Sensitivity Analysis on Regularity Based Driver Advisory Systems

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Abstract

Thanks to the introduction of Cooperative ITS, new methods can be proposed in order to reduce stop-and-go at traffic lights without solely relying on Transit Signal Priority. Driver Advisory Systems (DASs) are shifting the objective of reducing stops at traffic lights to the drivers by providing instruction of the optimal dwell time and speed profile. Recently, the objectives of DASs were extended in order to account for the regularity of the transit lines. In this work, we conduct a sensitivity analysis on the infrastructure and operation related factors that affect the performance of regularity based DASs. We test these parameters on a central avenue of the city of Luxembourg using simulation. The results show that regularity DASs are more efficient in great headway variations and both distance and cycle length affect their performance.

Keywords: Public Transport; Holding Strategy; Cooperative ITS; Driver Advisory Systems;

Introduction

During operation the services are exposed to endogenous and exogenous factors that cause disruptions and a vicious cycle of undesired phenomena. Starting from buses arriving in platoons, passengers experience longer waiting times and have to board in overcrowded vehicles or even fail to board, extending further the waiting time and resulting to missed transfers and discomfort. Excessive passenger transference activities affect running times and as a consequence the travel time. The poor performance makes the service unattractive and, from the operator's side, leads to poor administration of the available fleet and driving roster.

In order to restore regularity during operation, real time control strategies have been applied targeting to limit the impact from stochasticity sources and maintain a high level of service. One of the two main categories of stop-based strategies to maintain or restore regularity is holding. With holding, a vehicle remains at a stop for additional time until a predefined criterion is fulfilled. Holding strategy can be rule based [1]–[3] or optimization based [4]–[7]. Holding has been extremely effective in maintaining schedule [8], regularizing headways [1], [3], reducing bunching [9] and minimizing passenger cost [4], [5], [10]. The applications of holding have been extended to synchronizing transfers [11], [12] and control of multiple lines [13], [14]. A thorough literature review on public transport control has been conducted by Ibarra Rojas et al [15] and specifically on station based control strategies by Gkiotsalitis [16].

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Another main cause of disruption is the variation of running times between stops. An important parameter is the number and the location of signalized intersections along a bus route [17]. Bus stop and go actions increase travel time, cause discomfort to the passengers and increase tailpipe emissions and fuel consumption [18]. An effective way to provide the right of way to the buses is transit signal priority (TSP). Although TSP has proven to be extremely effective in providing priority to public transport [19], it causes significant delays to the rest of the traffic [20], [21]. Thanks to the advance in technology of connected and autonomous vehicles and the improvements in Vehicle-to-Vehicle (V2V) and Vehicle to Infrastructure (V2I) technologies alternatives to TSP have been introduced, shifting the objective from the traffic light to the driving operations. Two driver advisory systems were introduced: GLODTA (Green Light Optimal Dwell Time Advisory) [22] and GLOSA (Green Light Optimal Speed Advisory) [23]. The first instructs the bus to extend its dwell time in order to arrive during the green phase to the next signalized intersection while the latter, when the bus is within the communication range of the signal head, provides speed advisory in order to traverse the next signalized intersection without stopping. Illustrative examples of GLOSA and GLODTA are shown in Figure 1. GLOSA and GLODTA have been applied previously on public transport with main focus on increasing the speed and reducing fuel and energy consumption [24], [22], [25] .

