns, countries and continents. This means that, a solution, working well in a given country, will be seen as inefficient in another country. Moreover, not considering real-time information restricts the added-value of the proposed solution. Hence the development of dynamic approaches.

Dynamic approaches to manage traffic congestion have been recently developed thanks to technology and artificial intelligence [28]. [10] performed a literature review on static and dynamic traffic assignments. They put in evidence the limitations of static approaches that do not consider real-time measurements, detection, communication, information provision, or control. [29] offers a review of the recent implementations of dynamic traffic routing in traffic congestion problems. [30] compare and analyze the methodologies proposed by different researchers and highlight the open challenges in smart traffic. They promote the use of sensor-based techniques to predict and prevent traffic. [31] use sound sensors and machine learning to detect traffic congestion. They model the traffic parameters and the sound generation from passing vehicles and use the produced audio as a source of data for learning the traffic audio patterns. [32] summarizes researches conducted by applying methodologies of artificial intelligence. Strengths and weaknesses of reviewed models are summarized.

Our literature review indicates that there is no a general approach that can be applied everywhere around the world. If dynamic approaches seem to be more suitable for today’s societies, the specificities or challenges (funds, electricity, security, etc.) in developing countries are such cost and easy of implementation cannot be ignored. Hence our interests as we didn’t find many studies considering these two latter parameters (cost and ease of implementation).

In this study, we propose a novel and simple solution, easy to implement, and not requiring significant investment. The solution is based on two indicators (WL and IL) and they can be implemented on the road using basic solar powered sensors that will count vehicles and trigger an alert whenever an indicator (WL or IL) is reached.

3. Problem Description

The efficiency of a solution lies in its ability to fix, in a permanent way, a well-known problem.

Let us consider the situation at “Station Maccampagne” intersection in the town of Kinshasa, in the Democratic Republic of Congo. (See Figure 1).

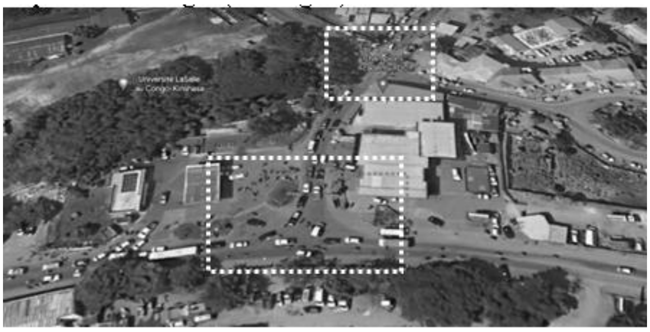

Figure 1. Skyview of the "Station Maccampagne" intersection in the town of Kinshasa (Democratic Republic of Congo)

The dot lines in Figure 1 are the regions of interests of our study. These regions are the places where traffic congestion occurs every day and at every hour during the day. The government has developed and put in place several strategies, but the situation has not really changed. Traffic congestion is still there and it’s getting even worse day after day.

Among solutions put in place by the local government, we can cite:

1. Road capacity increase with creation of few secondary roads;
2. Physical separations between road lanes;
3. Additional police officers to fine bad behaviors of drivers.

Regarding the first solution on road capacity, it has been observed the well-known phenomenon described as the Principle of Triple Convergence by [33] i.e., if a freeway is magically doubled in capacity overnight, the next day, traffic would flow rapidly because the same number of drivers would have twice as much road space. But very soon, the same road will be congested again because of new drivers or drivers who had been using alternate roads or drivers who used to drive during out of peak hours to avoid congestion.

Regarding the second solution on road lanes separation, it has been observed that local realities are such VIP cars, private cars, or police cars were systematically not respecting traffic rules and taking the road in the opposite way to avoid congestion. Consequences were that normal vehicles or other drivers followed the trend of not respecting rules, and the congestion did not disappear.

Regarding the third solution, the local economy is such that policemen are either not paid or have salaries not allowing them to live and feed their families. Instead of regulating the traffic, police officers spend their time asking for money and prioritizing VIP and private cars to get money. Consequences are such that police officers are becoming the source of traffic congestion instead of regulating traffic. Local drivers do not respect them, and everyone applies its own rule on the road.

