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Emissions Impacts of Transit Signal Prioritisation

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Abstract

The environmental implications of transport planning and infrastructure have become an important consideration across the last decade. Significant research has been carried out to identify methods to reduce the impact of transportation systems, in particular surface transportation systems, on the environment. Transit signal prioritisation has been widely used throughout mass-transit systems to ensure schedule adherence and reduce delays for transit vehicles, primarily buses at a minimised cost to other vehicles on the network. However these systems do not take into consideration the impact on the level of emissions created by the signal prioritisation scenario.

The paper demonstrates the emissions impact of a standard Transit Signal Priority (TSP) application simulated using the microsimulation tool, Paramics on the corridor network of El Camino Real, CA. Environmental performance data was collected using the emissions modelling tool “Paramics Monitor” and the results of the simulation indicate that even though emissions levels of busses reduce, the overall level of emissions tend to increase with the implementation of TSP.

Accordingly the research study further proposes a methodology for the determination of real time transit signal prioritisation optimisation model with the primary aim to minimise the environmental impact (emissions and fuel consumption). In other words, this will in the future result in the development of an Eco-Transit Signal Prioritisation application. The provision of priority considers a number of parameters including the vehicle’s location, speed, vehicle type as well as emissions (such as greenhouse gasses) and fuel consumption. In addition schedule adherence and the number of passengers on board also serve as important factors affecting both the level of emissions as well as delays experienced.

1. Introduction

Increasing population, expanding cities and society's dependence on the automobile has resulted in congested and polluted transport networks throughout the world. In recent times, governments and transport authorities have made it a primary focus to improve public transit services to encourage increased ridership, reducing congestion and ultimately reducing emissions and the dependence on fossil fuels (Smith et al., 2005). Delays experienced by public transit services at signalised intersections negatively impact the overall public transit journey travel time. These delays affect transit ridership and are obstacles in determining effective scheduling of public transit services. Transit Signal Priority (TSP) provides a traffic management solution in an attempt to mitigate these delays. TSP prioritises the movement of buses through the manipulation of signal timings following the detection of an approaching bus (Dion et al., 2005), minimising the delay of public transport whilst maintaining overall traffic flow.

In general, studies have shown that TSP has reduced travel time, improved service reliability at minimal cost to other traffic (Al-Mudhaffar and Bang, 2006, Martin and Zlatkovic, 2010, Chang et al., 1995, Baker et al., 2004, Smith et al., 2005, Agrawal et al., 2002). However these studies focus on the costs and benefits of TSP in relation to flow characteristics of the network without consideration of the environmental impact. Although TSP provides enhanced public transport services, the net environmental effect in relation to emission levels created by TSP has not been investigated in depth and will be the primary focus of this paper.

The study conducts a literature review of material related to TSP and its implementation as well as investigating research concerning the optimisation of emissions levels within transport networks. This is followed by a case study of El Camino Real, CA demonstrating the importance in considering the impact of TSP on emission levels of a transport network. Finally, presented is a potential methodology for the determination of a real time transit signal prioritisation optimisation model with the primary aim to minimise the environmental impact (emissions and fuel consumption) whilst maintaining the key benefits of transit signal prioritisation.

2. Literature Review

The primary aim of the study is to investigate the environmental impact of transit signal prioritisation. To date there has been no documented literature regarding this specific topic. However a review of research related to the implementation and effectiveness of TSP as well as a discussion of emissions optimisation models applied to different elements of transport networks are presented as a part of the literature review.

2.1 Transit Signal Priority

Transit signal priority techniques can be classified into two broad categories, "passive" or "active". Passive techniques involve the utilisation of coordinated signals for transit routes providing priority for all vehicles along the route and do not specifically target transit vehicles. Passive strategies are developed using historical data and do not require detection systems making it cost-effective. These strategies are successful when the frequency of public transit services are high and the dwell-time at stops are short and predictable (Wahlstedt, 2011). Active TSP techniques rely on detecting transit vehicles at approaches to intersections and adjusting the signal timings when a transit vehicle is present (Smith et al., 2005). Active methods involve the manipulation of the phase or timing structure of signals to allow preference to transit vehicles, some of the strategies include: green extension, red truncation, early red, phase rotation and actuated transit phases (Cornwell et al., 1986, Li et al., 2008). Active measures provide increased benefits to public transit vehicles however they pose greater delays on the remaining traffic at the intersection. Accordingly conditions such as setting limits for phase extension lengths or having selective periods of the day for prioritisation have been used to minimise the overall delay on intersections (Wahlstedt, 2011). Conditional active strategies have developed into a new stream of TSP implementation known as ‘adaptive strategies’. Adaptive strategies are active strategies but also account for current traffic conditions through real-time optimisation of performance criteria such as vehicle delay and the number of public transit stops (Zhou et al., 2007).

