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*Research Article*

# Evaluation of Congestion Relief Proposals in a Capital City

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This paper aims at analyzing three different solutions suggested for traffic congestion relief in Port Louis, the busiest city of Mauritius. It evaluates the impact of the three alternatives which are the use of Light Rail Transit (LRT) as an alternative mode of transport, the construction of a Ring road around Port Louis, and the upgrading of the current bus network into a Bus Rapid Transit (BRT) system. The impact of these three solutions has been evaluated by performing Traffic Cellular Automata (TCA) simulations. Our studies reveal that the Ring road will lead to more congestion while introducing the LRT or upgrading the current bus network will reduce congestion significantly.

## 1. Introduction

Traffic congestion is a condition on road networks which occurs as their use increases. It is characterized by slower speeds, longer trip times, and increased vehicular queuing. Mauritius is an island located in the Indian Ocean with a land area of 1865 $km^2$. At end of 2010, the population of the Republic of Mauritius stood at 1,283,415. The total road length on the island is of 2066 km. The motorization rate in Mauritius is of 230 and is likely to reach around 350 by the next decade [1]. In Mauritius the congestion cost has been evaluated to be around USD 0.1 billion per year [2]. Increased congestion also implies increased emission of Greenhouse gases (GHG). In 2010, 1323.8 thousand tons of GHG was emitted by the transport sector in Mauritius out of which 1261.2 thousand tons consisted of $CO_2$. The transport sector contributes 31.9% of the total $CO_2$ emission in Mauritius. Congestion is now common in both the rural and urban parts of the island. However, the Curepipe-Port Louis corridor, which accounts for nearly one-third of trips, remains the segment of greatest concern.

Traffic simulation techniques are now widely used throughout the world by road traffic planners and engineers to assist in decision making. Simulation in transportation is important because it can study models too complicated for analytical or numerical treatment, can be used for experimental studies, can study detailed relations that might be lost in analytical or numerical treatment, and can produce attractive demos of present and future scenarios. Traffic Cellular Automata (TCA), in recent years, has turned out to be an excellent tool for the simulation of large-scale traffic networks [3–5]. TCA models have been applied in Germany to develop a traffic information system for the freeway traffic in North Rhine-Westphalia, the most populous German state [5]. TCA models have also been used in Belgium for improving current and future traffic conditions [6]. Till now no study of traffic using computer simulations has been carried out in Mauritius [1].

In our work, TCA has been applied to assess the impact of three proposals for reducing the congestion level along the Curepipe-Port Louis corridor. The increased demand for passenger transportation in and around urban areas and the resulting traffic congestion have led many cities to build rapid transit systems and new conventional railway lines [7]. Two proposals from the government are the construction of a Ring road around Port Louis and the introduction of a Light Rail Transit (LRT) system. An additional proposal which we are putting forward is the upgrading of the current bus network in the region to a Bus Rapid Transit (BRT). Previous researchers have attempted to analyse the impact of a transit network for bus and LRT on various transit networks around the world. The simulations in our model have been performed using a multicell TCA model that includes anticipation and probability randomization. Our results indicate that while the Ring road will bring more congestion to traffic flow, the introduction of the LRT or the upgrading of the current bus network will lead to less congested traffic. This paper is organized as follows. Section 2 gives an overview of the region under study and the road network being considered. The methodology employed to implement the simulation model has been explained in Section 3. Section 4 provides the results and discussions. Finally, Section 5 gives the conclusions.

## 2. Region under Study

Figure 1 shows the road network in Mauritius [6]. The Port Louis to Curepipe corridor (M1) is heavily congested during the morning and afternoon peaks as persons move from their home to workplace and back. An origin-destination survey [8] revealed that 46% of trips amounted to through traffic which only bypassed Port Louis. 25% of traffic enters from the northern region while 21% enters from the southern region.

