THE INDICATIVE EFFECTS OF INEFFICIENT URBAN TRAFFIC FLOW ON FUEL COST AND EXHAUST AIR POLLUTANT EMISSIONS

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ABSTRACT

Poor urban traffic management such as poor intersection controls, congestions, illegal roadway blockages and construction works causes “stop-go” driving conditions with excessive idling resulting in wasted fuel and increased air pollutant emissions (CO_2, CO, NOx, HC, etc.) during idling conditions and acceleration from a stop position due to more energy required to move vehicles from a halt.

In this study the effects of traffic signal coordination on fuel cost and gas emissions were investigated by comparing the amount of idling time on streets with coordinated signals to those with uncoordinated signals during the off peak period.

It was found that signal coordination can reduce the idling fuel cost by more than 25 cents per kilometre in the CBDs. The possible reductions in idling gas emissions were found to be 80% for CO_2 and 77% for both CO and HC. These are significant reductions if the whole CBD network and all the vehicles within the network per annum are taken in to account.

1. INTRODUCTION

Vehicles have the potential to be the main contributors of air pollution in the central business districts (CBDs). This pollution is further exacerbated by poor urban traffic management. Poor urban traffic management includes poor intersection controls, congestion and un-coordinated traffic signals. There are many people living and moving in the CBDs, thus it is important for the city to reduce the air pollution as much as practically possible.

Uncoordinated traffic signals cause “stop-go” driving conditions, thus resulting in wasted fuel and increased exhaust emissions during idling conditions due to time added to trips. Exhaust emission comprise various gases such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (HC), etc (Souza et al, 2013). Carbon dioxide is produced as a by-product during the combustion of fossil fuels such as gasoline and diesel. Carbon monoxide is produced when fossil fuels are burned at high temperatures. NOx is the combination of nitrogen oxide and nitrogen dioxide and it exist at a certain level of exhaust emission. Hydrocarbons emissions are caused by unburned fuel passing through the engine exhaust (Rahman et al, 2013).

A significant volume of fuel could be saved and exhaust emissions could be reduced by implementing efficient traffic management that reduces excessive idling such as coordinated traffic signals in the CBDs.

The objective of this study is to investigation the suspected trend that uncoordinated signals may be causing increased vehicle fuel consumption and gas emissions in CBDs. The investigation was undertaken during the off peak hours using a petrol powered vehicle with a 1.4 litre engine capacity. The off peak period was selected for this investigation on the bases that if significant reduction in fuel consumption and emissions could be found in the off peak period then even more could be saved in the peak period as there would be more vehicles on the road.

2. METHODOLOGY

This investigation was carried out by undertaking off-peak travel time surveys along streets with coordinated and uncoordinated signals in both Pretoria and Johannesburg CBDs. The test vehicle was fitted with an On-board monitoring car chip unit that records the following data:

- Total journey time
- Total time spent idling (while stationary)
- Total time spent in different speed bands

The car chip also records the following information which is not used in this study.

- Maximum speed
- Number of acceleration events
- Number of hard breaking events
- Number of extreme braking events

The data was collected on 18 August 2014 in Pretoria CBD and on 22 January 2015 in Johannesburg CBD. The choice Pretoria CBD was based on close proximity to the author’s workplace. The Johannesburg CBD was selected based on the known presence of a street with coordinated traffic signals. Furthermore it is justifiable to compare the two CBDs as have similar characteristics in terms traffic compositions and street network. The routes were after a route identification site visit to the CBDs which included driving around the CBDs. The choice of test vehicle was based on availability.

This study also uses fuel consumption and emission rates determined in other studies.

3. RESULTS AND DISCUSSION

Table 1 shows the results of the journey time surveys conducted at streets with uncoordinated traffic signals in Pretoria CBD. Streets with signal coordination could not be found in Pretoria at the time of the investigation.

Table 1: Travel time survey results for streets in Pretoria CBD.

