OPTIMUM AND ROBUST OPERATION OF TRAFFIC RESPONSIVE CLOSED-LOOP SYSTEMS

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ABSTRACT

The Federal Highway Administration (FHWA) started the development of a structured approach to centralized traffic signal control, called Urban Traffic Control Software (UTCS), in the 1970s. The UTCS defined and tested various levels of traffic control, ranging from time-of-day plan selection to real-time adaptive signal control. Traffic signal vendors adopted some of the UTCS features in their current controllers, providing a widely available Traffic Responsive Plan Selection (TRPS) control mode in a setup known as closed-loop systems. TRPS is superior to the more typical time-of-day plan selection in its ability to accommodate abnormal traffic conditions such as incidents, special events, and evacuation emergencies. Although several studies showed great potential benefits of TRPS control (if properly configured), the TRPS mode remained largely underutilized due to its configuration complexity. This practice could be largely attributed to very minimal guidelines available on the setup of TRPS mode. In addition, TRPS setup is conceived as a big task that requires a considerable amount of time and resources to design, evaluate, and monitor successfully.

The TRPS mode uses count and occupancy data collected from system detectors. The information is aggregated by means of certain master controller functions using smoothing, scaling, and weighting factors. These TRPS factors are used to calculate the TRPS Pattern Selection (PS) parameters to select the most appropriate timing plan. Each system detector is assigned a weighting factor by which its data is multiplied during the aggregation process. The master controller compares each PS parameter value to its corresponding threshold to identify the appropriate PS level. The three PS levels are used as index values in a table lookup procedure. The lookup table entries determine which one of the pre-stored timing plans will be selected.

This paper presents a novel methodology for determining optimal values of TRPS parameters (detector weights, thresholds, etc.) and the corresponding optimal set of timing plans. The methodology incorporates Bayesian-based pattern recognition with a multi-objective evolutionary algorithm to produce optimal and robust design of TRPS control framework.

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KEY WORDS

Traffic Control, Closed-Loop Operation, Signal Systems, Adaptive Control Systems, Traffic Responsive Control.

INTRODUCTION

Traffic Responsive Plan Selection (TRPS) control mode provides efficient signal operation due to its ability to accommodate abnormal traffic conditions such as incidents, special events, and evacuation emergencies (Hanbali and Fornal 1997; Nelson et al. 2000). Although several studies showed great potential benefits of TRPS control once properly configured, the TRPS mode remained largely underutilized due to its configuration complexity. This practice could be largely attributed to very minimal guidelines available on the setup of TRPS mode. In addition, TRPS setup is conceived as a big task that requires a considerable amount of time and resources to design, evaluate, and monitor successfully.

The TRPS mode uses count and occupancy data collected from system detectors. The information is aggregated by means of certain master controller functions using *smoothing*, *scaling*, and *weighting* factors (Eagle Traffic Control Systems 1998; Econolite Control Products 1996; Naztec 2004). These TRPS factors are used to calculate the TRPS parameters to select the most appropriate timing plan. Each system detector is assigned a weighting factor by which its data is multiplied during the aggregation process.

TRPS threshold method utilizes several Computational Channel (CC) and Pattern Selection (PS) parameters from a group of *n* system detectors (*n* differs from one manufacturer to another) are aggregated into a CC parameter (i.e., by multiplying each system detector by its corresponding weight W) to arrive at the final selected timing plan. The name and number of CC parameters in a TRPS system differs from one manufacturer to another. The master controller compares each PS parameter value to its corresponding threshold to identify the appropriate PS level. The three PS levels are used as index values in a table lookup procedure. The lookup table entries determine which one of the pre-stored timing plans will be selected. Each PS parameter value merely specifies an index into the TRPS lookup table and not the actual cycle, splits, and offset values.

The objective of this research was to develop a methodology to configure the TRPS parameters in conjunction with the timing plans to provide a robust and steady operation of traffic signal systems.

