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Evaluating Emission Reduction Due to a Proposed Light Rail Service: A Micro-Level Analysis

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***Abstract*—**Carbon dioxide (CO_2) alongside other gas emissions in the atmosphere cause a greenhouse effect, resulting in an increase of the average temperature of the planet. Transportation vehicles are among the main contributors of CO_2 emission. Stationary vehicles with initiated motors produce more emissions than mobile ones. Intersections with traffic lights that force the vehicles to become stationary for a period of time produce more CO_2 pollution than other parts of the road. This paper focuses on analyzing the CO_2 produced by the traffic flow at Anzac Parade Road - Barker Street intersection in Sydney, Australia, before and after the implementation of Light rail transport (LRT). The data are gathered during the construction phase of the LRT by collecting the number of vehicles on each path of the intersection for 15 minutes during the evening rush hour of 1 week (6-7 pm, July 04-31, 2018) and then multiplied by 4 to calculate the flow of vehicles in 1 hour. For analyzing the data, the microscopic simulation software "VISSIM" has been used. Through the analysis, the traffic flow was processed in three stages: before and after implementation of light rail train, and one during the construction phase. Finally, the traffic results were input into another software called "EnViVer", to calculate the amount of CO_2 during 1 h. The results showed that after the implementation of the light rail, CO_2 will drop by a minimum of 13%. This finding provides an evidence that light rail is a sustainable mode of transport.

***Keywords*—**Carbon dioxide, emission modeling, light rail, microscopic model, traffic flow.

I. Introduction

THE greenhouse effect occurs when gases such as CO_2 absorb and release the radiation energy from the sun, preventing the energy from escaping the Earth's atmosphere [1]. The rise of industrial development has increased CO_2 concentrations within the atmosphere by about 200%, changing from 280 ppm prior to the industrial revolution to 400 ppm in the new millennium. It is predicted that this variation continues in an incremental trend [2].

Road intersections within the cities in high populated areas are places that produce large amounts of carbon emissions (CE) due to considerable variations in vehicle speed, vehicle concentration and stopping time duration behind the traffic signals [3]-[5]. In addition, constructions that are carried out on the road are also affecting the increment of CO_2 emissions.

Light rail train (LRT) transportation has various benefits for the cities and the residents. The main advantages of LRT can be summarized as: reducing the traffic congestion and air pollution, increasing property values alongside economic development, and providing a cheaper means of transportation [6]-[9]. Due to the fact that LRTs use electricity as the source of energy by means of cables that are located overhead of the vehicle or through a third rail between the tracks, it can be considered an eco-friendly transportation option.

In this report, we have focused on the amount of CE produced in Anzac Parade road – Barker street intersection in Sydney, NSW; and compared the CO_2 concentration before and after LRT implementation.

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II. Method

A. Modeling Software

Micro simulation software "VISSIM" was used to model the intersection in three stages: before (stage 1), during (stage 2) and after (stage 3) the construction and implementation of the LRT. VISSIM is a microscopic simulation software with flexible traffic flow. Each factor which is described in the software is simulated individually. The flow placed within the models and the overall traffic is the combination of the different flows interacting mutually. By using a satellite map of the location and the various tools provided for the simulation, it is possible to design the roads, directions, connections, type of vehicles, speed limit, speed reduction, traffic signs and flow. Moreover, the simulation software called "EnViVer" is used to combines the results of the VISSIM traffic simulation, with emission models pre-installed within it, to estimate the CO_2 produced by the traffic flow in the network.

B. Data Acquisition and Approximations

In order to prepare the initial data required to be implemented within the VISSIM models, a 15-minute film is recorded from the intersection showing all vehicles and the lanes in which they enter and/or exit, the recording is taken from two locations in order to cover all the traffic signals, lanes and vehicles. For simplicity, the data gathering is carried out for three working days in July 2018, during the peak traffic flow time of 5-6 pm.