## 3. Methodology

### *3.1. Traffic Cellular Automata*

TCA falls in the category of microscopic models which in particular has been very successful in simulating dense networks like cities. The model we implemented in our simulator has been adapted from that proposed by Hafstein et al. [5] which in turn was inspired by the one proposed by Nagel and Schreckenberg [9]. The differences between our model and the one implemented by Nagel and Schreckenberg are as follows:

(i) the model uses smaller cells of length 1.5 m,

(ii) a slow-to-start rule [10] has been applied,

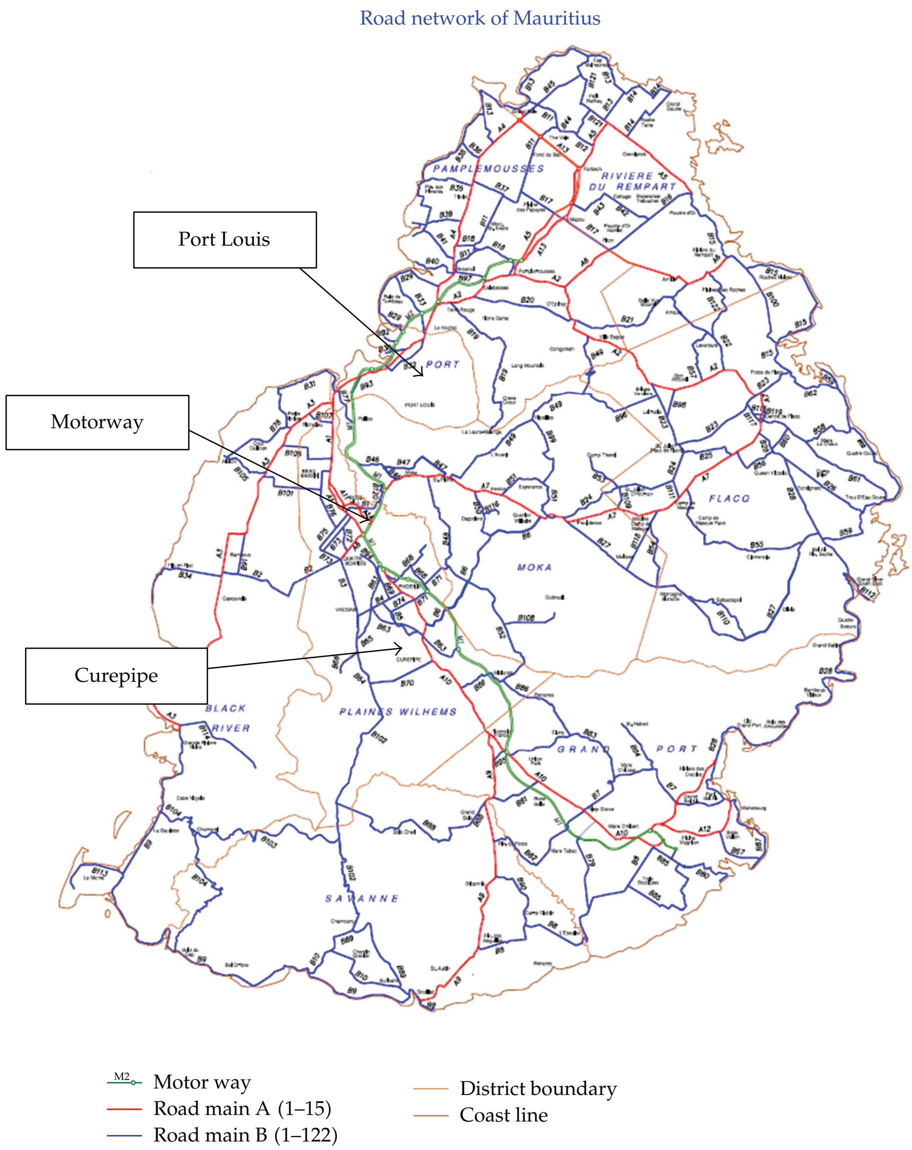


**Figure 1:** Road network map of Mauritius [6].

(iii) the model includes anticipation [4],

(iv) two classes of vehicles are used. Passenger cars occupy 4 cells while vans, lorries and buses (VLB) occupy 6 cells. The maximum speed of cars is of 17 cells/second (90 km/h) while that of VLB is of 10 cells/second (50 km/h).