TRAFFIC STATE GENERATION FOR CASE STUDY

The authors used a case study network consisting of four intersections and loaded it with several levels of traffic states. This global perspective classifies arterial volume into main three movements: 1) major external movements to the arterial, 2) internal local movements, and 3) additional cross-street movements. Preliminary PASSER (Chaudhary et al. 2002) runs were conducted to find the realistic limit of each movement in a 4-intersection system so that the intersections are not oversaturated. The levels for each external movement are shown in Table 1. For each level of the internal local traffic, the internal turning movements were calculated based on an assumption that every node produces equal amount of trips and these trips gets equally attracted by other nodes in the network. Levels and resulting interior turning volumes are shown in Table 2.

TABLE 1 Volume Levels for Arterial External Movements

Level	External Movement					
	EB-Thru	SB-Left	NB-Right	WB-Thru	NB-Left	SB-Right
1	400	0	0	400	0	0
2	800	200	200	800	200	200
3	1200	300	300	1200	300	300
4	1600	--	--	1600	--	--

TABLE 2 Volume Levels for Internal Local Movements

Cross Street Level	Volume	Int.	Direction											
			EB			WB			NB			SB		
			L	T	R	L	T	R	L	T	R	L	T	R
1	150	1	21	127	21	134	113	134	131	19	19	19	19	131
		2	59	272	59	96	267	96	94	19	56	56	19	94
		3	96	267	96	59	272	59	56	19	94	94	19	56
		4	134	113	134	21	127	21	19	19	131	131	19	19
2	300	1	42	253	42	267	225	267	263	38	38	38	38	263
		2	117	544	117	192	534	192	188	38	113	113	38	188
		3	192	534	192	117	544	117	113	38	188	188	38	113
		4	267	225	267	42	253	42	38	38	263	263	38	38
3	300 +100	1	42	253	42	267	225	267	263	138	38	38	138	263
		2	117	544	117	192	534	192	188	138	113	113	138	188
		3	192	534	192	117	544	117	113	138	188	188	138	113
		4	267	225	267	42	253	42	38	138	263	263	138	38

It was hypothesized that a traffic state that occurs more frequently should be favored by the algorithm when selecting the timing plans. The probability of a particular state was determined based on the average occurrence of that states as observed in data from 4 sites in Texas (Abbas and Sharma 2006; Abbas and Sharma forthcoming).

TIMING PLAN GENERATION

The combination of all traffic states used in this research resulted in formation of 3,888 instances (4 X 3 X 3 EB external movement X 4 X 3 X 3 WB external movement X 3 cross street levels). PASSER V was used to obtain timing plans for each of the states with 7 cycles each (60, 75, 90, 100,120, 150, and 180 seconds cycle lengths). Next, all over saturated states were removed, leaving only 1,479 states. PASSER V was then run again to obtain a matrix of delay and number of stops for each of the combinations to be used as an input for the genetic algorithm optimization.

After obtaining the state probabilities and state-plan delay mapping multi objective Genetic Algorithm (GA) was used to determine a maximum of 16 timing plans (a limitation imposed by traffic controllers) that would result in minimal delay, stops, and Degree of Detachment (DOD) among the traffic states. The DOD measure the degree by which a traffic states is detached from adjacent states. In this context, detachment occurs when the adjacent state (state that has a one level below or one above the current state's level) is associated with a different timing plan. If timing plans assignments are scattered as small clusters through out the state space, a high DOD value is obtained. Whereas solutions with timing plan assignments forming big clusters in the state space have low DOD values.

MULTI-OBJECTIVE OPTIMIZATION OF TRPS PARAMETERS

The TRPS configuration main challenge is in the multi-objective optimization involved in the configuration process. In TRPS mode, signal timing plans are selected from a look-up table based on real-time values of the three plan selection parameters. The look-up table consists of *K*=48 cells in a three-dimensional 4x4x3 grid. Although the 48 cells can be divided among the three plan selection parameters in many different ways, the 4x4x3 arrangement is consistent with most controllers approved by TxDOT and, therefore, it was the cell arrangement used in the present project.

According to this operational logic, the decision boundaries separating different groups (i.e., traffic conditions with common optimum timing plan) can either be parallel or orthogonal to each other. Each decision boundary is a plane parallel to one of the x_1-x_2, x_1-x_3, or x_2-x_3 planes in the x_1-x_2-x_3 coordinate system. A supervised discriminant algorithm developed in this study performed the plan classification and error reporting (Abbas et al. 2005a).