The traffic signal durations (red and green lights) corresponding to each phase is measured. Due to the fact that the signal traffic lights at Anzac Parade Road-Barker Street intersection use a specific algorithm that changes the signal durations based on traffic flows, the average time is calculated.

The number of lanes on Anzac Parade Road differs in each stage due to the light rail construction, whereas in Barker

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Street, it remains the same. In stage 1, the number of lanes entering and exiting Anzac Parade is 3×3. However, during and after the construction of the LR, it will become 3×2; i.e. 3 lanes entering and 2 lanes exiting the intersection.

In this case study, the most frequent vehicles that produce the most emissions are chosen as the input vehicles. These are city cars, busses and city duty heavy vehicles.

Due to lack of measuring instruments at the main locations, the speed of the vehicles is placed as the default vehicle speed at an intersection. For cars, the default vehicle speed is around 30 km/h, while for buses and heavy-duty vehicles it is approximately 25 km/h.

III. Results

A. Traffic Flow Data

By going through the recordings, the number of vehicles is counted on each lane at Barker Street – Anzac Parade Road intersection direction (Table I).

B. Data Analysis

1. VISSIM Modeling

By implementing all these various factors in the software, it is possible to produce a simulation almost parallel to the real world. Through the input data, three simulation models were created, as can be seen in Figs. 1-3. Fig. 1 shows the intersection on 2016, before the light rail was introduced on Anzac Parade Road. Fig. 2 represents the current time, while the LRT is not yet functional and the number of lanes is reduced to two. Finally, Fig. 3 shows the predicted model of what the intersection may look like after the LRT is implemented in the year 2020.

TABLE I
Average Cars on Each Route

First Day								
Barker-East		Barker-West		Anzac-South		Anzac-North		Total
F	65	**F**	68	**F**	140	**F**	144	
L	19	**L**	0	**L**	6	**L**	34	
R	36	**R**	4	**R**	29	**R**	2	
Sum	120	Sum	72	Sum	175	Sum	180	547
Second Day								
Barker-East		Barker-West		Anzac-South		Anzac-North		
F	33	**F**	18	**F**	59	**F**	72	
L	8	**L**	5	**L**	6	**L**	19	
R	23	**R**	4	**R**	23	**R**	2	
Sum	64	Sum	27	Sum	88	Sum	93	272
Third Day								
Barker-East		Barker-West		Anzac-South		Anzac-North		
F	32	**F**	28	**F**	72	**F**	97	
L	12	**L**	2	**L**	2	**L**	2	
R	37	**R**	1	**R**	19	**R**	2	
Sum	81	Sum	31	Sum	93	Sum	101	306

F: Forward, L: Left, R: Right

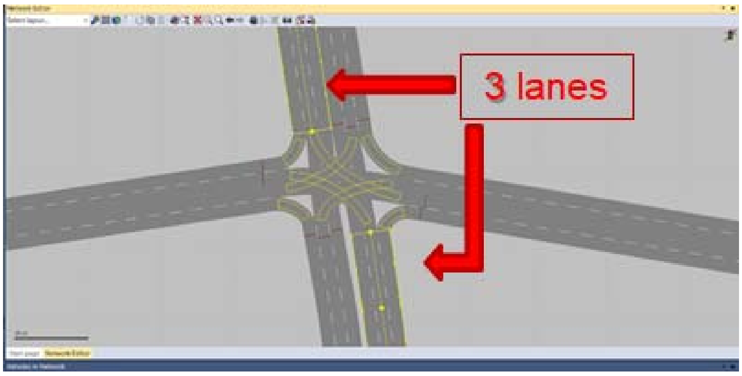

Fig. 1 Three lanes, no light rail, 2016 (stage 1)