Consider three vehicles $n$, $m$, and $l$ occupying consecutive positions as shown in Figure 2. The different steps used for vehicle movement can be summarized as follows.

*Step 1.* Read the values of $v_m(t)$, $d_{n,m}(t)$, and $d_{m,l}(t)$; $v_m(t)$ is the speed of vehicle $m$, $d_{n,m}(t)$ is the distance between $n$ and $m$, $d_{m,l}(t)$ is the distance between $m$ and $l$.

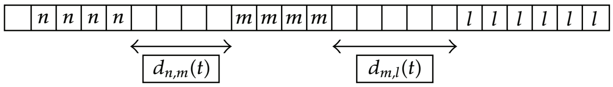


**Figure 2:** Segment of road occupied by 3 vehicles.

*Step 2.* Calculate $v^{\min}(t)$ and $d_{\text{eff}}(t)$:

$$\begin{gathered} v^{\min}(t) = \min(d_{m,l}(t), v_m(t) - 1), \\ d_{\text{eff}}(t) = d_{n,m}(t) + \max\left(v^{\min}(t) - d_s, 0\right) \end{gathered} \tag{3.1}$$

where $d_s$ is the safety distance taken as 6 cells in our model.

*Step 3.* Compare $d_{\text{eff}}$ to $v_n(t)$.
If $v_n(t) < d_{\text{eff}}$, then

$$v_n(t+1) = \min(v_n(t) + 1, v_{\max}). \tag{3.2}$$

Else $v_n(t+1) = d_{n,m}(t)$.

*Step 4* (Probability Randomization). With probability $p = 0.1$, the velocity of each vehicle (if greater than zero) is decreased by one.

Step 4 introduces a slowdown probability parameter. At each time step there is a probability $p$ that all vehicles will slow down to $v_i(t) - 1$. Step 4 introduces the slow-to-start condition whereby at every time step some stopped vehicles have to wait longer before they can continue their journey. This rule introduces individual velocity fluctuations due to delayed acceleration (imperfect driving). Delayed acceleration is a condition generally observed in traffic flow. Vehicle movement is updated in parallel at every time step which makes the model collision-free. At every time step the speed of each individual vehicles can increase by 1 cell/second. This implies that accelerating vehicles have a maximum acceleration of 5.4 $\text{ms}^{-2}$. A more detailed description of the model can be obtained from Fowdur and Rughooputh [11]. In our simulations we restrict to the afternoon peak congestion which is the most severe one in terms of the journey duration.

## *3.2. Simulation Parameters*

### *3.2.1. The Actual Network*

The actual flow of traffic in Port Louis consists of vehicles entering the motorway M1 from Quay D and vehicles generated within Port Louis. Incoming traffic from the North merges with traffic generated within Port Louis and exits Port Louis towards the South. Figure 3 shows the region concerned with the study.

Incoming traffic enters Port Louis at the Quay D roundabout on the M1 as from B30 junction and merges with traffic after 1.1 km (730 cells). The length of the exit road is considered up to the proposed entry point of the Ring Road. An arbitrary number of 300 cells,

