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OPTIMAL SIGNAL CONTROL FOR PRE-TIMED SIGNALIZED JUNCTIONS WITH UNCERTAIN TRAFFIC: SIMULATION BASED OPTIMIZATION APPROACH

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ABSTRACT

Pre-timed signalized junctions are prevalent in real world as they are inexpensive and easy to implement. Traffic flow in these junctions exhibit large variations even for the same time interval of the day. Hence, robust signal timings, those are less sensitive to uncertain traffic flow are desired. The existing signal control models for pre-timed junctions use min-max approach for robust signal control when the ranges of traffic flow are known. The limitation of these models are: (i) the optimality of solution is not guaranteed, and (ii) not scalable for larger ranges of traffic flow due to long computational times. In this work, we propose a simulation based optimization approach which overcomes these limitations. Simulation results show that our work performs better than the existing models for both under-saturated and over-saturated traffic flows. Also, the computational time taken by our approach is significantly less.

1 INTRODUCTION

Although the study of real-time traffic control systems is a recent trends, most of the signalized junctions around the world still use pre-timed traffic control. This is because real-time traffic control needs infrastructure, such as detectors and processors to calculate the optimal signal timings quickly for each cycle, which adds to the cost and needs maintenance. Due to these reasons, it is less likely that many of the several thousands of existing signalized junctions will be using real-time traffic control in near future. Thus, pre-timed signals which will continue to be prevalent, shall be made more robust to handle uncertain traffic flows. This work proposes a simulation based optimization approach to find the optimal green times for pre-timed signal control, in order to minimize the average delay per vehicle. These green times are less sensitive to uncertainty in traffic flow.

The existing approaches for pre-timed traffic control can be divided into three categories (Li 2011). Type 1 approaches consider traffic flow to be constant for different intervals. Hence, these models are more suited for constant traffic patterns that is rarely found in reality. Type 2 approaches approximate stochastic traffic flow using known distributions. These type of approaches can perform well only when the traffic flow approximation is less erroneous. But, it is not always possible to approximate uncertain traffic flows into some known distribution. Type 3 approaches (Yin 2008, Li 2011) use the ranges of uncertain traffic flows from historical data. It is relatively easy to estimate appropriate ranges of uncertain traffic from historic data as compared to approximating traffic flow to a known distribution. Hence, Type 3 approaches are more suitable for large scale deployment in junctions as they do not require accurate demands and demand probability distributions.

(Yin 2008, Li 2011) use min-max optimization approaches to obtain signal timings using the ranges of traffic flow. They minimize the maximum delays with respect to green times and demands for uncertain traffic volumes. The limitations of using min-max approach are: (i) the optimality of solution is not guaranteed, and (ii) not scalable for larger ranges of traffic flow due to long computational times. In this work, we propose a simulation based optimization approach to overcome these limitations.

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2 METHODOLOGY

We simulate tens of thousands of flow profiles in given range to capture the uncertainty in traffic flow. We then solve the optimization model (OPT) to obtain the optimal green times and corresponding delays for each flow profile. Using these values, we get the optimal green times (g^*) from gravity location model (GLM), that are less sensitive to uncertain traffic and minimize the overall delay. Both OPT and GLM are solved using Bonmin solver (Bonami and Lee 2015).

Parameters:

$N =$ Number of samples

$M =$ Number of movements

$q_j =$ Flow value of movement j

$d_j(g_j, q_j, C) =$ Avg. delay for movement j

$L =$ Total lost time per cycle

Decision Variables:

$g_j =$ Green time for movement j

$C =$ Cycle time

Optimization Model(OPT)

$$\min \sum_{j=1}^{M} \frac{q_j \cdot d_j(g_j, q_j, C)}{\sum_{i=1}^{M} q_i}$$

subject to:

$$g_j \geq g_{min}, \quad \forall j$$

$$C = \sum_{j=1}^{M} g_j + L$$

$$C_{\min} \leq C \leq C_{\max}$$

$$g_j \in \mathbb{Z}, \quad \forall j$$

Gravity Location Model(GLM)

$$\min \sum_{i=1}^{N} \sum_{j=1}^{M} d_j^i (g_j^* - g_j^i)^2$$

subject to:

$$g_j^* \geq g_{min}, \quad \forall j$$

$$C = \sum_{j=1}^{M} g_j + L$$

$$C_{\min} \leq C \leq C_{\max}$$

$$g_j^* \in \mathbb{Z}, \quad \forall j$$

The objective of OPT is to minimize the average delay per vehicle subject to bound constraints on cycle time and green times. We use HCM 2000 delay equation (Manual 2000) to calculate $d_j(g_j, q_j, C)$. We use GLM to obtain optimal green times that are less sensitive to uncertain traffic and minimize the overall delay subject to bound constraints on cycle time and green times.

3 RESULTS AND DISCUSSIONS

The robustness of our approach is tested using over-saturation and under-saturation cases proposed by (Yin 2008). For each of 10000 simulated flow profiles, we calculate average delay per vehicle obtained using reported green times of (Yin 2008) and (Li 2011), and compared with delays obtained from our model. Our model reduces the average delay per vehicle by 4% for over-saturation case, and 3% for under-saturation case. Also, (Li 2011) reported that their approach takes around 13 hours of CPU time to solve over-saturation case. However, our approach solves it within 7 CPU minutes. Hence, our approach finds the optimal green time within minutes, and reduces average delay per vehicle considerably.

Table 1: Comparison with the results of (Yin 2008) and (Li 2011)

Instance	Study	Cycle Time	Green times (s)				Average Delay (s)	**% reduction in average delay**
			Group 1	Group 2	Group 3	Group 4		
Over-saturation	(Yin 2008)	116	24	19	29	29	74.26	4.21
	(Li 2011)	118	24	20	30	30	74.02	3.90
	Ours	**95**	**18**	**17**	**23**	**23**	**71.13**	
Under-saturation	(Yin 2008)	68	13	11	16	14	35.72	2.80
	(Li 2011)	70	13	11	17	15	35.99	3.53
	Ours	**57**	**10**	**9**	**12**	**12**	**34.72**	

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