OPTIMIZATION OF TIME OF DAY PLAN SCHEDULING USING A MULTI- OBJECTIVE EVOLUTIONARY ALGORITHM

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ABSTRACT

Coordinating traffic signals can provide great savings to motorists in terms of reduced delays and number of vehicular stops. In order to maximize benefits, engineers need to use a mechanism by which the most optimal timing plans are activated when the traffic patterns change. Common ways of accomplishing this need is by using Time of Day (TOD) plan scheduling, or Traffic Responsive Plan Selection (TRPS). Out of the two modes, the TOD mode is by far the most common. Engineers, however, typically use their judgment to determine the TOD plan scheduling. Unless traffic patterns change at certain times of the day and remain constant until the next change—which is highly unlikely—it is very difficult to determine what the optimal break point would be. In addition, engineers would also face the challenge of selecting the timing plan that would be active during every scheduling period. This paper proposes the use of a multi-objective evolutionary algorithm to address these challenges. The author introduces the Degree of Detachment (DOD) as a performance measure of scheduling continuity. A high DOD translates into frequent changes in timing plans. Whereas a zero DOD translates into a one timing plan applied throughout the day. A non-dominated sorting genetic algorithm (NSGAII) is then used to optimize the TOD scheduling. This approach results in different Pareto fronts, corresponding to different DODs, where engineers can evaluate the incremental benefits associated with increasing the frequency of timing plan changes.

The DOD was able to provide a clustering procedure that does not suffer from drawbacks encountered by previous research methods. The paper illustrated the integration of a non-dominated sorting genetic algorithm with the DOD measure to optimize the TOD scheduling. Using sample field data from a coordinated system in Texas, the developed algorithm was able to produce five solutions that correspond to different number of allowed transitions during the day. Solutions with more frequent timing plan transitions exhibited lower delay and number of stops. However, it was found that no significant benefits were obtained for allowing more than four transitions in the day for this specific system.

The multi-objective evolutionary algorithm with DOD was successful in finding optimal selection of timing plans as well as the optimal TOD schedule. In addition, it provided

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several options for the analyst to choose from. All options being optimal, but different in the preference levels they assign to each of the two objective functions, delay and number of stops.

KEY WORDS

Traffic Control, Closed-Loop Signal Systems, Traffic Signal Timing, Time of Day.

INTRODUCTION

Coordinating traffic signals in a closed-loop system can provide significant reductions in travel and delay times. In order to achieve signal coordination, timing plans need to be developed so that the coordinated system can work in a synchronized mode. As traffic patterns change during the day, different timing plans need to be activated to achieve optimal performance. Several studies were conducted over the years to improve the development of optimal timing plans. Computer optimization packages, such as PASSER II *(Chaudhary et al. 2002)*, SYNCHRO (Trafficware 2000), and TRANSYT-7F (Wallace et al. 1998), are widely used to generate optimal timing plans. However, very limited research has been conducted on the optimization of the TOD plan schedule. In addition, very limited guidance is provided on which timing plan should be implemented during a TOD period. It is inevitable that during a TOD period, traffic patterns are not constant, and every traffic pattern could be used to generate its own optimal timing plan.

In practice, traffic engineers collect data for a representative day of the week and visually decide on when there is a significant change in traffic patterns. This procedure typically results in engineers deciding on dividing the day into am-peak, off-peak, and pm-peak periods. The engineers then proceed with using a representative traffic pattern from 15-minute counts obtained throughout each period, and design a timing plan for that pattern. The engineers then apply the resulting timing to the entire period. While this procedure is not very complicated, it usually results in sub-optimal and subjective decisions of when and which timing plans to be implemented in a coordinated system.

NON-DOMINATED SORTING GENETIC ALGORITHM

Non-dominated sorting genetic algorithm (NSGA II) was developed by Deb et al (Deb et al. 2002). The algorithm belongs to a set of multi-objective algorithms that strive to find the Pareto front (the front of compromised solutions) of all objectives. Solutions lying above the Pareto front are non-optimal solutions, while those lying below the Pareto front are infeasible solutions. All solutions on the Pareto front are optimal with regard to at least one objective. The shape of the Pareto front itself provides very valuable information to the analyst. One would know, looking at the Pareto front shape, how much other objective functions would be compromised if a selected objective function is to be favored.