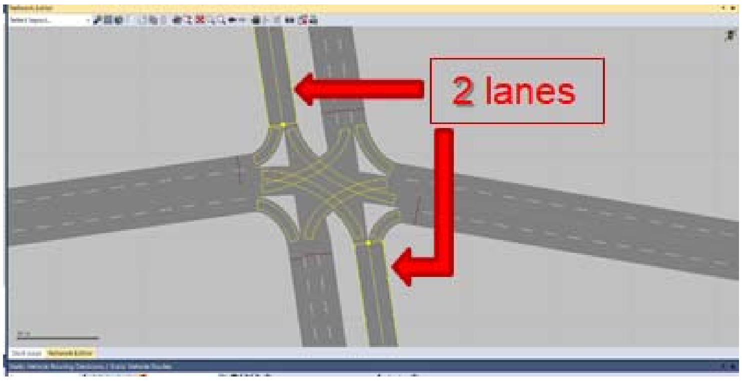

Fig. 2 Two lanes, light rail construction, 2018 (stage 2)

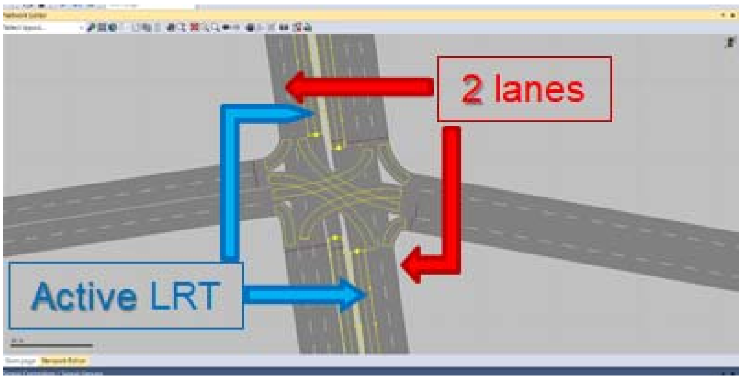

Fig. 3 Two lanes, light rail, 2020 (stage 3)

Since the LRT is not implemented yet, the exact flows of the trains are not very clear, therefore for the flow input, we have used the flow of LRT on one of the completed sections of the network (Sydney city center). The results of calculating the number of trains traveling at one of the intersections resembling that of Anzac Parade Road and Barker Street was an average of four trains per hour.

Finally, it is important to instruct the software regarding the type of outputs required: this is imperative for calculating the CO_2 at the intersection. For this analysis the extracted outputs are:

- Coordinate the front end of the vehicle at the end of the time step,
- Unique vehicle number,
- Simulation time (seconds),
- Speed at the end of the time step,
- Number of each vehicle type,
- Name of each vehicle type,
- Gradient on each lane,
- Total distance traveled (meters).

2. EnViVer Modeling

The simulation output carried out by VISSIM is compiled in an FZP file, which is then installed into the EnViVer software. Each vehicle described into the VISSIM simulation is re-introduced into EnViVer. For this simulation three types of vehicles were used considering: Light duty cars in city, Light duty bus in city, Heavy duty vehicles in city.

The VISSIM results are then fed within EnViVer provides analysis on the data in terms of vehicle speed and CO_2 within the grid area. Figs. 4-6 represent the vehicle speed at the intersection for each the stages, respectively. The green areas show vehicles speed of around 20 km/h to 30 km/h, the yellow for 10 km/h to 20 km/h, and the red for 10 km/h to 0 km/h (almost stationary).

As can be seen, the vehicle speed has small changes at each stage; however, it can also be seen that the speed of vehicles is reduced much sooner in Figs. 4 and 5 for the two lanes than that of Fig. 4 where the construction of the LRT has not yet begun.

The results of CO_2 emission per area for each stage can be seen in Figs. 7-9, respectively. By comparing them to the vehicle speed at the intersection, shown in the figures relevant to each stage, it can be seen that emissions at the center of the intersection is higher than that of the surrounding. It is consistent to the inverse relationship between the vehicles speed and the CO_2 produced per area.

