SIMULATION-BASED OPTIMIZATION OF TRANSIT PRIORITY SIGNAL PLANS FOR A NETWORK OF ADJACENT INTERSECTIONS

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INTRODUCTION

Efficient design of traffic signal systems can help improve accessibility and mobility (Park and Yun 2006). In recent years, increasingly complex signal plans that involve functionalities for vehicle and pedestrian actuations, transit priority and coordination between adjacent intersections are being used. These involve large numbers of parameters that need to be set. Analytic and macroscopic optimization methods are not suitable for this task, as they are generally unable to capture the stochastic nature of arrival patterns and traffic flow and realistically represent detector states. Stochastic optimization approaches, which rely on traffic simulation models to evaluate timing plans within an optimization framework, is an alternative approach. Most studies in this direction (e.g. Foy et al. (1992); Hadi et al. (1993); Park et al. (1999); Park et al. (2000); Rouphail et al. (2000); Park et al, (2001); Howell and Fu (2006); Yang and Liu (2008); Hu and Chen (2011); Geng and Cassandras (2012)) optimized the basic parameters of pre-timed signals of a single intersection to minimize delays or queue lengths. This approach was used in Park and Yun (2006), Branke et al. (2007), Park and Lee (2009), and Yun and Park (2012) to optimize actuated traffic signal plans, showing substantial improvements. Park and Schneeberger (2003) and Stevanovic et al. (2007) also included offsets to coordinate the control plans in multiple intersections. Stevanovic et al. (2008) and Stevanovic et al. (2011) also successfully included in the optimization transit priority parameters that determine the maximum green time extension and the maximum early green time provision to transit phases. Both these studies were computationally intensive. To reduce the computational effort, Wolput et al. (2015) and Balasha and Toledo (1992) developed mesoscopic traffic simulation models to be used within the optimization.

In this paper, an application of an optimization model for a small network of adjacent intersections that are controlled jointly by a complex control plan that incorporates transit priority and pedestrian actuations is presented. A mesoscopic traffic simulation, MESCOP, (Balasha and Toledo, 1992) is used to evaluate the performance of signal plan settings.

MEHODOLOGY

Simulation-Based optimization system

The simulation-based optimization uses a mesoscopic traffic simulation model, MESCOP, to evaluate traffic flow in and between the intersections being studied, the states of traffic detectors and actuators and the detailed control logic. MESCOP explicitly represents the movement of individual road users, including passenger cars, transit vehicles and pedestrians, through and between intersections. The signal control logic and parameters for single or multiple intersections are run every second to determine the light indications in the next second. The control logic uses information on current and previous indications and on the states of the detectors in the system (e.g. detectors activated) that are calculated in the simulation. The signal plan optimization is done off-line considering the entire period of interest at once. The average person delay is used as the objective function.

The optimization algorithm runs replications of the simulation, and with different values of the control plan parameters. It calculates the objective function value from the simulation results, determine new parameter values and set these values as inputs to the simulation model for the next simulation runs. A Genetic Algorithm (GA) (Holland (1992) was implemented for the optimization reported in this paper.

Case study

The optimization model was applied to the simultaneous control of three adjacent intersections along a large collector road in Haifa, Israel, which are shown schematically in FIGURE 1. Intersection 1 connects the collector to a major arterial (6-7 in the drawing). The movements that pass through this intersection include two Bus Rapid Transit (BRT) movements on dedicated lanes between points 6 and 7). BRT stops are located immediately upstream of the northbound stop line and 150m upstream of the southbound stop lime. Demand detectors are located on the minor approaches (from 4 and 8). On the arterial, there are extension detectors as well as three BRT detectors on each direction. There are also pedestrian push buttons for the crosswalks on the main arterial. At the two minor intersections (2 and 3), there are demand detectors on the minor approaches (from 2, 3, 4, 5) and extension detectors on the major approaches (from 1 and between the intersections). Pedestrian push buttons are available in all crosswalks in intersection 2 and the two pedestrian movements to cross the main road in intersection 3.

The peak hour traffic flows in the system are presented in TABLE 1. These values were estimated from traffic count measurements. The three intersections are controlled jointly. They are coordinated through shared cycle time and offsets. The control logic uses functions to skip, extend or terminate phases, respond to pedestrian push button requests and provide transit priority and compensation for the BRT vehicles in intersection 1. The control logic for all three intersections includes a total of 84 parameters that are related to signal timings, pedestrians waiting times and the BRT priority functions described above.