Recently there have been great advances in the formulation of adaptive Transit Signal Priority strategies. Li et al. (2008) developed a traffic responsive signal control system with TSP which provides priority based on the trade-off between bus delay savings and the impact of the rest of the traffic. This study looked at mitigating the fundamental issue of the impact of TSP on other vehicles on the network. Ma et al. (2011) presents a dynamic programming model developed to optimise TSP with multiple priority requests whilst minimising excessive delays for other vehicular traffic. The model is capable of capturing the impact of bus requests with various occupancy and schedule deviations, and different traffic demand levels on approaches to the intersection. Christofa and Skabardonis (2010) investigates the impact of transit route conflicts on TSP. The strategy developed determines the signal timings that minimise the total person delay in the network while assigning priority to the transit vehicles based on their occupancy. The study discusses the importance of minimising total person delay by assessing the occupancy levels of both transit and private vehicles. Occupancy and frequency of transit services are significant factors in determining the benefit of a TSP strategy as low occupancy and frequency will not provide the delay reduction benefits on a person delay level. Zhou et al. (2007) applies the parallel genetic algorithm to optimise real time signal control in the presence of TSP. The method aims at optimising the phase plan, cycle length and green splits at isolated intersections taking into account both transit and general vehicles. Like the other studies mentioned, this approach also provides a benefit for transit vehicles whilst minimising the impact of other vehicles using the network.

Though these studies have provided options to mitigate the negative effects of TSP there has not been an assessment or consideration of the environmental impacts of TSP. This study looks at initially investigating the impact of a basic active TSP strategy on the level of emissions through a simulation case study. This is followed by proposing a methodology, based on studies reviewed within the literature, for the formulation of an adaptive TSP strategy which minimises the level of emissions whilst optimising transit signal priority.

2.2 Emissions Optimisation

Congestion and delay results in vehicles functioning at below-optimal speeds, and stop-go behaviour experienced results in greater acceleration and deceleration events which in turn lead to incomplete combustion and additional emissions (in particular carbon monoxide (CO), nitrogen oxides (NOx) and volatile organic compounds (VOC’s)) being produced (De Coensel et al., 2012, Pandian et al., 2009). Since the implementation of TSP is known to create delays for non-transit vehicles it is beneficial to investigate the impact on the level of emissions as a result of TSP strategies and attempt to minimise the level of emissions being produced. Accordingly it is important to review literature related to emissions optimisation in the context of transport networks to appropriately formulate an optimisation model for TSP which minimises the level of emissions.

Zegeye et al. (2013) states that “Traffic emission and fuel consumption models provide the estimate or prediction of emission and fuel consumption of vehicles in a traffic flow based on the operating conditions of the vehicles.” Furthermore emissions models are separated into macroscopic and microscopic models like traffic flow models. As this specific study is focussed on microscopic behaviour, microscopic emissions model plugins are used to conduct the study and are proposed to be used for the eco-transit signal priority application.

To the authors' knowledge there has been no significant research undertaken regarding emissions optimisation modelling of transit signal priority. However there have been a few emissions studies completed for signalised intersections and coordinated signals. Rakha et al. (2000) presented efficient signal coordination can reduce emissions by up to 50% considering a signalised arterial route. The results were shown using simulation modelling as well as using instantaneous speed and acceleration data from floating cars. The impact of signal coordination on the level of emissions was investigated by Unal et al. (2003) who performed field experiments to measure on-board air pollutants along a signalised arterial route with and without the presence of coordination. They found that there was a reduction in emissions of 10 to 20% depending on the type of vehicle and level of congestion experienced. Li et al. (2009) integrates a modal emission model (CMEM) with Paramics to evaluate vehicle emissions at signalised intersections. In addition they propose an advanced driving alert system which provides signal information to users to prevent hard braking and accelerating as they approach intersections.

Recent studies have attempted to develop signal timing optimisation models to minimise congestion and emissions. Stevanovic et al. (2009) utilised microscopic simulation to develop signal timing optimisation models which minimise fuel consumption and vehicle emissions. VISSIM, CMEM and VISGAOST were linked together and seven signal timing objective functions were assessed to determine the lowest fuel consumption and CO_2 emissions. The findings suggest that formula commonly used to estimate fuel consumption within traffic simulation tools are not adequate to use for the objective function and additional research is necessary to optimise these timings whilst minimising emissions. However Stevanovic et al. (2009) also mentions that for the purposes of understanding the overall impact of a signal prioritisation scheme on the level of emissions, microsimulation software emissions plugins such as Paramics Monitor can be used as an effective assessment tool. This is confirmed with the results of the case study modelling described in the following sections. Park et al. (2009) has conducted similar research to Stevanovic et al. (2009), utlising a genetic algorithm to develop an optimal solution which minimised emissions whilst maintaining traffic flow. Ma and Nakamura (2010) estimates emissions based on average traffic conditions at an intersection level and derives an analytical procedure to optimise cycle length against vehicle emissions. These studies provide invaluable insight into emission trends and optimisation models for individual intersections and coordinated networks. However there is limited research regarding the impact of TSP applications on the level of emissions. TSP signal timings contrast regular coordinated timings as it provides preference to a specific vehicle type and restricts flow of the remaining traffic at each intersection thus different emissions profiles are experienced. Accordingly the current study aims at demonstrating this phenomenon using a microsimulation case study of the El Camino Real network.