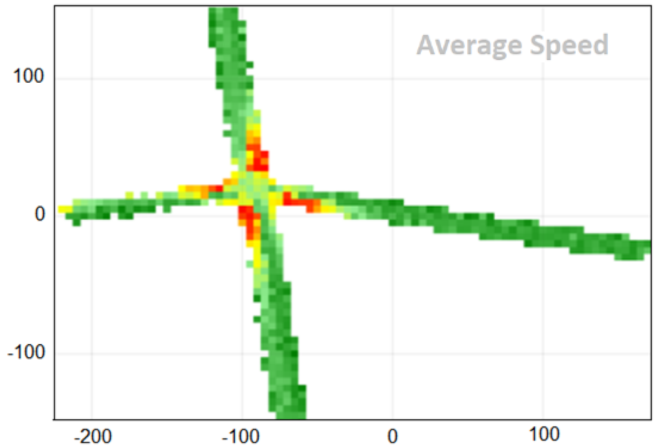

Fig. 4 Average speed of vehicles (m/s) – status: 3 lanes, no LRT

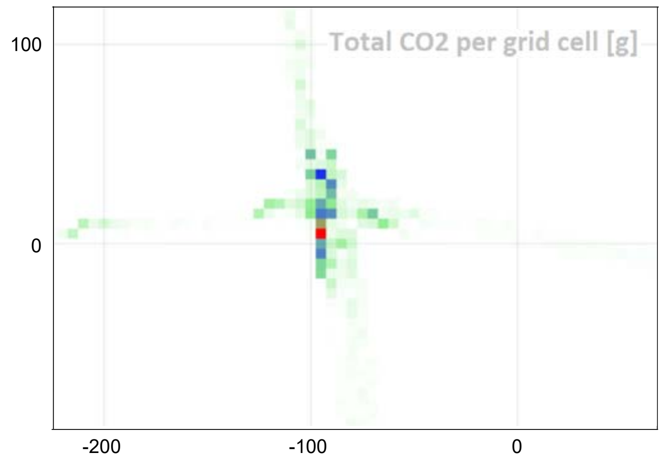

Fig. 5 Total CO_2 per grid cell (grams) – status: 3 lanes, no LRT

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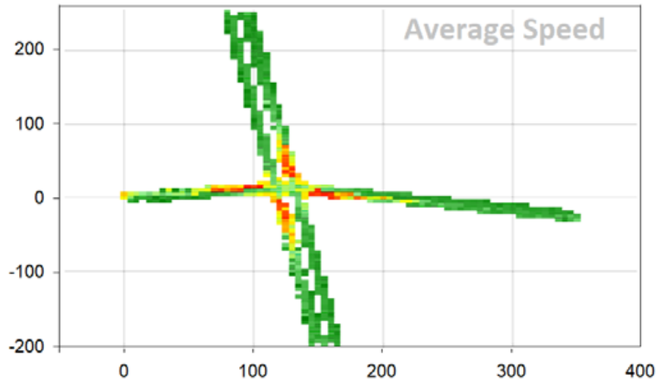