In summary of the three approaches put in place by the government, it’s obvious that local realities have not been considered. It’s like if the government has copied solutions from developed countries and didn’t consider the challenges to fix locally. Moreover, the influence of intelligent transportation systems development and the impact of the COVID-19 is not considered at all [34].

In our study, we tackle this problem by first, performing a survey to understand local realities through concrete data collection around the region of interest. Then, we propose a novel approach based on WL and IL to dynamically anticipate traffic congestion and help authorities in their decision-making. WL and IL can be implemented using simple solar powered sensors.

4. Survey – Data Analysis and discussion

The survey took place around our region of interest (see Figure 1) at “Station Maccampagne” in Kinshasa, in the Democratic Republic of Congo.

More than ten questions have been asked to 340 people on the road. In this study, we only focus on five main questions. Among 340 respondents, only 310 forms were correctly filled and thus considered for our analysis. People were randomly selected but a specific attention was put on the age, sex, cars (private or public), and professional activity to have a relatively good representation of the population.

Here are the five questions we analyze in this study:

- Have you ever faced traffic congestion?
- How much time do you usually spend in traffic congestion?
- Is there a specific day where traffic congestion is specifically intense?
- What is the main cause of traffic congestion in Kinshasa?
- What can be done to reduce time and impact of traffic congestion?

Section 3.1 gives an overview of the population of respondents and, **section 3.2** briefly discusses results that will support implement of WL and IL. We aim at identifying one or two actions that could be immediately put in place when WL is reached to avoid reaching IL.

4.1. Population of Respondents

Table 1 gives the number of respondents to the survey, classified per sex, age, type of used car, and professional activity.

Table 1. Characteristics of the population of respondents

	Total	Age					Type of cars		Professional Activity	
		<18	18-30	30-45	45-60	>60	Private	Public	Yes	No
Women	121	6	32	32	46	5	50	71	61	60
Men	189	6	104	45	26	8	37	152	131	58
Total	310	12	136	77	72	13	87	223	192	118

Note that the whole population is represented even if the class of 18-30 years old is the most significant. The main set of respondents do not have private cars but, most of them have a professional activity. This is normal as the main population represented here is between 18 and 30 years. They just entered the active or professional and have not yet bought their first cars.

4.2. Analysis and Discussions of Responses

1) **Question1**: Have you ever faced traffic congestion?

All respondents were unanimous, and the answer was “yes”. Traffic congestion is a fact and reality. Everyone is impacted. There is a need to find a solution.

2) **Question2**: How much time do you usually spend in traffic congestion?

Table 2 summarizes collected answers. Note that a third of the respondents to the survey indicate spending more than three hours on traffic jams every day.

Table 2. Overview of time spent in traffic congestion

Time spent in traffic congestion	
<=1h	59%
]1h, 3h]	4%
>=3h	37%

59% of people indicate spending less than one hour but let us precise that the survey does not consider the overall time required for people to reach their destination. It’s obvious that traveling from a place A to a place B is very challenging and there is a kind of resignation from the population.

3) **Question3**: Is there a specific day where traffic congestion is specifically intense?

Figure 2 indicates that Monday and Saturday are the worst days for taking the road in Kinshasa.

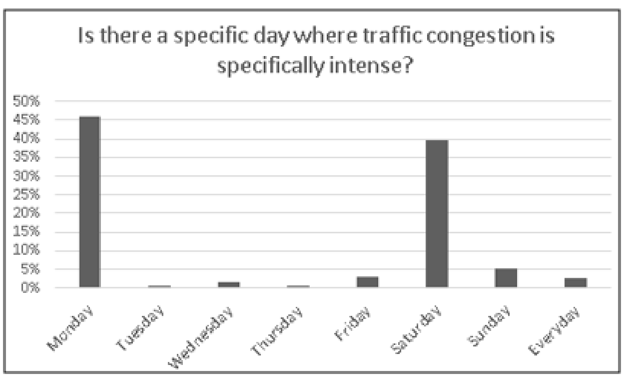

Figure 2. Congestion Vs. Days of the week

Additional investigation (not reported in this paper) indicates that the situation on Monday is due to the fact that a lot of people come to the town for their work and stay for the whole week. The situation on Saturday is mainly due to religious events.