Street Name	Direction	From	To	Signal Coordination (Yes/No)	Distance (km)	Travel Time (min)	Total IdleTime	%Idle Time
Nana Sita WB	West Bound	Nelson Mandela	Princes Park	No	2	00:05:39	00:01:26	25%
Nana Sita	East Bound	Princes Park	Nelson Mandela	No	2	00:07:17	00:02:58	41%
Francis Baard	East Bound	Princes Park	Nelson Mandela	No	2.1	00:08:51	00:03:04	35%
Pretorius	West Bound	Nelson Mandela	Princes Park	No	2.2	00:16:02	00:08:38	54%
Bosman	North Bound	Vesagie	Boom	No	1.5	00:07:07	00:02:48	39%
Sisulu	South Bound	Bloed	Francis Baard	No	1	00:03:27	00:00:50	24%

As seen in Table 1, the idling time along a street with uncoordinated traffic signals ranges from 25% to 54% of the total journey time. A 40% idling time is indicative of a street along which one stops at every signal OR is indicative of heavy delays caused by constructions works on one of the intersections along the surveyed street such as Pretorius Street. Construction work results in random, much higher delays than normal uncoordinated signals as seen in the case of Pretorius Street. The AM and PM peak period are expected to be worse as there would be increased traffic volume.

Table 2 shows the results of the travel time surveys conducted in Johannesburg CBD along Simmonds Street with uncoordinated signals and along Sauer Street with fully coordinated signals along the surveyed section.

Table 2: Travel time survey results for streets in Johannesburg CBD.

Street Name	Direction	From	To	Signal Coordination (Yes/No)	Distance (km)	Total Travel Time	Total IdleTime	%Idle Time
Simmonds	West Bound	Bree	Anderson St	No	0.8	00:04:18	00:01:41	39%
Sauer	East Bound	Anderson St	Bree	YES	0.8	00:03:35	00:00:15	7%

Table 2 shows that complete and optimal signal coordination such as one along Sauer Street in Johannesburg can bring down the idling time to about 7% of the total travel time. It should be noted that one of the traffic signals along the surveyed section on Sauer Street was not working at the time of the survey. If the signal was working the idling time could be have been less than 7%. Simmonds street with uncoordinated signals has high percentage of idling time which is similar to the streets in Pretoria CBD.

Speed Profiles

Figure 1 and 2 show the speed profiles of surveyed streets in Pretoria and Johannesburg CBDs respectively.