Fig. 6 Average speed of vehicles (m/s) – status: 2 lanes, LRT in construction

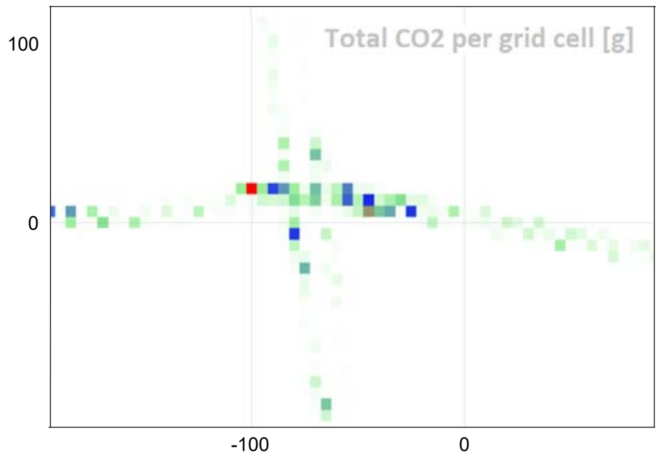

Fig. 7 Total CO_2 per grid cell (grams) – status: 2 lanes, LRT in construction

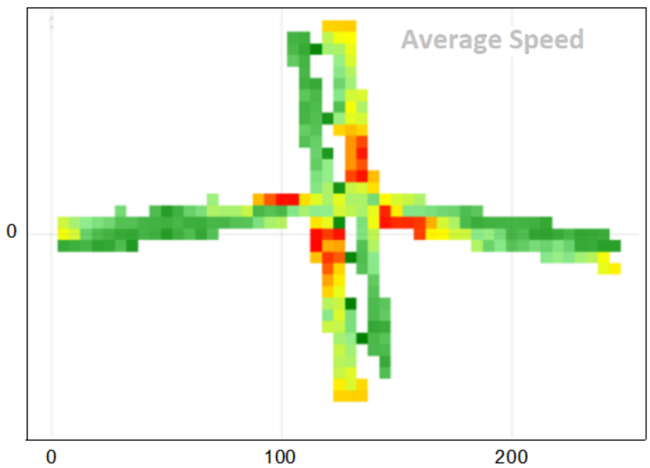

Fig. 8 Average speed of vehicles (m/s) – status: 2 lanes, LRT completed

The total emissions produced at each of the stage models input into EnViVer are shown in Table II. As can be seen, the emissions during the construction stage are larger than before light rail began. This could mostly be due to the decrease in the number of lanes in which the same flow of traffic is expected to run through; increasing the number of cars reducing their speed to stop behind the traffic lights, and therefore, raising the collective CO_2 emissions per area. After the completion of the light rail, emissions begin to go down; although within the model, the flow of the road has been kept the same as the last two stages. However, the simulation models in VISSIM and EnViVer take into account that the implementation of a new transportation system also affects the CO_2 components being released.

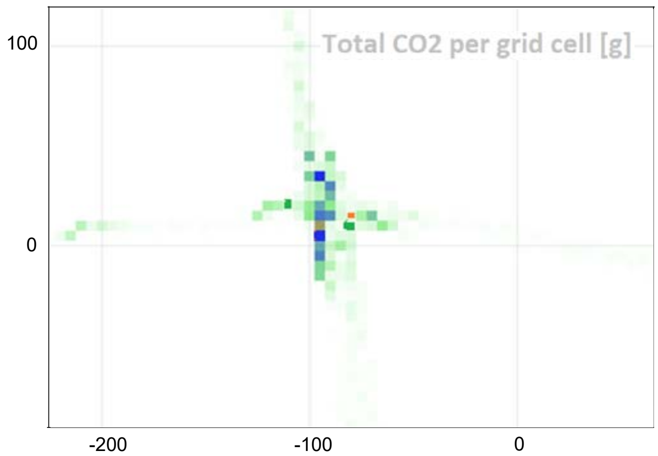

Fig. 9 Total CO_2 per grid cell (grams) – status: 2 lanes, LRT completed

TABLE II
CO_2 EMISSIONS PRODUCED IN EACH MODEL

Stage	Year	CO_2
1	2016	195.209 (kg) 603.862 (g/km)
2	2018	270.209 (kg) 690.221 (g/km)
3	2020	169.728 (kg) 1268.253 (g/km)