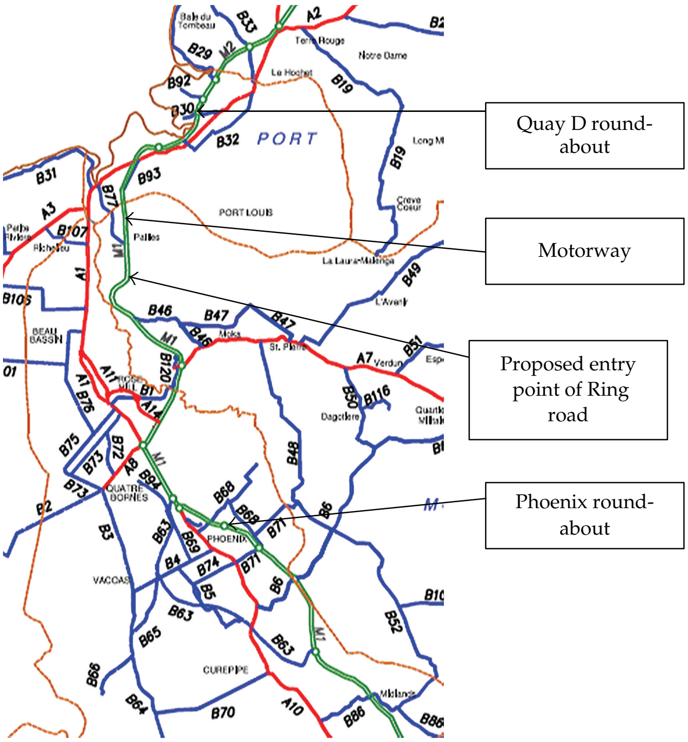


**Figure 3:** Region under study.

representing a road stretch of 450 m has been assigned to the street from which vehicles merge with those from the North. The implementation of the cellular automata model has been represented in Figure 4.

### *3.2.2. The Ring Road*

The Ring road is a proposed track linking the Quay D roundabout to the motorway at Pailles. The main aim of the Ring road is to provide an alternative path for the actual through traffic in Port Louis. It further aims, through additional entry points, to provide an alternative path for vehicles within Port Louis to leave. Figure 5 shows the track of the Ring road [12].

The length of the Ring road is 10.6 km. Cellular automata implementation of the Ring road will consist of a street of length 7000 cells linking the Quay D roundabout to the motorway. It is estimated that the safe driving speed over it would be around 70 km/h.

### *3.2.3. The LRT*

The LRT has been described as one of the centrepieces of the integrated transport system for Mauritius [6]. Covering a distance of some 25 km, the LRT will have some 13 stations, mainly located in town centres along the route where existing transport terminals already exist. The end-to-end journey time would be approximately 32 minutes and carriages would be air-conditioned, to ensure maximum attraction of car users. Headways would vary by time of

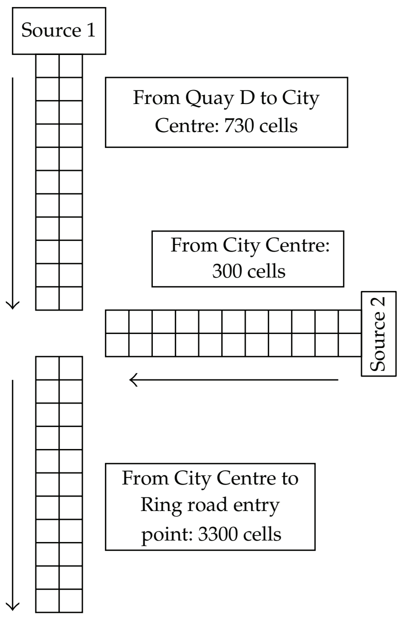


**Figure 4:** Cellular automata implementation of road network.


**Figure 5:** Proposed path of Ring road [12].

**Table 1:** Operating characteristics of the LRT [6].

| Characteristic | |
|---|---|
| Length of line | 24.9 km |
| Average time at stops | 20 seconds |
| Number of stops (stations) | 13 stations |
| Journey time, one way | 32 minutes |
| Time round trip | 70 minutes |
| Commercial speed | 43 km/h |
| Peak train frequency | 12 per hour |
| Vehicle capacity | 250 per unit (500 per train) |
| Vehicle length | 30 m per unit (running two units) |
| Vehicle width | 2.65 m |
| Seating % full | 25–30% |
| Peak pax capacity | 6000 per hour/direction |
| Predicted traffic | 93,000 pax (year 2006/working day) |
| Vehicle required | 28 units, 14 trains |
| Total vehicle required | 31 units |

day, but are expected to be of the order of 5 minutes in peak periods. Access to stations would be by an integrated system of comfortable and reliable feeder buses [6]. The operating characteristics of the LRT system are summarised in Table 1.

If the LRT is implemented, the road network will remain similar to that of Section 3.2.1 since the LRT network will be an independent one and will not interfere with the current network. In our work we investigate the effect of commuters gradually shifting to the LRT. We independently investigate the effect of 20%, 40%, 60%, 80%, or 100% of commuters choosing the LRT. In such a case, the traffic entering Port Louis from the North will remain the same since the LRT is not being extended to the northern part of the island. However, the traffic generated within Port Louis will decrease since commuters are now expected to use the LRT to travel from Port Louis to Curepipe.