4) **Question4**: What is the main cause of traffic congestion in Kinshasa?

Table 3 shows the causes of traffic congestion reported by the local people. Note that the two most important causes are the road situation and driving habits.

These results indicate that there is a way to reduce traffic congestion with smart approaches like WL and IL. Indeed, if road conditions or lack of road require significant investment, anticipating driving habits can help in reducing traffic congestion (see Section 5 – Warning Limit and Inhibit Limit).

Table 3. Causes of traffic congestion in Kinshasa

Causes of traffic congestion in Kinshasa	
Poor road conditions or lack or roads	**43%**
Bad driving habits	**29%**
Police officers	6%
Mismanagement of priorities	6%
Lack or pedestrians crossing	4%
Religious events	3%
High number of taxis and buses	2%
Accidents	2%
Arbitrary parking on public roads	2%
Broken down vehicles on the road	2%
Incomprehension between drivers	1%
Motorcycles	1%
Misuse of sirens	1%
Untrained drivers on the road	0%
Unknown reasons – We come out of traffic jam without knowing the cause	0%
Violation of highway code.	0%

5) **Question5**: What can be done to reduce time and impact of traffic congestion?

Table 4 gives the top five answers of respondents regarding solutions to be put in place to reduce traffic congestion in the town ok Kinshasa (in Democratic Republic of Congo). Note a direct correlation with question 4. It seems that roads are in so bad conditions that they are the major concern of the population.

Table 4. Solutions to reduce traffic congestion

What can be done to reduce time and impact of traffic congestion?	
Create new roads / alternative roads	**61%**
Create car parks	**14%**
Study and review behavior of local drivers	***11%***
Remove shops on the roads	11%
Regulate the number of motorcycles	3%

The two first solutions require massive investment whereas the third proposal (drivers’ habits) can be partially managed or anticipated using WL and IL.

Indeed, in our approach, WL acts as an alert and IL indicates that it is too late to avoid traffic congestion. When WL is reached, specific actions must be immediately put in place to avoid or mitigate the risk of reaching IL. The survey shows us that once WL is reached, there would be a need to anticipate drivers’ habits on some specific points. This will help to avoid reaching IL and mitigate the impact of a potential traffic jam.

5. Warning Limit and Inhibit Limit

Warning Limit (WL) and Inhibit Limit (IL) [11] are two key parameters that can help to trigger an alert whenever the risk of traffic congestion is imminent or when the situation starts to become critical. These two parameters are determined empirically using traffic data collection. WL helps to prevent traffic congestion and IL indicates that traffic congestion is in place.

5.1. Data Collection

The study has been performed at “Station Maccampagne” intersection in the town of Kinshasa, in the Democratic Republic of Congo. (See Figure 1).

Data were collected using tally counters, every day between 4:00PM and 6:00PM, and during a period of one month (May 2023 and June 2023). Two points of interests were considered as shown below (Figure 3). Point A and B are located +/- 1km from the region of interest.

The approach has consisted in counting the number of vehicles and reporting numbers on tally sheets every 15 minutes. Two people located on points A and B were counting (using tally counters) the number of vehicles without interruption for 2 hours (from 4pm to 6pm) and reporting results on tally sheets every 15 minutes (4:15pm, 4:30pm, … 5:45pm, 6:00pm). Focus was given to vehicles that were going towards our region of interest. Vehicles leaving the region of interests were not counted.

During the process of counting, a distinction was made between taxi and private cars.

Figure 4 and Figure 5 give the minimum, the maximum, and the average number of all vehicles (private and public cars) entering in the region of interest during data collection.

Figure 4 reports data from point A and Figure 5 reports data from point B.