The NSGAII is similar to simple GAs in the use of the selection, crossover, and mutation operators (Goldberg 1989). However, prior to the selection step, the algorithm ranks the whole population based on all objectives. All individuals in the population that are non-dominated (i.e., there does not exist an individual that is better than this individual in all objectives) are assigned a rank of one. These individuals with rank one are removed from consideration and all other individuals are ranked again and are assigned a rank of two. The process continues until all individuals are assigned a rank. After the process is completed, a crowding distance is calculated for all individuals. The crowding distance is used to diversify the population by assigning a higher value to individuals with larger cuboid formed by the individual and its neighboring individuals. The selection operator is then applied while assigning higher fitness to individuals with higher ranks and crowding distances. The algorithm ensures elitism by combining the parent population with the children population before the crossover and mutation operators are applied.

DEGREE OF DETACHMENT

The author defined a new MOE for the purpose of clustering traffic patterns while accounting for the general preference of avoiding zigzag changing in timing plans. The DOD measures the degree by which a time period (or equivalently, the traffic pattern at the time period) is detached from adjacent periods in term of its assigned timing plan. In this context, detachment occurs when the adjacent traffic pattern (pattern that occurs one time period before or one time period after the current pattern's time period) is associated with a different timing plan. As such, the DOD value for a given TOD plan schedule can be calculated as:

$$DOD = \sum_{\forall_i} (DOD_{i1} + DOD_{i2})$$

where,

$$DOD_{i1} = \begin{cases} 0, \text{ if } X_{i-1} = X_i \\ 1, \text{ otherwise} \end{cases}$$

$$DOD_{i2} = \begin{cases} 0, \text{ if } X_{i+1} = X_i \\ 1, \text{ otherwise} \end{cases}$$

and,

X_i= plan assigned to time period i

It can be deduced that for a 96 time periods (24 hours with 4 periods per hour), the maximum possible DOD is 190 while the minimum possible DOD is zero.

CASE STUDY

The procedure proposed in this paper is illustrated with a case study in Odem, Texas. The coordinated system consists of three intersections on US 77. The intersection Layout and geometry are shown in Figure 1. Figure 1 also shows a PASSER V network of the same system.