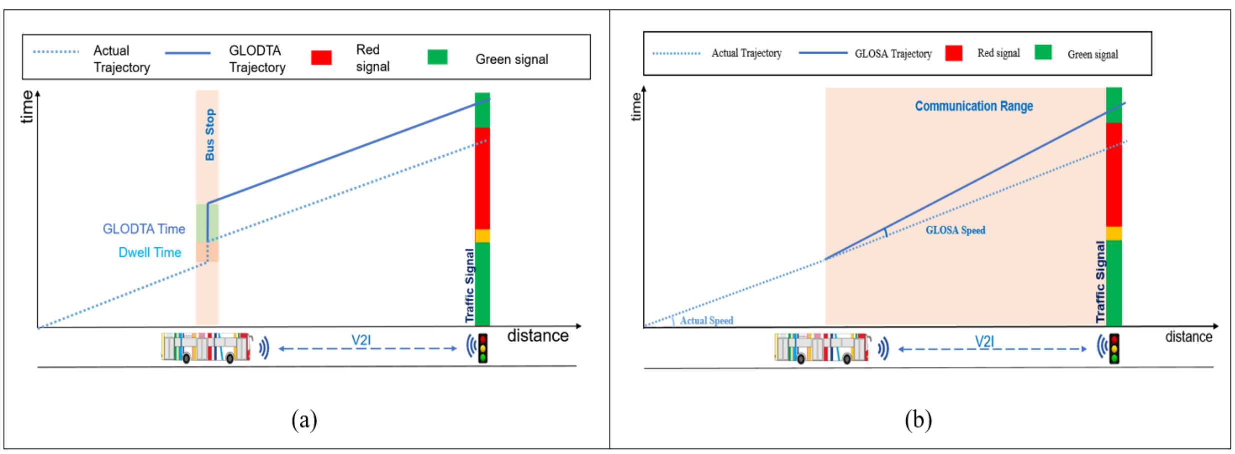

Figure 1 Representation of (a) GLODTA and (b) GLOSA

The two advisory systems and TSP have as objective to reduce stop-and-go at signals but they completely neglect the regularity of the lines. Recently, Laskaris et al suggested a combination of rule based holding with GLODTA [26] and GLOSA [27] in order to satisfy both objectives. In the respective studies, the hybrid controllers have proven to meet both objectives but as shown in the work of Seredynski et al [28] the performance of DASs differs depending on the configuration of the transit route. Hence, this study focuses therefore on identifying under which network characteristics the regularity based DASs can be applied. After briefly presenting the two hybrid controllers, we test different parameters using simulation and conclusions are drawn.

Regularity DASs

R-GLODTA

R-GLODTA combines holding for regularity and holding to reduce the number of stops at traffic signals. After the completion of dwell time at stop, candidate holding times to restore regularity are calculated using a rule based approach and GLODTA times that ensure traversing the downstream signalized intersection during green. The final holding time fulfills both criteria, if needed, otherwise the controller aims to meet one of the missing objectives. Results on a high frequency line shown that R-GLODTA can meet both objectives but it most of the cases required more time than traditional holding of regularity [26].

R-GLOSA

R-GLOSA is the second combination of holding for regularity and DAS to reduce the requests for TSP. After the completion of dwell time, R-GLOSA provides a pair of additional times at stop for regularity and a recommended speed in order to arrive during green phase at the downstream signalized intersection. As with R-GLODTA, if one of the objectives is fulfilled the controller focuses on the objective that has not been met. Simulation tests proved that R-GLOSA can perform equally to strong TSP, accounting for the regularity of the line and reducing the variability of travel time [27].

Case Study

We apply the hybrid controllers on a main artery of the city of Luxembourg. Avenue John Fitzgerald Kennedy (JFK) is the main avenue of Kirchberg district. Along the avenue many important landmarks of the city are located, such as the EU parliament, sport facilities, the university Campus, Luxexpo and shopping malls. Moreover, JFK connects the city with the ring road and the airport. JFK has dedicated bus lanes and all intersections are signalized. A schematic representation of the study area in given in Figure 2.

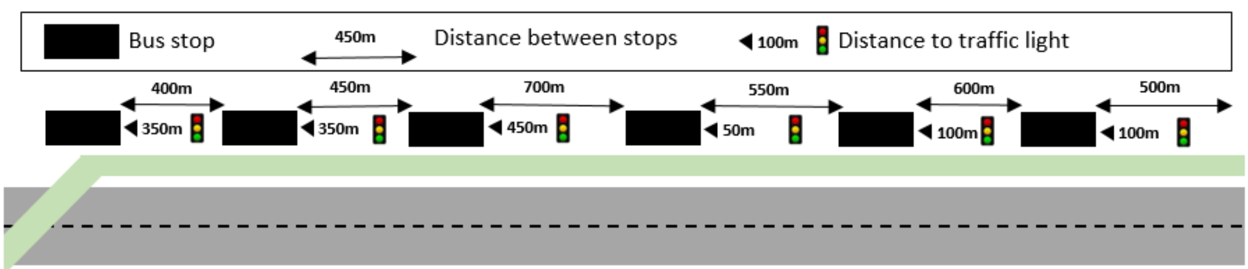

Figure 2 Schematic representation of the JFK Corridor

The parameters tested can be divided to two main categories:

- Infrastructure related; and
- Operation related.

In the first category, we examine the location of the bus stop subject to the downstream signal head and as well as the signal timings. We categorize stop location subject to the downstream intersection to far side (FS) and near side (NS) stops. The distance between bus stop and signalized intersection affects the quality of prediction of the expected arrival time at the intersection and the GLODTA time and GLOSA speed advisory. As shown in Figure 2, half of the stops are FS and the other half is NS. We test also three cycle lengths from short to the average duration for main urban arteries. In the second category, operation parameters are included such as the control scheme used and factors affecting operation such as demand variations and the variability of headway upon entrance to the study area. The effect of all the aforementioned parameters on the regularity based DASs are tested in different scenarios summarized in Table 1.