Note that the average number of cars varies depending on the location (point A or point B). This is normal as at the point B, cars are going downtown. The flow is therefore important.

Regarding the volume of private cars versus public cars (taxis), it has been observed that the number of private cars is always higher than the number of taxi as shown in Figure 6 and Figure 7 However, the difference is not significant. This indicates that a lot of people do not own a car and that the increased number of taxis strongly contributes to traffic jam as most of taxi drivers do not learn and apply traffic regulation.

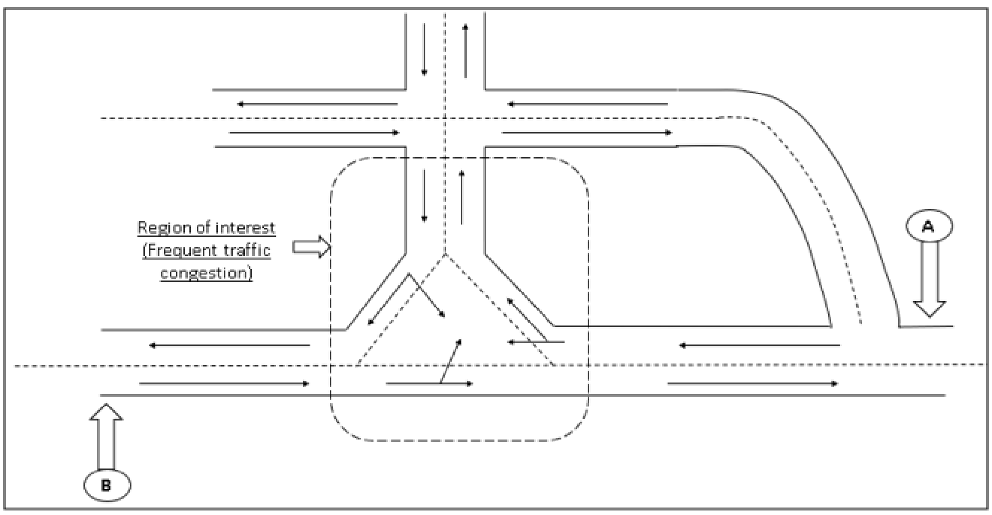

Figure 3. Data collection points (A,B) and region of interest

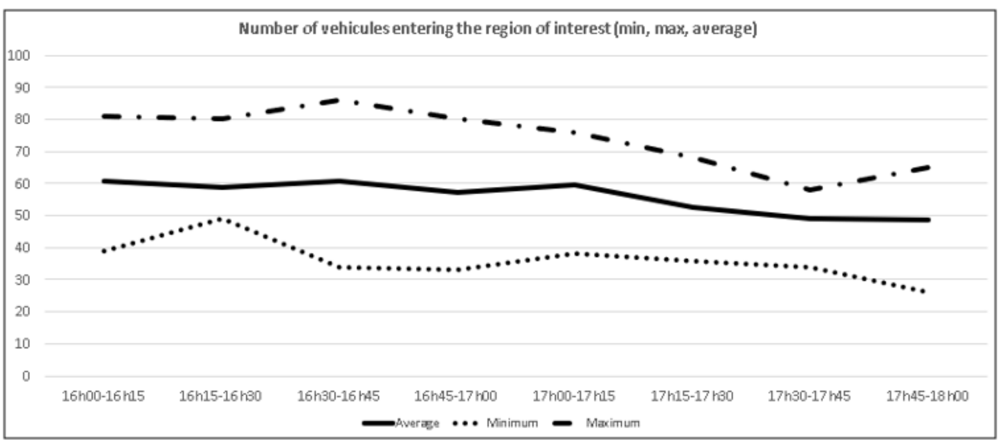

Figure 4. Point A - Number of cars for WL and IL computation

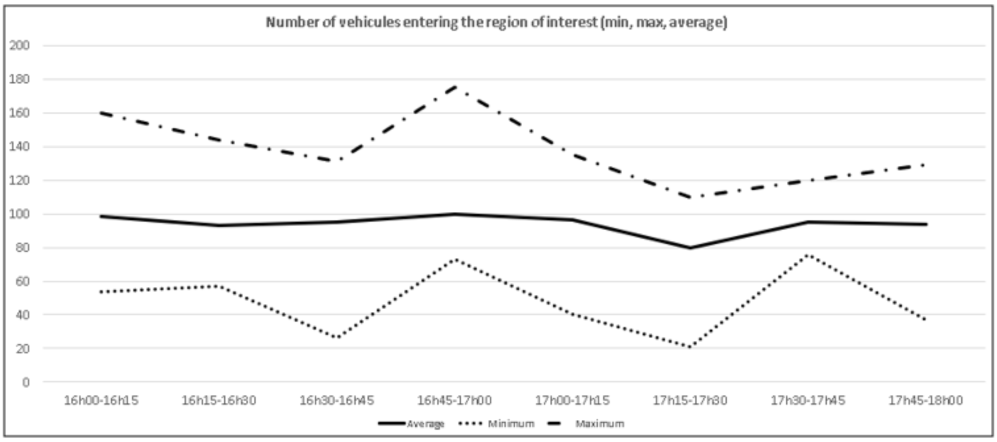

Figure 5. Point B - Number of cars for WL and IL computation

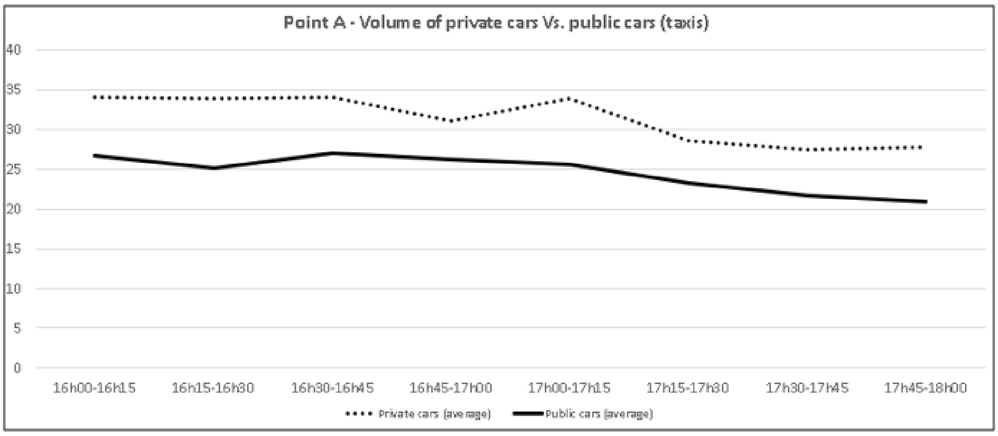

Figure 6. Point A - Comparison of private vs. public cars

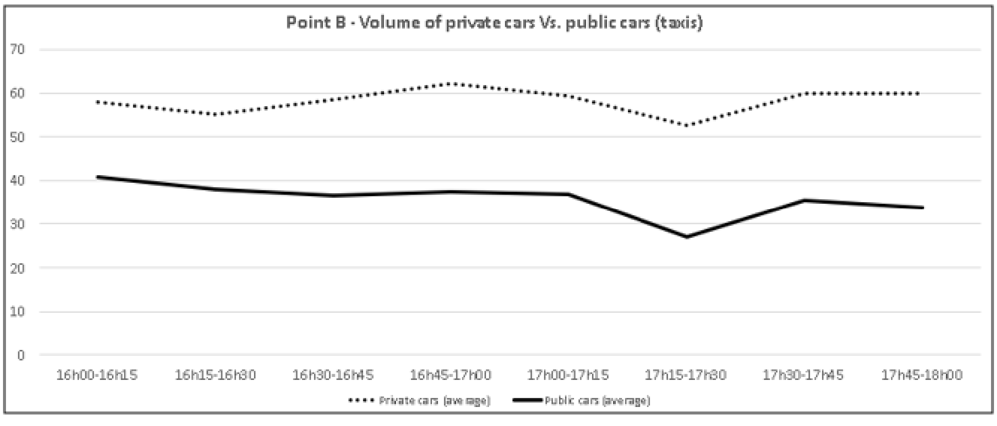

Figure 7. Point B - Comparison of private vs. public cars

Our approach of computing WL and IL consists in identifying the time when the number of cars crossing a point A or B starts to decrease before stabilizing. When such an event occurs, the probability of having traffic jam is very high. We use this information to set the IL. And from the IL, we derive the WL to act as an alert that alerts authorities to put in place immediate actions like reinforcing controls of points A or B, and tracking drivers habits to avoid or mitigate traffic jam (see discussion in section 5.2).

A model to compute WL and IL is presented and discussed in the next section.

5.2. WL and IL Computation