The calibration of the simulation model included estimating the demand matrix (TABLE 1) and the queue discharge rates. For the latter, the number of vehicles that were discharged in each cycle in the movements in intersection 1 were observed with cameras that are installed there. To validate the model, it was run with the observed demand and calibrated discharge rates. The observed and simulated allocations of green times to the movements in intersection 1 are compared

TABLE 1. The origin-destination flows in the network (vph)

O/D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	-	272	120	8	161	235	472	64
2	112	-	300	1	28	41	83	11
3	143	292	-	1	19	28	64	8
4	75	30	9	-	42	4	9	1
5	156	61	19	47	-	41	81	11
6	88	34	11	13	36	-	1400	106
7	228	90	28	33	95	1400	-	55
8	38	15	5	6	16	104	58	-

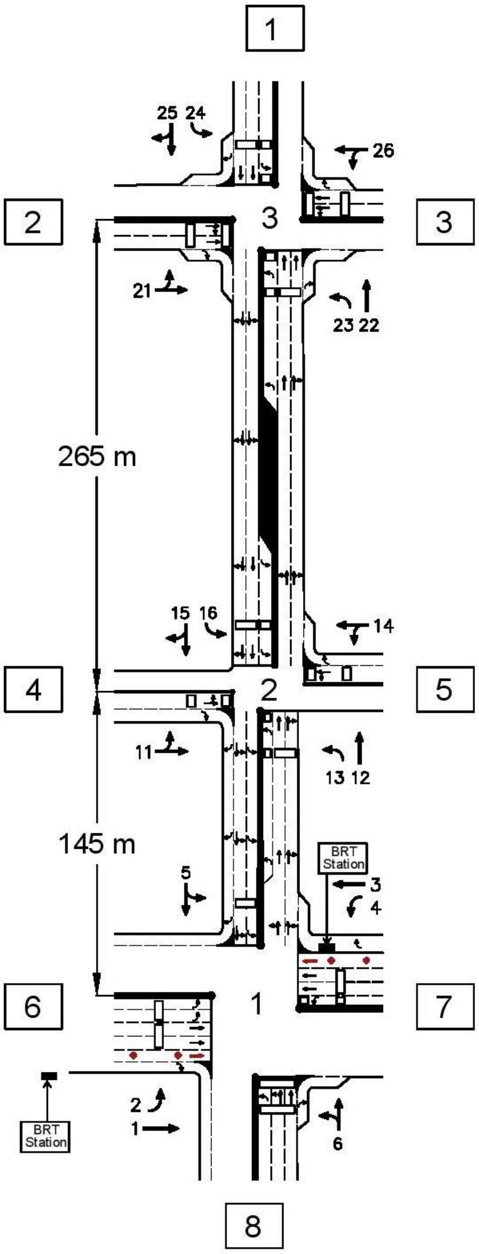

FIGURE 1. The case study network

Initially, optimization of all 84 parameters jointly was conducted. The optimization results were compared with the base design, which is implemented in the field. Then, to assess the effect of various factors on the network performance and the optimal control settings, an experiment was designed, in which three factors were modified: Level of demand, Distribution of demand among OD pairs and Distances between intersections. A full factorial design with 27 combinations of the factor levels was used. For each of these scenarios, the optimization was run in two methods:

1. Joint optimization, in which all 84 parameters were optimized simultaneously.
2. Sequential optimization, in which each intersection was first optimized separately, ignoring the effect of the adjacent ones.

RESULTS

Base case

The results of optimization of all 84 parameters jointly are compared to the base design, which is implemented in the field. FIGURE 2 shows the average delays to the various road users in the base and optimal designs. The person delay decreased by 35%. This is mostly due to a decrease (38%) in the delay to vehicle passengers that constitute 77% of road users. In contrast, the delays to BRT passengers and pedestrians increased. However, these constitute only 18% and 5%, of road users, respectively, and their delays remain relatively low.

In the control plan itself, the most influential differences in the parameter values are that the cycle time was increased from 120 to 150 seconds and that green times for the major movements in main intersection (movements 1 and 3) and those along the collector's corridor (movements 5, 15, 25). This increase is partly a result of the lower lost times (by 7%) due to larger cycle times and partly at the expense of the minor movements in the three intersections.