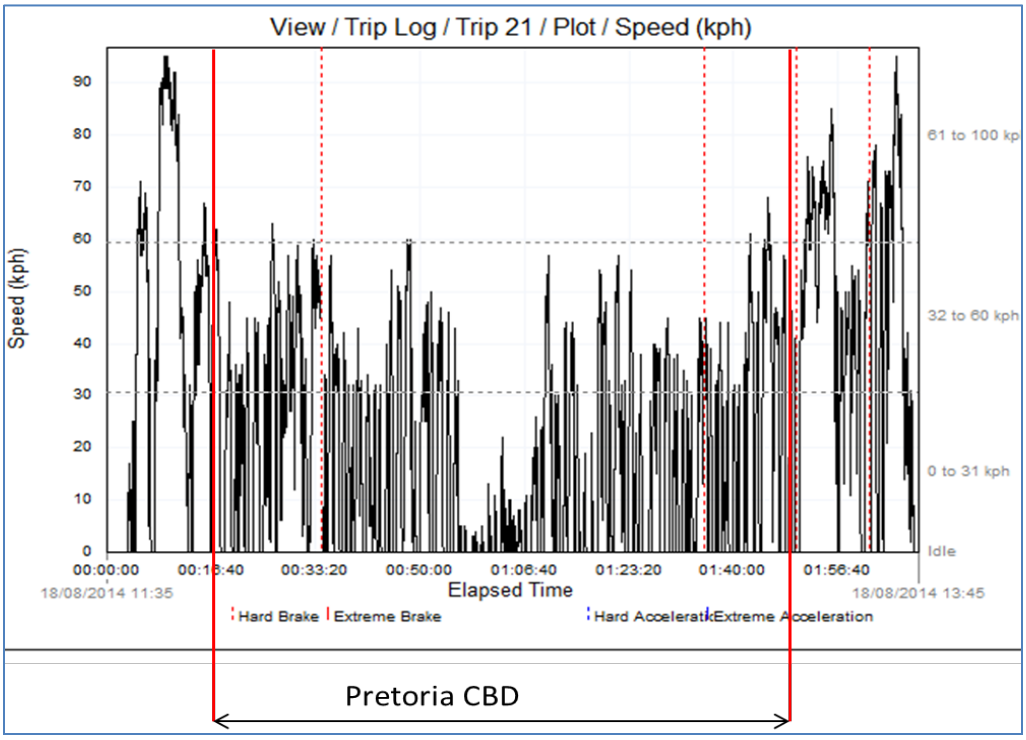

Figure 1: **Speed profiles of surveyed Pretoria CBD streets during off peak**

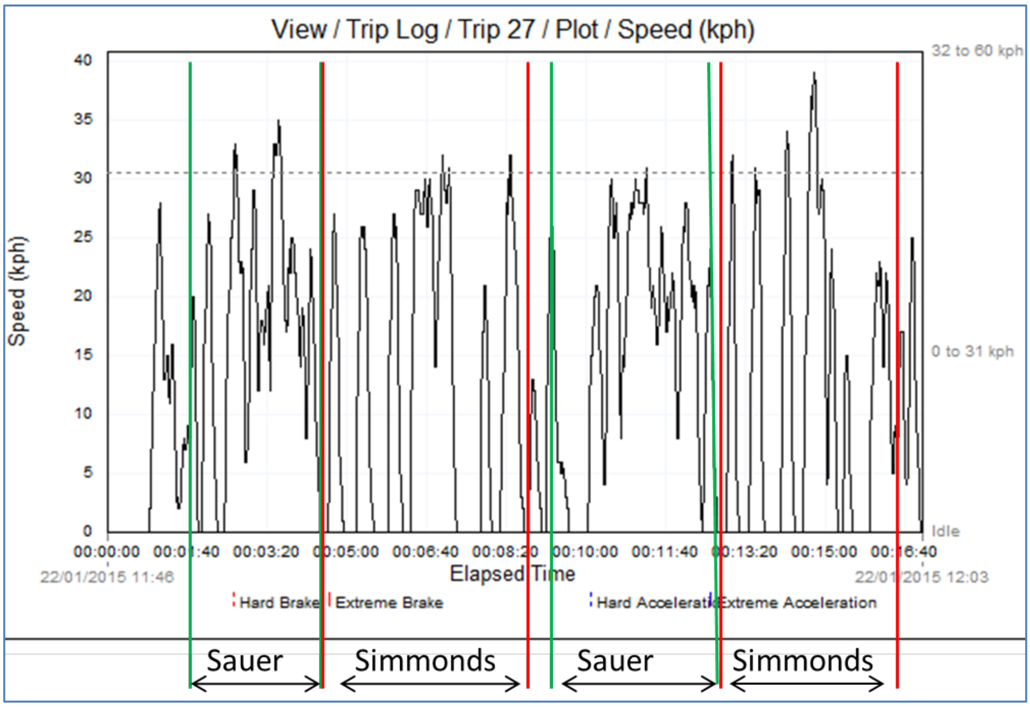

Figure 2: Speed profiles of Simmonds Street and Sauer Street in Johannesburg during off peak

Uncoordinated traffic signals cause stop-go driving conditions as shown in Figure 1 for street surveyed in the Pretoria CBD and Figure 2 for Simmonds Street in Johannesburg CBD.

Sauer Street has signal coordination which provides a green wave as seen in Figure 2.

4. ESTIMATION FUEL COSTS AND EMISSIONS

This sections aims at showing the economic and environmental effects of optimal signal coordination. All estimations are based on a 1.4 litre petrol engine (Test vehicle).

Table 3 and Table 4 below show the estimated fuel cost and emissions associated with idling while driving in the CBD.

- Idling fuel consumption estimation

Gaines et al (2012) found that the idling fuel usage varies from 0.2 to 0.5 gal/hour for passenger vehicles across a range of sizes and increased with engine idle speed. This fuel usage translates to 0.263 to 0.526 ml/s.

  - The idling fuel used in this study is an average of 0.395 ml/s.
  - R11.02 per litre of petrol was used for fuel cost.

- Estimation of air pollutant emissions

  Forbes P. et al. (2009) estimated the emission rates for CO and HCs under idling conditions for petrol vehicles. These rates are used in this study although it is acknowledged that the rates may have changed with new fuel efficient vehicles arriving into the country.