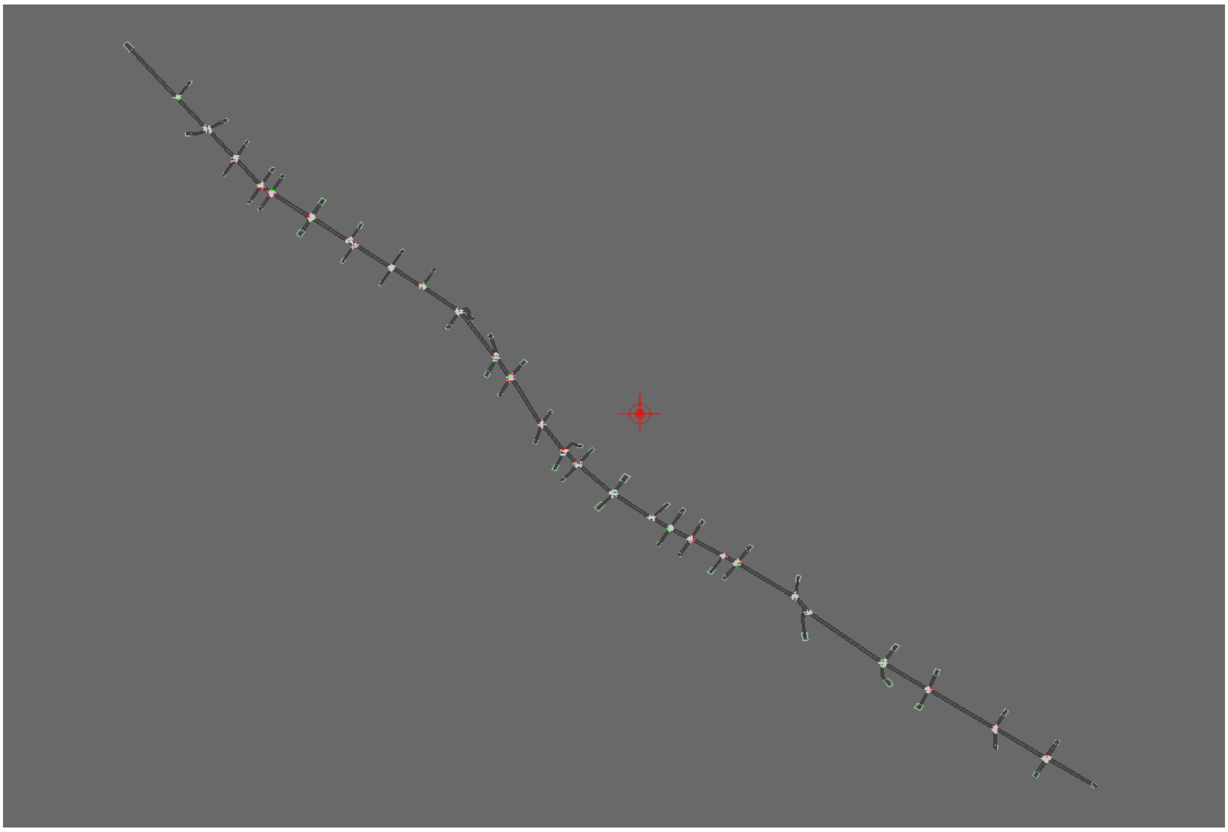
3. Case Study: El Camino Real, California Microsimulation Model

The following section details the Paramics modelling of the case study network of El Camino Real, California, USA. The modelling demonstrates the impact of a standard active TSP strategy on the level of emissions for a transport network. It is important to note that this case study considers a specific TSP algorithm applied to a corridor network and is not a generalisation of emissions modelling of a variety of TSP scenarios across different networks taking into consideration factors such as ridership. The model serves only to provide a demonstration of the potential impact TSP can have on the level of emissions in a network.