In order to compute WL and IL, we consider the variation of the average number of cars entering into our region of interest. Let us introduce some notation:

- $\boldsymbol{p}$: A defined point or time of measurement. Example: 4:00pm, 4:15pm, 4:30pm, …, 6:00pm.
- $\boldsymbol{P}$: Total number of points of measurements.
- $\boldsymbol{R}$: Total number of measurements for a defined point of measurement p. This is linked to the period or duration

of data collection.

- $\boldsymbol{x_r}$: A measurement at a defined point of measurement p.
- $\boldsymbol{I_{L_s}}$: Inhibit Limit for a section s.
- $\boldsymbol{W_{L_s}}$: Inhibit Limit for a section s.

Using notations above, IL and WL can be determined as follows:

$$I_{L_s} = Min\left\{\frac{1}{R}\sum_{r=1}^{R} x_r, \frac{1}{R}\sum_{r=1}^{R} x_{r+1}, \dots, \frac{1}{R}\sum_{r=1}^{R} x_{r+P-1}\right\} \quad (1)$$

$$W_{L_s} = \frac{1}{P}\sum_{p=1}^{P}\left(\frac{1}{R}\sum_{r=1}^{R} x_r\right)_p - \frac{Max\left\{\frac{1}{R}\sum_{r=1}^{R} x_r, \frac{1}{R}\sum_{r=1}^{R} x_{r+1}, \dots, \frac{1}{R}\sum_{r=1}^{R} x_{r+P-1}\right\} - I_L}{2} \quad (2)$$

For our study, using the formula above, we can compute IL and WL as follows:

For point A of our region of interest, we obtain:

- IL = 50.
- WL = 55.

For point B of our region of interest, we obtain:

- IL = 80.
- WL = 90.

These values of IL and WL can be set on different regions of interest in a town. Technically, solar powered sensor combined with an electronic card can be put in place to trigger a signal whenever WL is reached. The information will help authorities to understand variation throughout time and track some specific events not linked to traffic jam. For example, if traffic jam frequently occurs whereas WL is not reached, it may indicate that some specific events need to be monitored.

6. Conclusion and Perspectives

In this paper, we proposed a novel approach to anticipate and reduce the impact of traffic congestion without significant investment. The approach is based on two simple indicators called Warning Limit and Inhibit Limit. WL is a limit above which traffic congestion is most likely to happen, and IL is the limit above which congestion is in place or can no more be avoided. WL and IL can be dynamically computed using solar powered sensors combined to a simple electronic board.

The approach has been tested on real conditions. Results indicate that, with a low investment, traffic management can be improved, and traffic congestion mitigated for a less stressed and well-being life in society.

A survey on reasons of traffic congestion is also reported and results can be used in combination to WL and IL to prevent critical traffic congestion.

However, our model has been tested on a set of data of one month only. There is thus a need to collect additional data on a longer period to track some specific events that may not be seen in a set of data of one month. Moreover, with emerging technologies such as autonomous vehicles and artificial intelligence, many other parameters will have to be considered, and the problem tackled in a different way. Autonomous vehicles will be able to reduce traffic jams thanks to travels in platoons and ability to split or combine transportation to take passengers from various locations [34]. Artificial intelligence will enable high level of anticipation and prediction based on real-time analysis of a huge number of parameters.

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