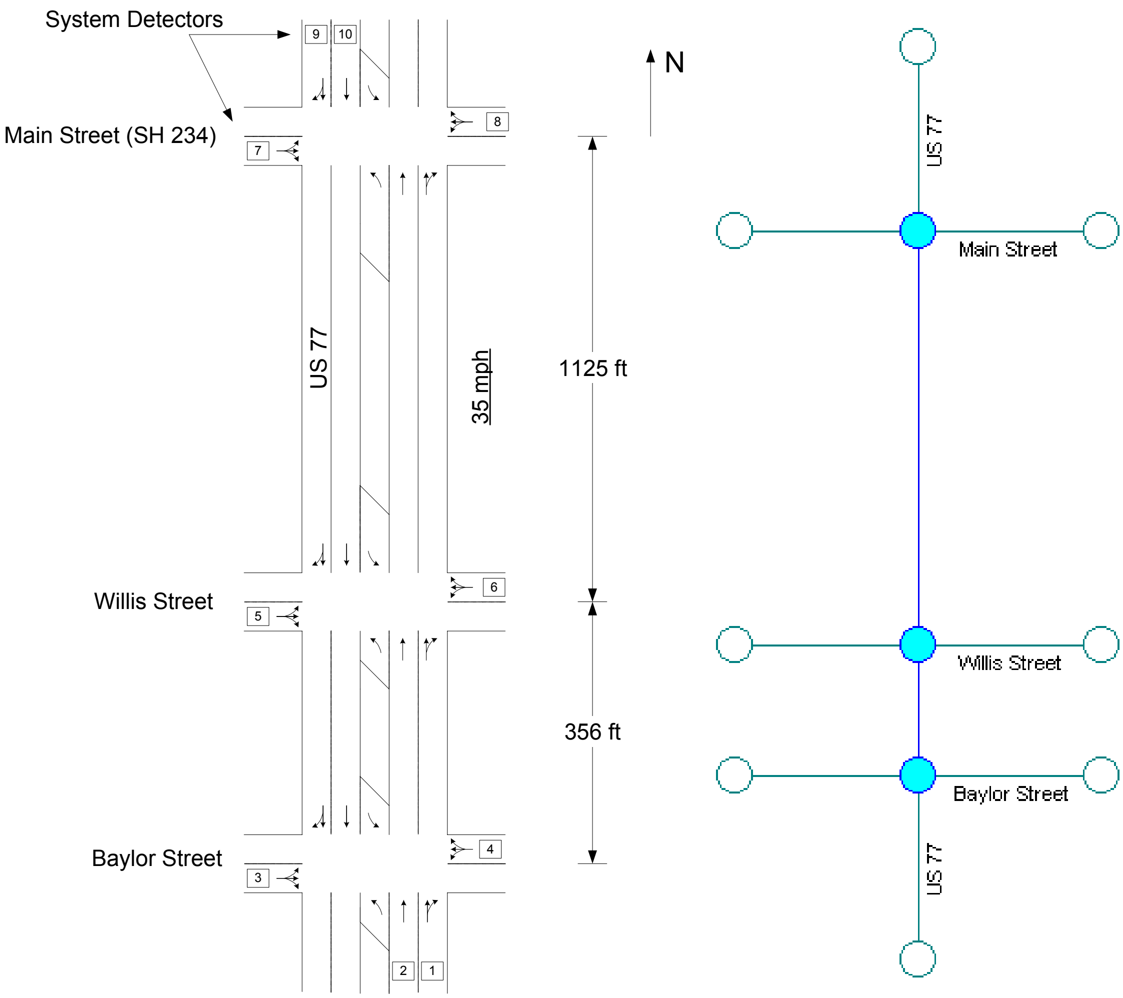

FIGURE 1 Odem Coordinated System and PASSER V Network.

Traffic data was collected in the site for 10 days using the system detectors. Out of these days, a most typical day was selected for the procedure's demonstration. Figure 2 shows traffic volume variation of each movement for the three intersections. The figure illustrate that during a typical day, large variation of volume occurs at all intersections with gradual volume increase in the morning and gradual decrease at the end of the day.