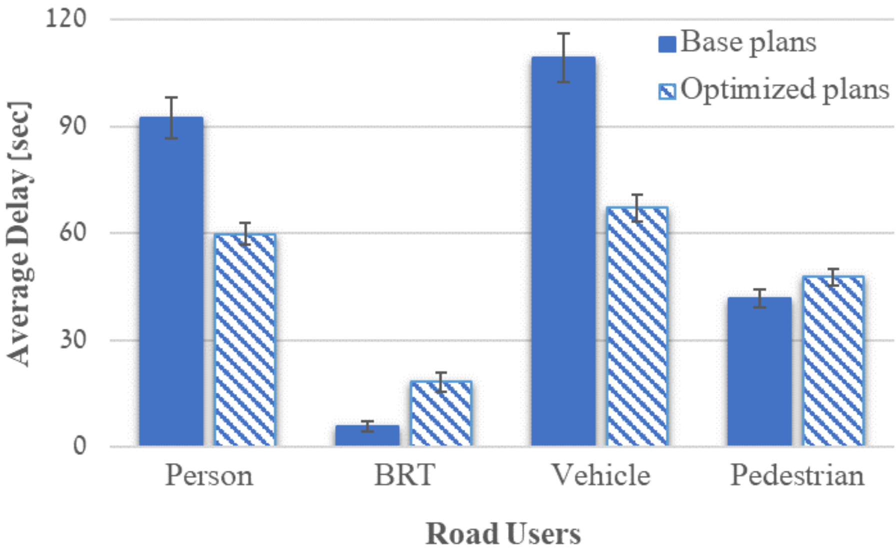

FIGURE 2. Average delays and 95% confidence intervals for the various road users in the base and optimal plans

The improvement in flow of the vehicle traffic comes at the cost of a negative impact on the BRT vehicles. Their delay increases by 12 seconds. This is a result of a reduction in the priority coverage in the optimal plan and an increase in the compensation mechanism requirements. The compensation mechanism guarantees minimum green times to the minor movements in intersection 1 over a given number of cycles. As a result, BRT priority, which was never denied to the compensation constraints in the base plan was denied in 1.7% of the cycles.

Experiments

The results for the 27 scenarios with varying levels of demand, its distribution and the distances between the intersections are presented in TABLE 2.

In all scenarios, the joint optimization outperformed the sequential one, by 7.9% on average, thus supporting its use in the control design. These differences are larger when the distance between the intersections is smaller (on average, 9.3%, 7.5% and 6.9%, for the scenarios with -33%, 0%, +33% change in the distances, respectively). They also increase when demand is shifted from the arterial, only using intersection 1, to the collector, also using the other intersections (on average 5.4%, 8.7% and 9.7% for the scenarios with 0%, 20%, 50% demand shift). The effect is less clear for the overall level of demand. The simultaneous optimization improves the most, 9.9%, with the highest demand (20% increase). But, it improves 7.4% with the lowest demand (base demand) and only 6.4% with the medium level (10% increase).

Scenario	Demand level (%)	Demand shift (%)	Intersections' distances change (%)	Average person delay (seconds)		Difference (%)
				Joint optimization	Sequential optimization	
1	0	0	0	59.9	61.3	2.3
2	10	0	0	85.1	87.0	2.1
3	20	0	0	113.7	131.5	13.5
4	0	20	0	117.1	126.2	7.1
5	10	20	0	137.4	147.7	7.0
6	20	20	0	163.1	182.0	10.4
7	0	50	0	178.9	196.5	9.0
8	10	50	0	212.9	230.9	7.8
9	20	50	0	233.2	255.2	8.6
10	0	0	+33	57.3	59.0	2.9
11	10	0	+33	81.9	84.4	3.0
12	20	0	+33	111.2	120.5	7.7
13	0	20	+33	108.9	115.7	5.9
14	10	20	+33	131.9	137.5	4.1
15	20	20	+33	154.6	172.9	10.6
16	0	50	+33	166.4	185.1	10.1
17	10	50	+33	201.6	220.3	8.5
18	20	50	+33	216.3	239.0	9.5
19	0	0	-33	62.5	65.3	4.3
20	10	0	-33	93.1	94.8	1.7
21	20	0	-33	127.3	142.7	10.8
22	0	20	-33	131.3	147.1	10.7
23	10	20	-33	146.4	166.7	12.2
24	20	20	-33	175.2	195.4	10.3
25	0	50	-33	190.1	221.4	14.1
26	10	50	-33	220.9	249.2	11.3
27	20	50	-33	245.2	266.4	8.0
	Average			145.3	159.3	7.9

TABLE 2. Optimal person delays in the various scenarios of the experiment

CONCLUSION

This paper presented a case study of application of simulation-based optimization for actuated traffic signal plans with transit priority for a network of adjacent intersections. The case study results showed a potential for substantial improvement in the average person delay. They also demonstrated the usefulness of jointly optimizing the control parameters for the adjacent intersections over optimizing each intersection separately. The experiment scenarios showed that the optimization results vary with the situation and therefore cannot be easily generalized. a potential future research direction is to expend the experiment reported in this paper to investigate different control plan strategies, particularly those that involve transit priority functionalities, to create more general guidelines for strategy selection for various intersection layouts and demand characteristics. This experiment would also require integration of an independent traffic model for evaluation of the control plans performance. Among others, this had been done by Yun and Park (2012) and Stevanovic et al. (2008).

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