The study area simulated is the El Camino Real road corridor extending 10 kilometres from Palo Alto to Mountain View in California. This is a corridor model considering primarily the performance of the major arterial, El Camino Real (ECR model). Twenty eight coordinated signalised intersections have been modelled to assess the effect of the implementation of transit signal prioritisation (TSP) on adjacent connections throughout the length of the corridor. Figure 1 presents a highlighted map of the study area and Figure 2 shows the network within Paramics.

Figure 1: Study Area (Google Maps, 2013)

Figure 2 : Study Area, Paramics Network Model



A calibrated and validated AM model was created with duration of 2 hours and 15 minutes from 7:15AM to 9:30AM (including a 15 minute warm up period) and the following scenarios were assessed;

- ***Scenario 0 (Basel Model) – without the implementation of the TSP algorithm***
- ***Scenario 1 (TSP Model) – with the implementation of the TSP algorithm***

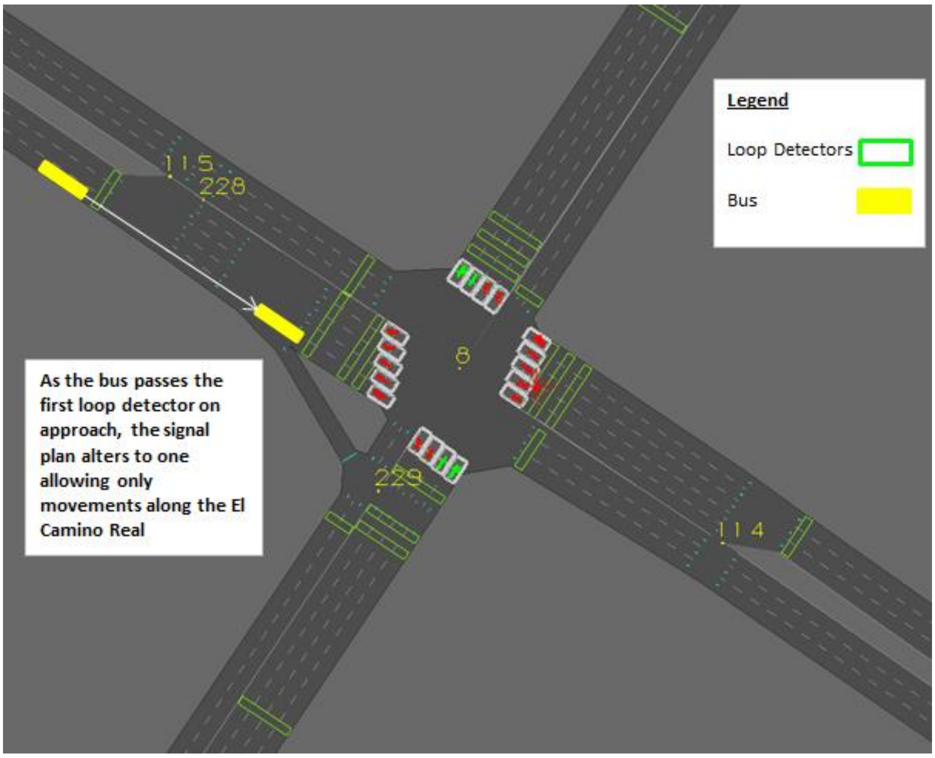
A standard active TSP algorithm was applied to the base ECR model to understand what impact any form of signal priority has on the emissions levels and traffic flow performance of the model. This is an essential step prior to developing an algorithm which can optimise emissions levels as it provides an understanding of the impact of TSP on the environment.

The transit signal priority algorithm developed for the TSP model is a 'phase insertion strategy' and can be described as follows;

- The existing signal plans that have been implemented in the base model remain in operation without the presence of a bus.
- As presented in Figure 3, when a bus passes the first loop detector to an approach, a bus priority phase of either 10s or 20s green time was provided to through movements along the El Camino Real is triggered to allow buses to traverse without delay. The duration of the green time was determined based on the distance from the first loop detector to the stop lines of the intersection.
- Following this phase, the original signal plan is reinitiated for regular traffic flow without a presence of a bus.

This algorithm is only suited for a corridor model, such as the ECR model, considering transit vehicles that traverse along the corridor only. If this is not the case, there is a potential for conflicts of priority when transit vehicles approach the intersection from adjacent roadways.