Table 1 Scenario Parameters

Infrastructure related		Operation related		
Bus Stop Location	**Cycle Length**	**Control Scheme**	**Headway Deviation**	**Demand**
Near Side	60sec	No Control	Perfectly Regular	Low
Far Side	90sec	R-GLODTA	50% deviation	Actual
	120sec	R-GLOSA	Perfectly Irregular	Peak

All scenarios are tested using simulation. The study area is coded in Mathworks Matlab. The movement of buses in the links between stops follows the microscopic car following model of Gipps [13] in order to monitor traffic dynamics. Traffic lights are coded using the concept of the "phantom vehicle" utilizing the car-following behavior of the vehicles. Passenger demand is given in the form of arrival rates and follows a Poisson distribution. The entrance time of the vehicles in the study area is sampled by Gamma distribution. By changing the shape and the size of the distribution, the vehicle can enter into the study area from a perfectly regular to a perfectly irregular fashion. Fifty replications are conducted per scenario in order to achieve statistically significant results.

Selected Results

Regularity Indicators

Along all three-demand levels, the effectiveness of the controllers depends on the level of disruption of line and behaves in a similar fashion. Table 2 presents the results of the regularity indicators obtained for the actual demand scenarios. It is worth noticing that the regularity based DASs counteract when there is no disruption on the line. Allowing to the vehicles to traverse during green has an impact on the regularity of the line, as it slightly increases the variation of headway and the level of bunching. R-GLOSA is proven to improve drastically the operation in the remaining scenarios. The compromise between holding for regularity and holding for traversing during green limits the effectiveness of R-GLODTA.

Table 2 Regularity Indicators for the Actual Demand Scenarios

		Actual Demand					
		No Control		R GLODTA		R GLOSA	
Headway Deviation	Cycle Length	Coefficient of Variation of Headway	Level of Bunching	Coefficient of Variation of Headway	Level of Bunching	Coefficient of Variation of Headway	Level of Bunching
0% Headway Deviation	60sec	0.11	0.00	0.13	0.00	0.11	0.00
	90sec	0.11	0.00	0.15	0.01	0.12	0.00
	120sec	0.11	0.00	0.16	0.02	0.12	0.01
50% Headway Deviation	60sec	1.08	0.60	1.00	0.58	0.97	0.52
	90sec	1.07	0.59	1.00	0.57	0.97	0.53
	120sec	1.08	0.60	1.04	0.59	1.00	0.54
100% Headway Deviation	60sec	1.47	0.72	1.41	0.71	1.32	0.64
	90sec	1.47	0.73	1.39	0.71	1.34	0.65
	120sec	1.47	0.73	1.38	0.70	1.34	0.65

Stops at traffic lights

Figure 3 illustrates the frequency of stopping at traffic lights for all control schemes, under the different scenarios and parameters. Overall, R-GLODTA is the most effective regularity DAS in reducing the number of stops, while R-GLOSA should be preferred for short cycles and low passenger demand.

R GLODTA outperforms the other schemes in all scenarios. R-GLODTA becomes more effective with the increase in the magnitude of disruption. In perfectly irregular services, more holding time is needed to restore regularity, providing sufficient time for the vehicle to arrive within the time interval with green indication. The number of stops decreases as well with the increase of the length of the cycle of the corresponding traffic light. At the 50% headway deviation scenarios, the performance of the controller is stable. On the other hand, when services are regular and only the objective of mitigating the stop and go actions should be met. By setting as priority to maintain regularity, the criterion is not always met, and as the length of phases increase more time is required and this gradually reduces the performance of GLODTA.

R-GLOSA seems to be effective for short cycles and its performance decreases drastically with the increase of the cycle length. This can be explained by the fact that the target speed is often outside the limits set and a difference can be seen between the Far Sided and the Near Sided Stops in the effectiveness of the controller. Indeed, as it can be seen in Table 3, the number of vehicles stopping at traffic lights increases significantly with the distance. For Near Side stops, the distance between the stop and the intersection is not sufficient in order for the vehicle to develop the target speed.

Table 3 Frequency of stop at traffic lights for the actual demand scenarios

		R GLODTA		R GLOSA	
	Cycle Length	Far Side Stops	Near Side Stops	Far Side Stops	Near Side Stops
0% Headway Deviation	60sec	25%	23%	28%	34%
	90sec	16%	35%	18%	39%
	120sec	32%	46%	42%	57%
50% Headway Deviation	60sec	30%	28%	19%	37%
	90sec	17%	31%	17%	35%
	120sec	21%	34%	30%	51%
100% Headway Deviation	60sec	18%	31%	19%	34%
	90sec	16%	28%	16%	32%
	120sec	18%	28%	27%	47%

Conclusions

We conducted a sensitivity analysis for parameters that affect the performance of R-GLODTA and R-GLOSA. We applied the two regularity based DASs on a major artery of the Luxembourg and we tested their performance under different infrastructure and operation related parameters. The combination of control for regularity and mitigating the stop and go actions is not successful under low headway variation. The combination of speed advisory and holding under R-GLOSA is more effective in regulating the operation for the rest. However, R-GLOSA should be preferred on stops close to intersections and traffic lights with short length. R-GLODTA becomes more effective in reducing frequency of stops at traffic lights with longer cycle length, while improving the regularity of the line.