#### *3.2.4. Transition to Bus Network*

Here we consider a BRT without any dedicated lane for buses. Hence the road network will remain similar to that of Section 3.2.1. In this case the number of cars both entering Port Louis from the North and generated within Port Louis will decrease. However, an increase in the number of buses will be observed at the expense of cars. It has been estimated that one bus will replace 30 cars. This will lead to a change of the ratio of cars to buses from the actual 8 : 1 to around 3 : 2. Similar to our investigation of the LRT, we investigate the effect if 20%, 40%, 60%, 80%, or 100% commuters gradually shift to the BRT.

## 4. Results and Discussion

### *4.1. Maximum Number of Persons Displaced*

The three proposed solutions which are the Ring road, the LRT, and the transition to a bus network were compared based on travel times, the maximum number of persons displaced,

**Table 2:** Total number of vehicles leaving each street.

| Simulation | Quay D | Port Louis Centre | Exit at Ring road entry point | | | |
|---|---|---|---|---|---|---|
| | | | Cars | Buses | HGV | Total |
| Actual | 1224 | 1194 | 1934 | 242 | 242 | 2418 |
| Ring road | 491 | 1826 | 1925 | 240 | 240 | 2388 |
| LRT20 | 1316 | 1050 | 1886 | 240 | 240 | 2372 |
| LRT40 | 1472 | 896 | 1942 | 240 | 240 | 2426 |
| LRT60 | 1640 | 724 | 1884 | 240 | 240 | 2372 |
| LRT80 | 1836 | 554 | 1910 | 240 | 240 | 2372 |
| LRT100 | 1996 | 394 | 1890 | 240 | 240 | 2380 |
| BRT20 | 1032 | 1032 | 1548 | 276 | 240 | 2066 |
| BRT40 | 902 | 902 | 1160 | 404 | 240 | 1798 |
| BRT60 | 716 | 722 | 776 | 588 | 240 | 1600 |
| BRT80 | 656 | 656 | 388 | 684 | 240 | 1308 |
| BRT100 | 514 | 514 | 0 | 788 | 240 | 1024 |

and the total number of vehicles entering and leaving each road. The hourly number of vehicles exiting the Quay D, the Port Louis Centre, and the exit at the Ring road entry point is summarised in the Table 2. The terms LRT20, LRT40, LRT60, LRT80, and LRT100 correspond to 20%, 40%, 60%, 80% and 100% of commuters shifting to the LRT, respectively. While the terms BRT20, BRT40, BRT60, BRT80, and BRT100 correspond to 20%, 40%, 60%, 80% and 100% of commuters shifting to the BRT, respectively.

In the actual case, the ratio of cars to buses and Heavy Goods Vehicles (HGV) is of $8:1:1$. The number of passengers per car can be estimated to be 1.5. We can therefore estimate the number of persons displaced per hour as follows:

$$\begin{aligned} \text{number of persons displaced by car} &= 2418 \times 0.8 \times 1.5 = 2902, \\ \text{number of persons displaced by bus} &= 2481 \times 0.1 \times 40 = 9672. \end{aligned} \tag{4.1}$$

The number of heavy goods vehicle (HGV) is of around 240 per hour. HGV's have not been taken into account for the calculation of the number of persons displaced since they are not concerned with public transportation. The maximum number of persons that can be displaced is summarised in the Figure 6.

It is observed that the LRT will be useful only if it can attract at least 60% of users. For the bus transition even if only 20% of users shift to it, the maximum number of users that can use the network will be higher than in the actual case. For the case where more people shift to the BRT, even larger number of persons can be displaced making the option sustainable for future trends.

### *4.2. Travel Time Analysis*

The travel times obtained in the different simulations form the Quay D to the entry point of the Ring road are given in Figures 7 and 8.