  - CO – 19.7 grams per litre
  - HC – 2.08 grams per litre

  The CO_2 emissions rates used is 2.4 kg per litre of petrol based on GHG Protocol 2011.

Table 3: Estimated idling fuel cost and emissions under uncoordinated traffic signal conditions

Street Name	Direction	Idle Time per kilometre (sec/km)	Idle Engine Speed (rpm)	Fuel Consumption (l/s)	idling Fuel Consumption (l/km)	Fuel Cost/km	CO (g/km)	HCs (g/km)	CO2 (g/km)
Nana Sita	West Bound	43	800	0.000395	0.017	R 0.19	0.335	0.035	39.524
Nana Sita	East Bound	89	800	0.000395	0.035	R 0.39	0.693	0.073	81.806
Francis Baard	East Bound	88	800	0.000395	0.035	R 0.38	0.682	0.072	80.536
Bosman	North Bound	112	800	0.000395	0.044	R 0.49	0.872	0.092	102.946
Simmonds	South Bound	126	800	0.000395	0.050	R 0.55	0.982	0.104	116.045
Average		**83**	**800**	**0.000395**	**0.033**	**R 0.36**	**0.645**	**0.068**	**84.171**

Pretorius Street was not included in the analysis shown in Table 3 due to the construction activities that were taking place during the time of the survey.

It can be seen from Table 3 that the estimated average fuel cost associated with idling would be about 36 cents per kilometre while driving in the CBD.

Table 4: Estimated idling fuel cost and emissions under coordinated traffic signal conditions

Street Name	Direction	Idle Time per kilometre (sec/km)	Idle Engine Speed (rpm)	Fuel Consumption (l/s)	idling Fuel Consumption (l/km)	Fuel Cost/km	CO (g/km)	HCs (g/km)	CO2 (g/km)
Sauer	North Bound	19	800	0.000395	0.007	**R 0.08**	**0.146**	**0.015**	**17.234**

The investigation has shown that signal coordination could reduce the fuel cost relating to idling time from 36 cents per kilometre to 8 cents per kilometre as seen in Table 4, resulting in fuel cost savings of about 28 cent per kilometre. Emissions reduce substantially as well; by 0.499g/km for CO, 0.053g/km for HC and 66.937g/km for CO_2. This is a significant saving or reduction on fuel, emissions and cost if traffic signal coordination could be applied on a network level, taking into account number of vehicles entering the network per day (or annually). For vehicles with large engine capacity (greater than 1.4 litres) the potential savings could be more than the 30 cents per kilometre.

5. CONCLUSIONS

This study has demonstrated that traffic signal coordination in CBDs could significantly reduce the amount of idling time experienced in the CBDs such as Johannesburg and Pretoria thereby reducing fuel cost and exhaust air pollutant emissions associated with idling.

Excessive idling of about 25% to 40% of the total travel time with idling time of over 80sec per kilometre could be reduced to less than 7% with idling time of 19sec per kilometre by implementing traffic signal coordination which provides a green wave.

It is estimated that about 28 cents per kilometre could be saved by implementing traffic signal coordination. The reductions in idling gas emissions were found to be 77% for both CO and HC and 80% CO_2.These are a significant saving on a network level with all vehicles within the network annually.

Madireddy et al (2010) have shown that implementing a green wave can reduce the **overall** gas emissions on a route by about 10% in Zurich. De Coensel at al (2012) have found that the introduction of a green wave could reduce the overall exhaust emissions by 10% to 40%.

This study examines the fuel consumption and emissions that are **only associated with idling time**. It should be noted that further fuel is wasted during acceleration and deceration. It is acknowledged that the sample sized for coordinated signal was too small to present real scientific and statistical evidence as there was only one street surveyed. However, the results confirm a suspected trend. Further empirical research should be undertaken as more samples for coordinated signals become available.

6. RECOMMENDATIONS

It is recommended that a wider scope of empirical research based on local South African conditions be undertaken in order to develop good practice guidelines for traffic management that takes into account energy demand, environmental implications, safety and other generalised cost of travel. This will ensure that the traffic engineering fraternity does its part in contributing to the environmentally friendly CBDs.

7. REFERENCES

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