The multi-objective optimizer was integrated with the supervised discriminant analysis algorithm. Input data was obtained from CORSIM (ITT Systems & Sciences Corporation 2003) simulation where each of the 14 selected timing plans was run with all 1,479 traffic states. The algorithm is shown in Figure 1.

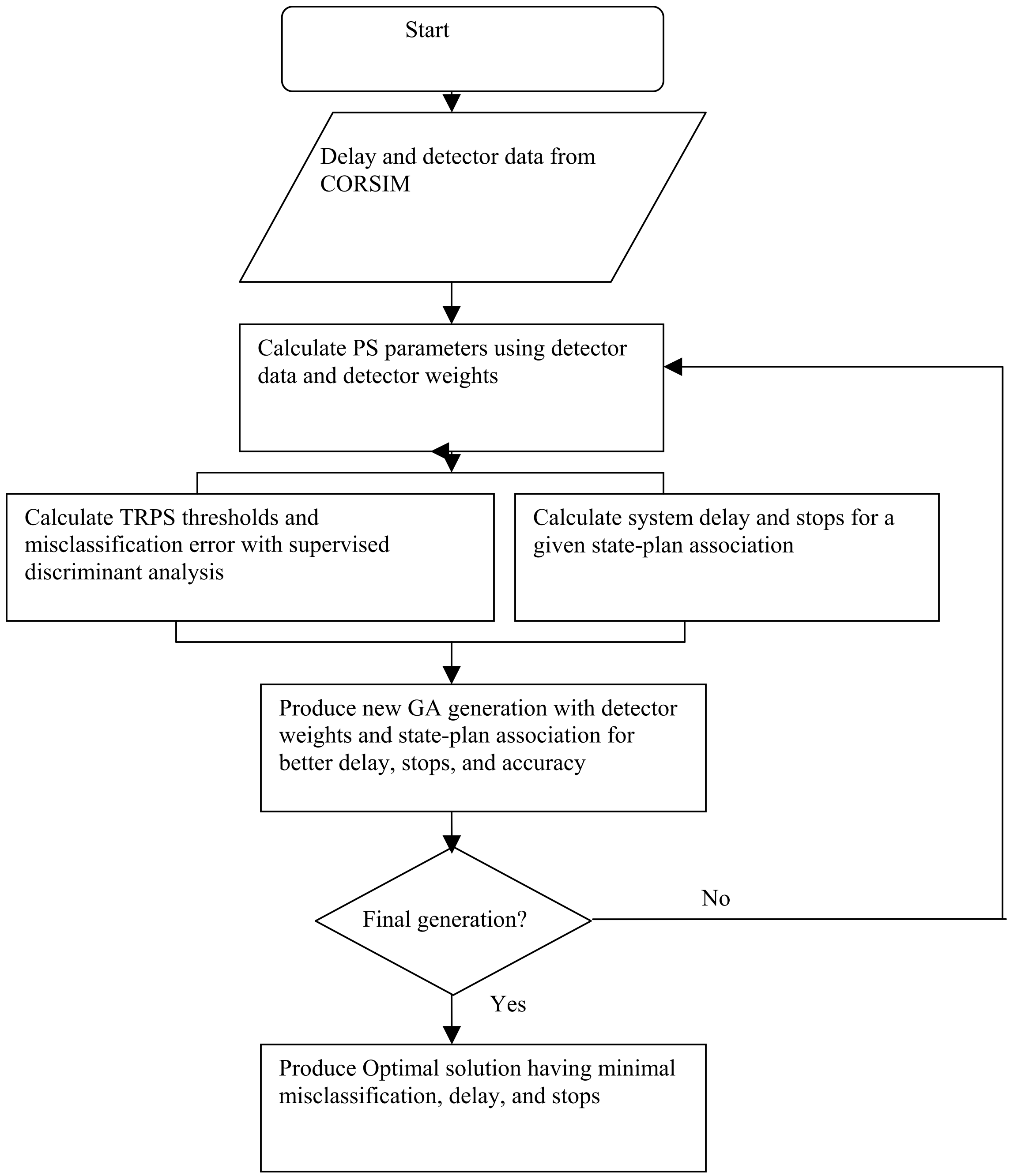

FIGURE 1 Multi-Objective TRPS Configuration Algorithm.