Figure 3: Representation of standard TSP applied to an individual intersection



3.1 Emissions Modelling Results

Emissions analysis has been conducted by using data obtained from using the Paramics module “Paramics Monitor”. This software plugin collects pollution and emission levels for every link in the network by summing the emissions for each individual vehicle within the link. Monitor determines the level of emissions by considering the vehicle type, speed, acceleration and time on the network as well as considering the link gradient. The modelled parameters are compared with predefined emissions distributions to calculate the level of emissions for a specific time step. Total emissions values are provided for 15 minute increments throughout the duration of data collection period between 8:00AM and 9:00AM for Scenario 0 and Scenario 1. Paramics Monitor provided emissions statistics regarding the following pollutants (units);

- Carbon Monoxide (mg)
- Carbon Dioxide (mg)
- Total Hydrocarbons (mg)
- Oxides of Nitrogen (mg)
- Fuel Consumption (ml)

3.1.1 Base Model: Scenario 0 Results

Table 1 presents the level of emissions generated by all vehicles for Scenario 0 and Table 2 contains the level of emissions created by buses only. The data between 8:00AM and 8:45AM indicates that as the model progresses with time and the overall number of vehicles present on the network increase, the level of emissions increase. Between 8:45AM and 9:00AM the volumes start to depreciate and accordingly the level of emissions produced also declines.

Table 1 - Scenario 0 Emissions levels for all vehicles

Emissions Levels and Fuel Consumption for All Vehicles					
Time	Carbon Monoxide (mg)	Carbon Dioxide (mg)	Total Hydrocarbons (mg)	Oxides of Nitrogen (mg)	Fuel Consumption (mL)
8:00AM to 8:15AM	1.02E+07	1.25E+09	6.67E+05	1.19E+06	5.30E+05
8:15AM to 8:30AM	1.05E+07	1.28E+09	6.87E+05	1.23E+06	5.46E+05
8:30AM to 8:45AM	9.37E+06	1.15E+09	6.13E+05	1.11E+06	4.89E+05
8:45AM to 9:00AM	7.38E+06	9.18E+08	4.86E+05	9.22E+05	3.90E+05

Table 2 - Scenario 0 Emissions levels for buses

Emissions Levels and Fuel Consumption for Buses only					
Time	Carbon Monoxide (mg)	Carbon Dioxide (mg)	Total Hydrocarbons (mg)	Oxides of Nitrogen (mg)	Fuel Consumption (mL)
8:00AM to 8:15AM	9.84E+03	7.52E+06	3.28E+03	4.06E+04	2.83E+03
8:15AM to 8:30AM	9.79E+03	7.52E+06	3.26E+03	4.04E+04	2.83E+03
8:30AM to 8:45AM	9.42E+03	7.25E+06	3.16E+03	3.93E+04	2.73E+03
8:45AM to 9:00AM	1.07E+04	8.24E+06	3.55E+03	4.43E+04	3.10E+03

3.1.2 TSP Model: Scenario 1 Results

Similar to the results of Scenario 1, Table 3 presents the level of emissions generated by all vehicles for Scenario 1 and Table 4 contains the level of emissions created by buses only. As per the results of Scenario 0, similar trends of increasing levels of emissions occur with increasing vehicle numbers.

Table 3 – Scenario 1 Emissions levels for all vehicles

Emissions Levels and Fuel Consumption for All Vehicles					
Time	Carbon Monoxide (mg)	Carbon Dioxide (mg)	Total Hydrocarbons (mg)	Oxides of Nitrogen (mg)	Fuel Consumption (mL)
8:00AM to 8:15AM	1.11E+07	1.34E+09	7.23E+05	1.25E+06	5.70E+05
8:15AM to 8:30AM	1.13E+07	1.36E+09	7.34E+05	1.23E+06	5.78E+05
8:30AM to 8:45AM	1.09E+07	1.32E+09	7.12E+05	1.19E+06	5.60E+05
8:45AM to 9:00AM	9.18E+06	1.12E+09	5.99E+05	1.02E+06	4.75E+05

Table 4 - Scenario 1 Emissions levels for buses only

Emissions Levels and Fuel Consumption for Buses only					
Time	Carbon Monoxide (mg)	Carbon Dioxide (mg)	Total Hydrocarbons (mg)	Oxides of Nitrogen (mg)	Fuel Consumption (mL)
8:00AM to 8:15AM	8.69E+03	6.68E+06	2.85E+03	3.56E+04	2.52E+03
8:15AM to 8:30AM	9.34E+03	7.20E+06	3.02E+03	3.79E+04	2.71E+03
8:30AM to 8:45AM	8.83E+03	6.79E+06	2.88E+03	3.60E+04	2.56E+03
8:45AM to 9:00AM	9.09E+03	7.02E+06	2.95E+03	3.71E+04	2.64E+03

3.2 Comparison of Scenarios

Table 5 and Table 6 present the percentage change in emissions levels and fuel consumption between scenarios for all vehicles and buses respectively. Table 5 indicates that there is an increase in emissions and fuel consumption with the implementation of TSP to the network. This is understandable as providing priority to transit vehicles can create additional delays to vehicles on adjacent approaches which in turn can create greater levels of emissions for all vehicles. However when considering the emissions levels of buses alone, as shown in Table 6, the implementation of TSP considerably reduces the delays experienced by a bus at signalised intersections, thus reducing the idle time and ultimately overall travel time for the bus. This results in a reduction in overall emissions and fuel consumption for buses.