The present study will be extended for multiple lines accounting for the right-of-way and for mixed traffic conditions. In addition, R-GLODTA and R-GLOSA will be extended in order to account for multiple traffic lights and be compatible with other control strategies.

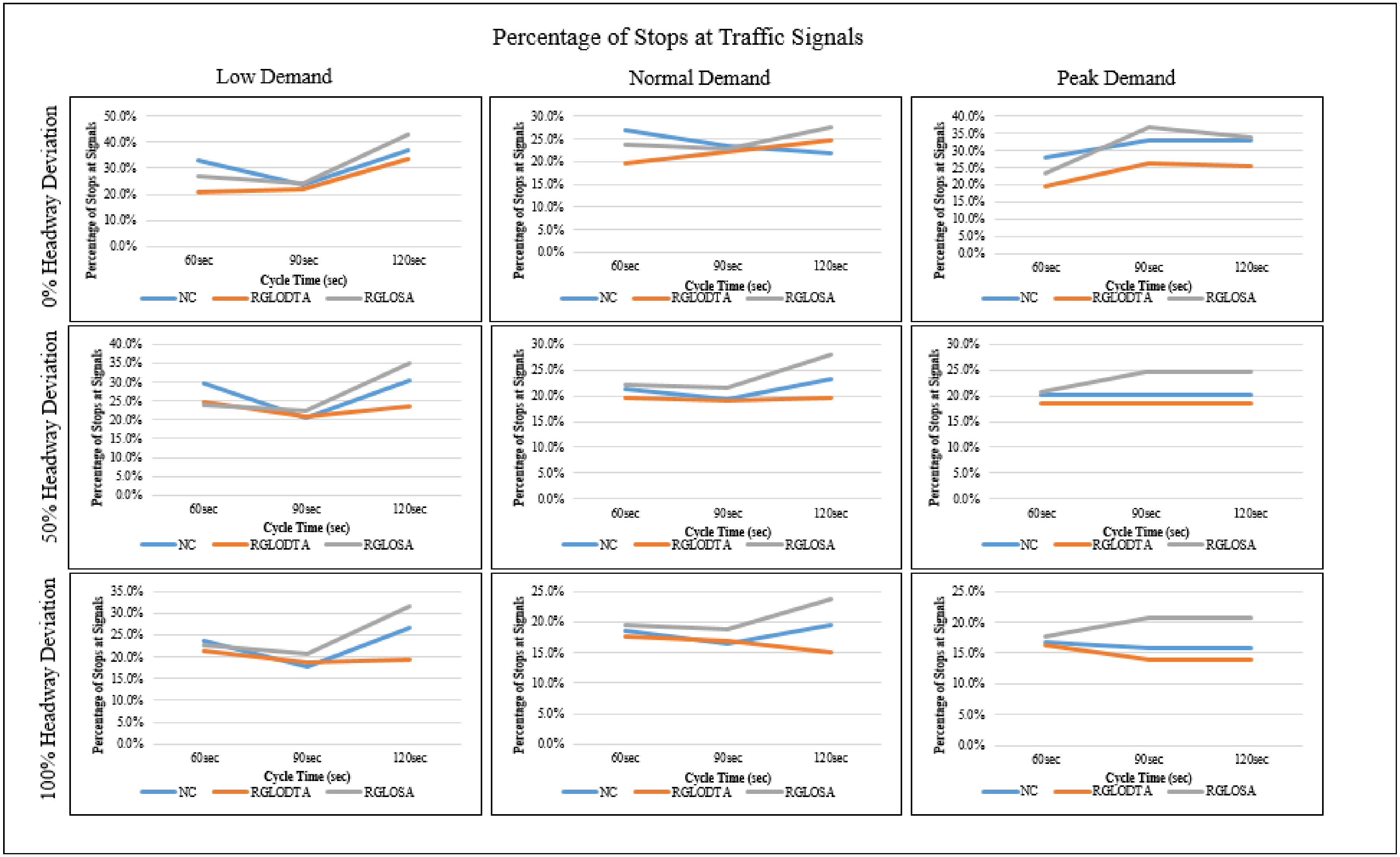

Figure 3 Percentage of Stops at Traffic Signals

Acknowledgements

Part of this research was performed as part of the FNR-CORE project eCoBus C16/IS/11349329.

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