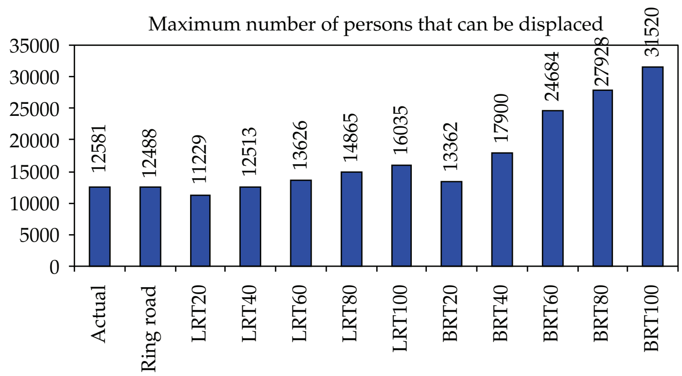


**Figure 6:** Maximum number of persons displaced.

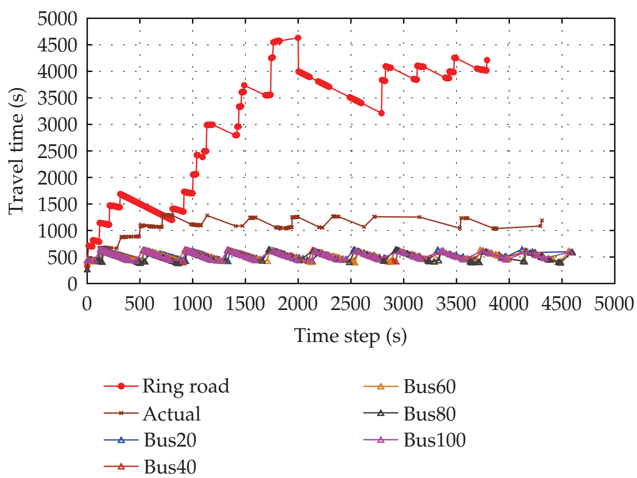


**Figure 7:** Travel time from Quay D to proposed Ring road entry point for the BRT.

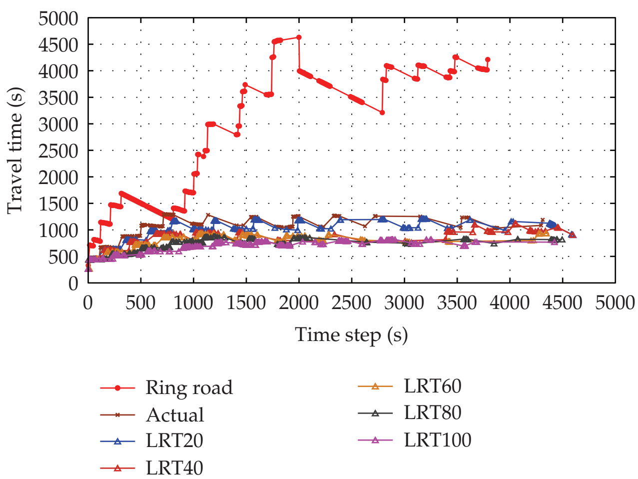


**Figure 8:** Travel time from Quay D to the proposed Ring road entry point with the LRT.

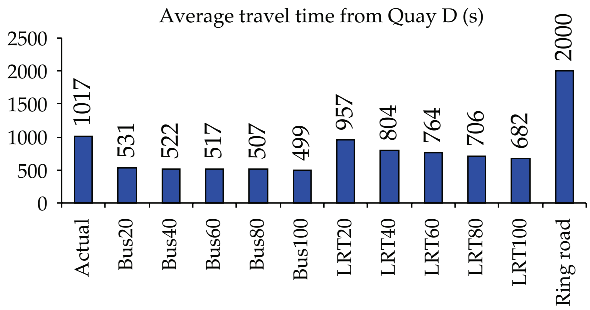


**Figure 9:** Average travel time from Quay D.

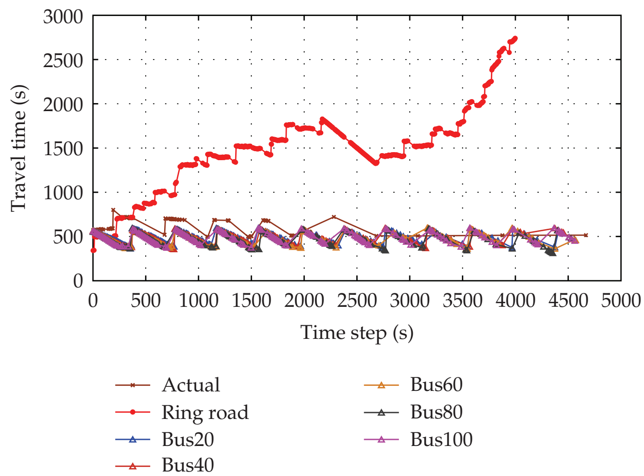


**Figure 10:** Travel time from the City Centre to proposed Ring road entry point for the BRT.

It is observed that with the BRT, a significant decrease in travel time is obtained. For the LRT, as drivers gradually shift to the LRT, the travel time decreases gradually. This effect can be further observed in Figure 9 which gives the average travel time from Quay D.

Figures 10 and 11 show the travel times obtained from the City Centre. In this case it is observed that the travel time from the City Centre for the BRT decreases while that for the LRT increases. The average travel times are given in Figure 12.

It is therefore observed that with the Ring road, there is a significant increase in travel time for vehicles entering from Quay D as well as those joining the motorway from within Port Louis. The main reason for this is an