Table 5 - Percentage change between scenarios of emissions levels and fuel consumption for all vehicles

Percentage Change in Emissions and Fuel Consumption with the Implementation of TSP (considering all vehicles)					
Time	Carbon Monoxide	Carbon Dioxide	Total Hydrocarbons	Oxides of Nitrogen	Fuel Consumption
8:00AM to 8:15AM	8.49%	7.49%	8.29%	5.09%	7.46%
8:15AM to 8:30AM	7.30%	5.87%	6.85%	0.24%	5.88%
8:30AM to 8:45AM	16.65%	14.43%	15.99%	7.03%	14.48%
8:45AM to 9:00AM	24.42%	21.48%	23.19%	10.08%	21.63%

Table 6 - Percentage change between scenarios of emissions levels and fuel consumption for buses only

Percentage Change in Emissions and Fuel Consumption with the Implementation of TSP (considering only buses)					
Time	Carbon Monoxide	Carbon Dioxide	Total Hydrocarbons	Oxides of Nitrogen	Fuel Consumption
8:00AM to 8:15AM	-11.63%	-11.14%	-13.01%	-12.33%	-11.14%
8:15AM to 8:30AM	-4.54%	-4.17%	-7.19%	-6.13%	-4.17%
8:30AM to 8:45AM	-6.24%	-6.34%	-8.86%	-8.31%	-6.34%
8:45AM to 9:00AM	-14.72%	-14.85%	-16.72%	-16.35%	-14.86%

These results are again reflected graphically in Figure 4 and Figure 5 considering total Carbon Dioxide (CO_2) levels produced in Scenario 0 as compared to Scenario 1 for all vehicles and buses respectively.

Figure 4: CO_2 Level comparison for all vehicles

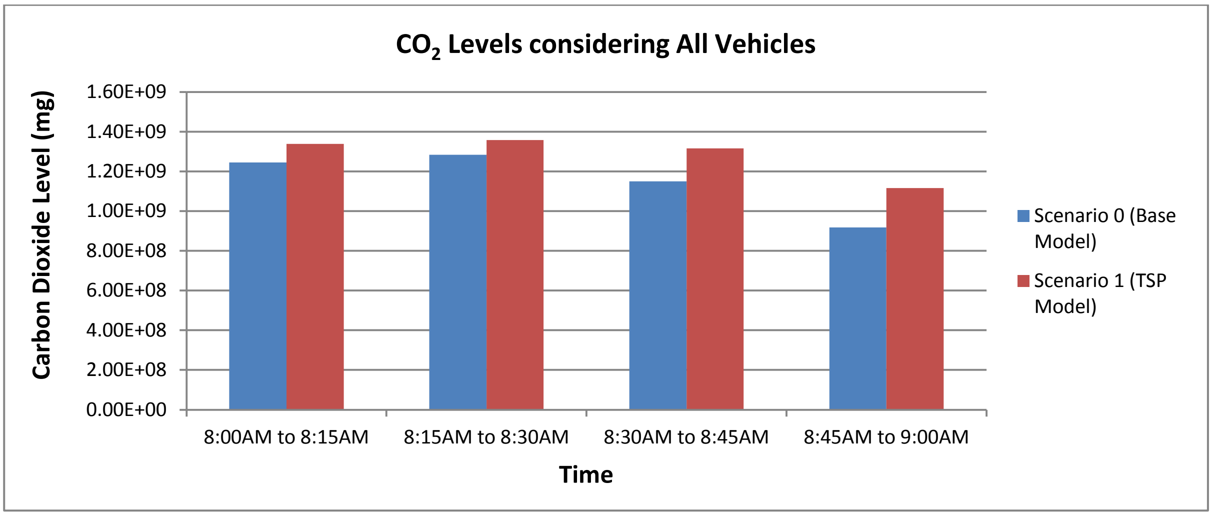
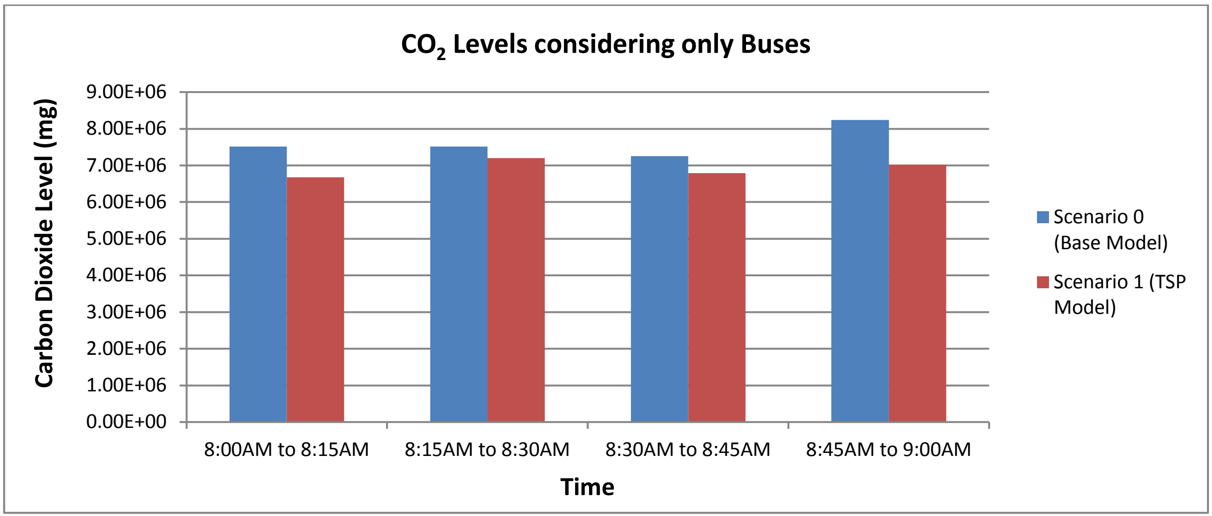