Optimization Results

The multi objective GA resulted in a selection of only 14 timing plans to handle all traffic states with a reduction of 53% in delay and 16% in stops in comparison to the worst solution encountered during the optimization run. This result could be interpreted as 53% savings in delay and 16% savings in stops compared to an aged TOD design with 14 timing plans (which is very rare). The benefits compared to the typical 3-plans aged TOD design would be even higher (a typical 3-plan TOD design is less optimal than a 14-plan TOD design since a wider range of traffic will need to be addresses by the same timing plan).

TRPS parameters obtained from the optimization resulted in 99% classification accuracy. The Pareto front obtained form the optimization is shown in Figure 2.

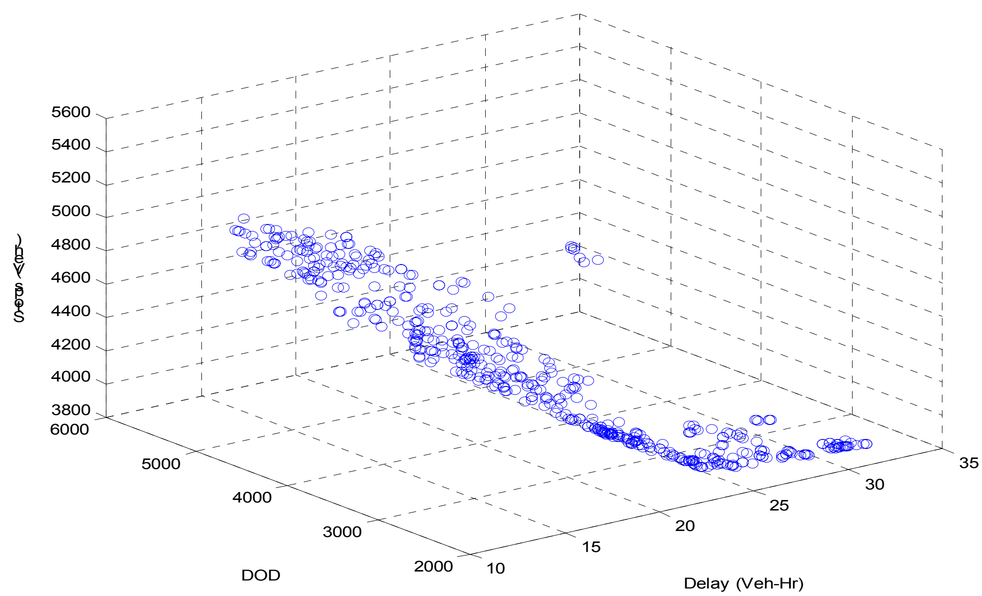

FIGURE 2 Multi-Objective Optimization Output Pareto Front

A step-wise discriminant analysis was used to determine critical location of system detector (Abbas and Sharma 2004). It was found that a collection of thirteen system detectors placed at strategic locations can provide a robust and accurate classification of different traffic states. System detectors are all located 400 feet upstream of the traffic signal in the inside lane. Thoughtful investigation of the system detector locations suggests that TRPS mechanism works best when the following traffic movements can be sensed: through movements at the exterior intersections, left-turning movements that leave or exit the coordinated system, and movement at one of the cross streets (cross street with most traffic variation). The developed methodology is currently being implemented in Texas(Abbas et al. 2005b).

CONCLUSION AND RECOMMENDATIONS

TRPS mode provides a mechanism by which the traffic signal system is able to change timing plans in real-time in response to changes in traffic conditions. However, there are very limited guidelines to configure a TRPS system for optimal and robust operation. In this paper, the authors presented a new TRPS configuration methodology. The methodology followed a comprehensive approach that utilized a multi-objective evolutionary algorithm and a supervised discriminant analysis. The multi objective algorithm resulted in a selection of 9 timing plans to be used with the TRPS mode. The combination of these plans is expected to achieve at least 53% savings in delay and 16% savings in stops compared to an aging TOD design.

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