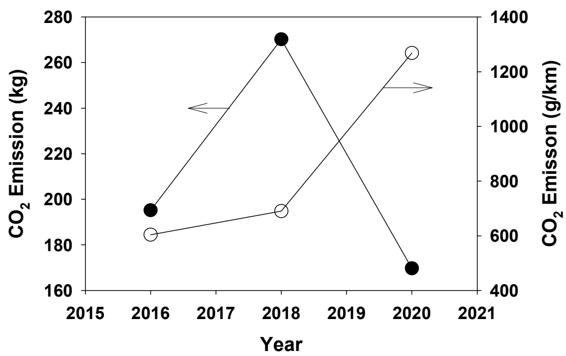

Fig. 10 Carbon emissions produced in kg and in g/km

By placing the CO_2 emissions produced in each stage into Fig. 10, the rise of CE during the construction stage can clearly be seen. However, after the LRT is put into place, the amount of CO_2 (filled black circles) decreases, whereas the CO_2 produced in grams per km (open black circles) is still

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rising; this is due to the fact that the LRT reduces the CO_2 being produced on the road, and therefore the amount of CE is lowered. However, the flow of vehicles still remains the same as before with the addition of the LRT; thereby, the amount of CE per unit length continues to increase.

By subtracting the CO_2 produced in each stage and comparing it with the initial amount, we have found the percentage of emissions increasing or decreasing, as follows:

$$((270.209-195.209)/195.209)\times 100=+38.4\% \quad (1)$$

This shows 38.4% increase in CO_2 emission between stages 1 and 2, while

$$((169.728-270.209)/270.209)\times 100=-37.2\% \quad (2)$$

Equation (2) shows a 37.2% decrease in CO_2 emission between stage 2 and stage 3. Finally,

$$((169.728-195.209)/195.209)\times 100=-13.0\% \quad (3)$$

Equation (3) shows a 13.0% decrease in CO_2 emission between stage 1 and stage 3. Even though it is clear that the LRT can successfully reduce CE in the area of the intersection by a minimum of around 13% between the start of the project and after the installation is completed; the construction stage still increases the amount of CO_2 produced by 38%. According to this, during the light rail construction, there is a large amount of CO_2 entering the air – not including the emissions produced by the construction equipments on site – increasing the negative effects on the environment. However, this is only for the duration of the construction. After completion, the CO_2 will drop by 37%. However, this decrease is less than the initial rise at the beginning, because the construction phase has a closed period of time, and the working phase of the LRT is set for the far future. That being said, the overall CO_2 reduction is not exactly 13%, due to the fact that the reduction of vehicle flow has not been included within stage 2 and stage 3. By introducing a new public transportation, it is expected that people will tend to swap from the use of private cars to public transport, and thereby, reduce the number of vehicles on the road. Accordingly, the number of vehicles standing stationary at the intersection may decrease resulting in lesser CO_2 being produced at the final stage. Therefore, the emissions shown in Table II for stage 3 are expected to drop even further, resulting in an even larger decrease in CO_2, according to (3).

IV. Conclusion

Light rail is a more eco-friendly means of transportation in comparison to cars and other fossil fuel-based private vehicles. By using electricity – a renewably energy – as a fuel source it lessens the negative impacts on the environment. By presenting three stages of simulation models created to represent the Anzac Parade Road – Barker Street intersection in Sydney, before, during and after the construction of LRT; using VISSIM and EnViVer software programs, it is possible to calculate the CO_2 emissions for each of the stages.

The results show that by starting construction and shutting down some of the lanes in order to make room for the LRT tracks, the conjunction of vehicles produce 38.4% more CO_2. The vehicle flow is also expected to remain the same as it was before construction since no alternative means of transportation or routes have been presented for the path. However, it is expected that after construction is completed and the LRT is fully installed and working, the CO_2 drops by 37.2%. It is not able to state that the traffic flow continues to remain the same in all three stages; therefore, the 37.2% drop is a minimum of CO_2 emission that will decrease due to light rail.

Finally, by comparing the CE before light rail started construction and after it is fully working, it can be seen that a 13% drop of CO_2 can be expected from imputing the LRT in our interested intersection. Although this figure could still be reduced considering a decrement in the vehicle flow after the LRT construction is completed.

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