Figure 5: CO_2 level comparison for buses only



The emissions modelling results indicate that there is a need to evaluate the environmental impact of TSP strategies. The case study of ECR shows that with the implementation of TSP the level of emissions produced by buses reduces however the overall level of emissions increases due to the increased delay experienced by other vehicles within the network. Therefore it would be a valuable contribution to develop a TSP optimisation model that has its primary aim to minimise emissions of the overall network. In other words, this will result in the development of an Eco-Transit Signal Prioritisation application. The following section of the paper will discuss approaches derived from literature in formulating an Eco-Transit Signal prioritisation application.

4. Eco-Transit Signal Priority Methodology

The goal of the Eco-Transit Signal Priority application will be to allow a transit vehicle approaching a signalized intersection to request signal priority. This application will consider the vehicle's location, speed, and vehicle type and in addition consider the current level of emissions of the specific region (GHG's and all other significant pollutants) to determine whether signal priority should be granted. Information collected from other vehicles approaching the intersection, a transit vehicle's adherence to its schedule, or the number of passengers on the transit vehicle need to also be considered in granting priority. If priority is granted, the traffic signal would hold the green on the approach until the transit vehicle clears the intersection. For the development of the Eco-Transit Signal Priority application, there are several studies that can be used as direction.

Dion et al. (2005) used the transit priority feature with an adaptive signal control system and a similar logic can be developed for the Eco-Transit Signal Priority application. The logic used within Dion et al. (2005) is as follows;

1. Approaching buses are detected at a user-specified distance upstream of the signal stop line.
2. If a bus is to enter the intersection during the green interval, no signal alteration is made.
3. If a bus is to arrive after the end of the green, the green is extended at increments of "*n*" seconds until either the vehicle has left the approach or the maximum green is reached. The time required for the extensions is taken from the next phase in the cycle that has not been reduced to its minimum allowed duration.

4. If a bus is detected while another traffic approach is being served, the active green phase is terminated after an increment of "*n*" seconds, or as soon as the minimum green time is satisfied, to allocate service to the approaching bus as quickly as possible. The green is returned to the prioritized approach only after having satisfied the minimum green, amber, and all-red intervals of all the intermediate phases in the phase sequence. Following the early green recall, the green time on the prioritized approach is terminated at its normal end point.
5. If a priority request has already been granted during the signal cycle, no additional changes are made to the signal timings for the remainder of the cycle to minimize traffic disruption.
6. Priority requests are granted on a first-come first-served basis. In the highly unlikely event that two or more requests are received at the same instant in time from conflicting approaches, no changes are made because there is no means to prioritize the priority requests.

This logic is further subject to the four following constraints:

- Service of minimum green times assigned to each phase.
- Extensions cannot result in green phases exceeding their maximum defined duration.
- Cycle length is fixed to preserve coordination with adjacent intersections.
- No phase skipping while transitioning to and from a priority phase.