additional delay introduced at the point where the Ring road merges with the motorway. The average travel time on the Ring road has been calculated to be of 2000 seconds (33.3 minutes) during peak congestion. This time is again far greater than the actual travel times.

With the LRT a decrease in travel time has been achieved for vehicles entering at the Quay D entry point. This has resulted from the fact that with the LRT traffic generated from within Port Louis will drop drastically. As expected, the larger the number of drivers shifting to the LRT, the greater will be the drop in traffic volume. Vehicles entering Port Louis will then face a smaller waiting time at the intersection with the road bringing traffic generated

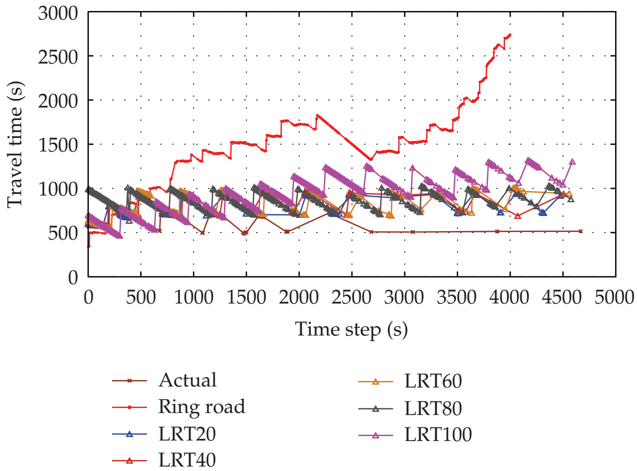


**Figure 11:** Travel time from the City Centre to proposed Ring road entry point for the LRT.

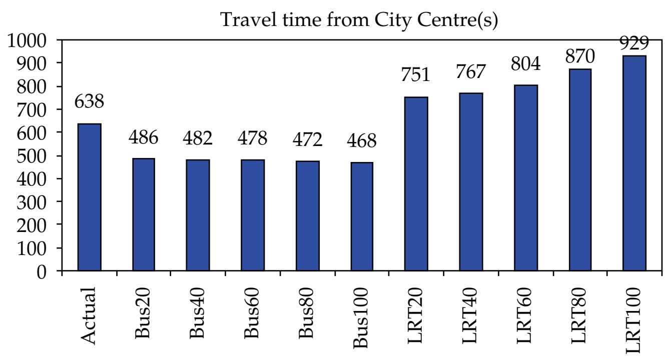


**Figure 12:** Average travel time from Quay D.

within Port Louis. However, vehicles leaving Port Louis are bound to experience a longer waiting time resulting in an increase in their travel time.

By the BRT a significant decrease in travel time is observed both for vehicles entering from Quay D and vehicles generated within Port Louis. As more drivers shift to the BRT, the travel time decreases gradually.