The maximum green time was determined using Equation (1) (Dion et al., 2005).

$$ge_{\max i} = min\left(g_{\max i}; C - a_i - \sum_{j=1}^{n}\left(g_{\min j} + a_j\right) for\ all\ j \neq i\right) \qquad \textbf{Equation (1)}$$

Where: $ge_{\max i}$ = Maximum allowed duration of phase i,

$g_{\max i}$ = User-defined maximum green for phase i,

$g_{\min j}$ = User-defined minimum green for phase j,

C = Cycle length

a_j = Intergreen duration at end of phase j, and

n = Number of phases within the signal cycle

The modification of the methodology necessary for the Eco Transit Signal Priority application will involve the assessment of the level of emissions being generated during step 4 of the TSP algorithm. Once the level of emissions is taken into consideration priority can be provided to the transit vehicle if the emissions levels are minimised. In order to predict the level of emissions, an emissions modelling tool needs to be utilised as a part of the application. MOVES is one of the latest vehicle emission-modelling tools being used by several government Environmental Agencies. It can estimate macro, meso and microscale vehicle emissions and has the ability to estimate particulate and air toxic emissions, for alternative fuel vehicles. Integrating the Eco Transit Signal Priority Application with MOVES would be beneficial as it will have the ability to model emissions for future year vehicles. MOVES can use "Through Link-Specific Vehicle Operating Mode Distributions" (OpMode distributions) from vehicle driving cycles as inputs and can output emission rate look-up tables for each OpMode distribution to estimate emissions.

In order to formulate an optimisation model it is essential to consider methods to minimise the delay whilst minimising the level of emissions. An active Transit Signal Priority method suggested by Christofa and Skabardonis (2010) uses an optimization function to minimize delay by adjusting green times. The mathematical program minimizes the total person delay at the intersection by changing the green times for each phase i, G_i within the cycle under consideration (indexed by T), constrained by the minimum green times for each lane group j, $G_{j\ min}$ and a fixed cycle length, C. The mathematical program that optimizes the signal settings for any design cycle T, is shown in Equation (2) (Christofa and Skabardonis, 2010). A similar function can be used for the Eco-Transit Signal Priority application. An additional parameter that minimizes emissions and fuel consumption can be added to the objective function to determine green times while granting priority to transit vehicles.

$$\min \sum_{a=1}^{A} o_a d_a + \sum_{b=1}^{B} o_b d_b$$
$$\text{s.t.} \sum_{i \in I_j} G_i \geq G_{j\ min}$$
$$\sum_{i=1}^{N} G_i = C$$

Equation (2)

Where:
- o_a = passenger occupancy of auto “a”
- o_b = passenger occupancy of transit vehicle “b”
- d_a = control delay for auto “a”
- d_b = control delay for transit vehicle “b”
- A = total number of autos served during the design cycle T or the next one T+1
- B = total number of transit vehicles served or arrived during the design cycle T
- G_i = green time allocated to phase “I”
- $G_{j\ min}$ = minimum green time allocated to lane group “j”
- C = cycle length
- I_j = set of phases that can serve lane group “j”
- N = number of phases in a cycle

Overall, the transit priority application modelling should cover the following:

- Traffic controller obtains transit vehicle’s location.
- Wireless communication system facilitates request submission with the vehicle location, occupancy, schedule, type of transit vehicle, and emissions/fuel consumption associated with it.
- Traffic signal control system that obtains real-time information about signal phase and timing and traffic counts at each approach of the intersection.
- Application that assesses requests and grants priority and adjusts phase timings accordingly.
- If priority is granted, the application uses an appropriate strategy to maintain signal coordination.

5. Conclusion

Numerous studies have revealed that Transit Signal Priority (TSP) implementation has the potential to reduce transit delays, improve reliability of services and increase ridership at a minimised cost to other road users. However to date there has not been research regarding the environmental implications, regarding emissions levels, of TSP applications.

This study demonstrates the emissions impact of a standard active, “phase insertion”, TSP application simulated using the microsimulation tool, Paramics on the corridor network of El Camino Real, CA. Environmental performance data was collected using the emissions modelling tool “Paramics Monitor”. The results of the case study show that whilst the transit contribution to emissions is minor, on average there is an 11% increase in emissions of overall traffic with the implementation of TSP across the modelled hour. The demonstration indicates that there is merit to developing a real time TSP optimisation model with the aim of minimising emissions levels while maintaining the benefits of TSP, an Eco-Transit Signal Prioritisation application.

Finally the study presents a potential methodology for the formation of an Eco-Transit Signal Prioritisation application based on previously conducted studies. The provision of priority considers a number of parameters including the vehicle’s location, speed, vehicle type as well as emissions (such as greenhouse gasses) and fuel consumption. In addition schedule adherence and the number of passengers on board also serves as important factors affecting both the level of emissions as well as delays experienced.

Based on the results of the simple case study considering the impact of TSP on the level of emissions, future work will concentrate on developing and applying the proposed methodology to formulate and test an Eco-Transit Signal Prioritisation application. It is envisaged that such an application can serve as a plugin to microsimulation software such as Paramics whilst utilising a microsimulation emissions model such as MOVES to estimate the levels of emissions in real time.

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