With the BRT40 the maximum number of persons displaced is greater than for the LRT100. The travel time form Quay D will decrease by 49% while with the LRT100 it will decrease by 33%. Travel time form the City Centre for the BRT 40 decreases by 24% while for the LRT100 it increases by 46%. Hence, in terms of travel time and maximum number of persons displaced, the BRT40 outperforms the LRT100.

### *4.3. Carbon Dioxide Emission Analysis*

In this section we provide an analysis of the difference in the amount of $CO_2$ emitted by the three proposed solutions. In Mauritius the average $CO_2$ emissions from cars is of 158 g/km [6]. The amount of $CO_2$ emission from buses has been taken as 1015.4 g/km while the $CO_2$

**Table 3:** Hourly $CO_2$ emission from the 3 proposed solutions.

| | Quay D to Ring road entry point | | | City Centre to Ring road rntry point | | | Ring road | | Hourly $CO_2$ emission/tons |
|---|---|---|---|---|---|---|---|---|---|
| Simulation | Cars | Bus | $CO_2$/tons | Cars | Bus | $CO_2$/tons | Cars | $CO_2$/tons | |
| Actual | 982 | 121 | 1.68 | 952 | 121 | 1.48 | 0 | 0 | 3.16 |
| Ring road | 116 | 121 | 0.85 | 908 | 121 | 1.44 | 880 | 1.46 | 3.75 |
| LRT20 | 1074 | 121 | 1.77 | 808 | 121 | 1.35 | 0 | 0 | 3.32 |
| LRT40 | 1232 | 121 | 1.92 | 656 | 121 | 1.22 | 0 | 0 | 3.34 |
| LRT60 | 1400 | 121 | 2.08 | 484 | 121 | 1.08 | 0 | 0 | 3.36 |
| LRT80 | 1596 | 121 | 2.26 | 314 | 121 | 0.93 | 0 | 0 | 3.39 |
| LRT100 | 1756 | 121 | 2.42 | 154 | 121 | 0.79 | 0 | 0 | 3.41 |
| BRT20 | 774 | 138 | 1.59 | 774 | 138 | 1.42 | 0 | 0 | 3.01 |
| BRT40 | 580 | 202 | 1.79 | 580 | 202 | 1.60 | 0 | 0 | 3.39 |
| BRT60 | 388 | 294 | 2.18 | 394 | 294 | 1.95 | 0 | 0 | 4.13 |
| BRT80 | 194 | 342 | 2.28 | 194 | 342 | 2.04 | 0 | 0 | 4.32 |
| BRT100 | 0 | 394 | 2.41 | 0 | 394 | 2.16 | 0 | 0 | 4.57 |

emission resulting from electricity generation for the LRT is of 2970.2 g/km [13]. Using these figures and data obtained from the simulations performed, the total amount of $CO_2$ emitted for each network has been calculated. Vehicles traveling from Quay D to the Ring road will cover a distance of 6.045 km while those coming from the City Centre will travel 5.400 km. Vehicles taking the Ring road will travel 10.500 km. Table 3 summarises the hourly amount of $CO_2$ emission from the different situations investigated.

Table 3 suggests that, compared to the actual case, a net improvement in the hourly $CO_2$ emission is achieved only by the BRT20. The emission of the LRT, however, compares favourably with BRT40.

## 5. Conclusions

The aim of this paper was to analyse three different solutions for traffic congestion relief in Port Louis. TCA simulations were performed to investigate the impact on travel time and the maximum number of persons that will be displaced in the three different alternatives. Our study has shown that Ring road option will not lead to any reduction in the congestion level at Port Louis. On the contrary it will lead to further congestion and will have higher $CO_2$ emissions compared to the actual case, the LRT and the BRT. This will be caused mainly by the fact that commuters using the ring road will travel an additional 5 km before reaching their destination and the additional delay created at the point where vehicles from the Ring road merge with the motorway. This second inconvenience will result in a decreased capacity of both the motorway and the Ring Road.

The LRT can be envisaged as a long-term solution because of its lower $CO_2$ emission. It, however, suffers from longer travel times and lower carrying capacity than the BRT. Thus, our studies reveal that the BRT40 can be set as the target that authorities should go for.

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