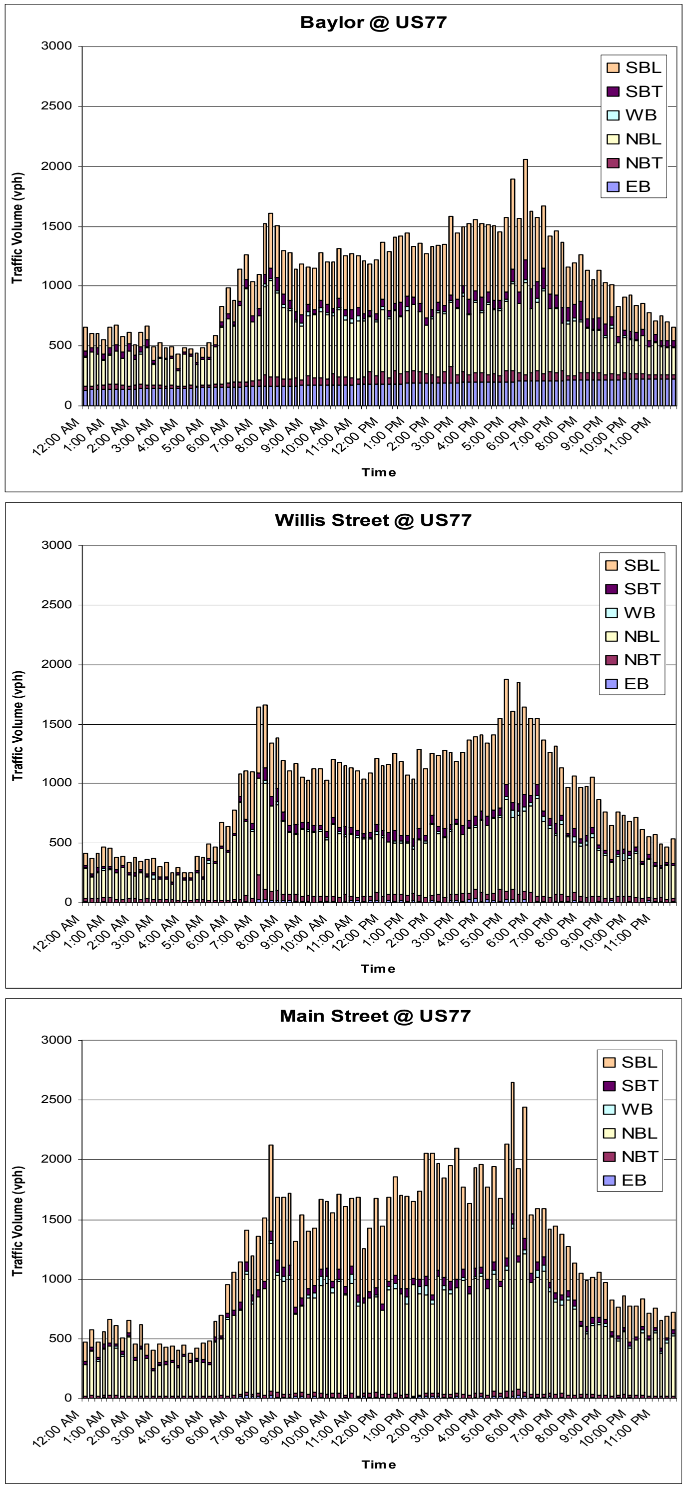

FIGURE 2 Traffic Variations in Odem System.

TIMING PLAN GENERATION

Odem coordinated system offered 96 volume patterns per day (data uploaded every 15 minutes) PASSER V was used to generate timing plans for each traffic pattern. Cycles used in the analysis ranged between 45 seconds to 180 seconds. The plan that produced the minimum number of stops for a traffic pattern was retained as the optimal plan for that pattern. The 96 traffic patterns therefore resulted in the production of 96 timing plans. The 96 selected plans were then run with all of the 96 traffic patterns to obtain the total number of stops for all plan-pattern combinations. This 96 by 96 performance matrix was then used as an input to the NSGA-DOD algorithm.

STOP AND DOD EVOLUTION

The NSGA-DOD algorithm was run with a population size of 200, crossover probability of 0.8, and mutation probability of 0.01. The stop and DOD values were plotted for all generation. Both best and worst values in a single generation were plotted for each objective function. It should be noted that the DOD improved from 190 to 38 within the first 1000 generations (about 15 minutes of comuter real time). The algorithm was able to reduce the total number of stops from about 75,000 to 55,000 vehicular stops.

THE PARETO FRONT

One of the very nice features of the multi-objective optimization algorithms is the production of the Pareto front. The Pareto front eliminates the need for trying, for example, different number of break points in the TOD schedule to compare results. The multi-objective optimization algorithm computes and produces the Pareto front at the end of the optimization run. Since the Pareto front shows the front of all non-dominated solutions, the engineer can select any of the solutions lying on the Pareto front without jeopardizing optimality. More importantly, one can tell exactly how much more cost is incurred on a certain objective if another objective was favored by a certain amount.

Figure 3 shows the Pareto front produced by the NSGA-DOD algorithm at the end of the optimization run. Note that the engineer can tell, looking at the figure, how much reduction in total number of stops is possible if the engineer is willing to live with additional number of plan schedule changes.

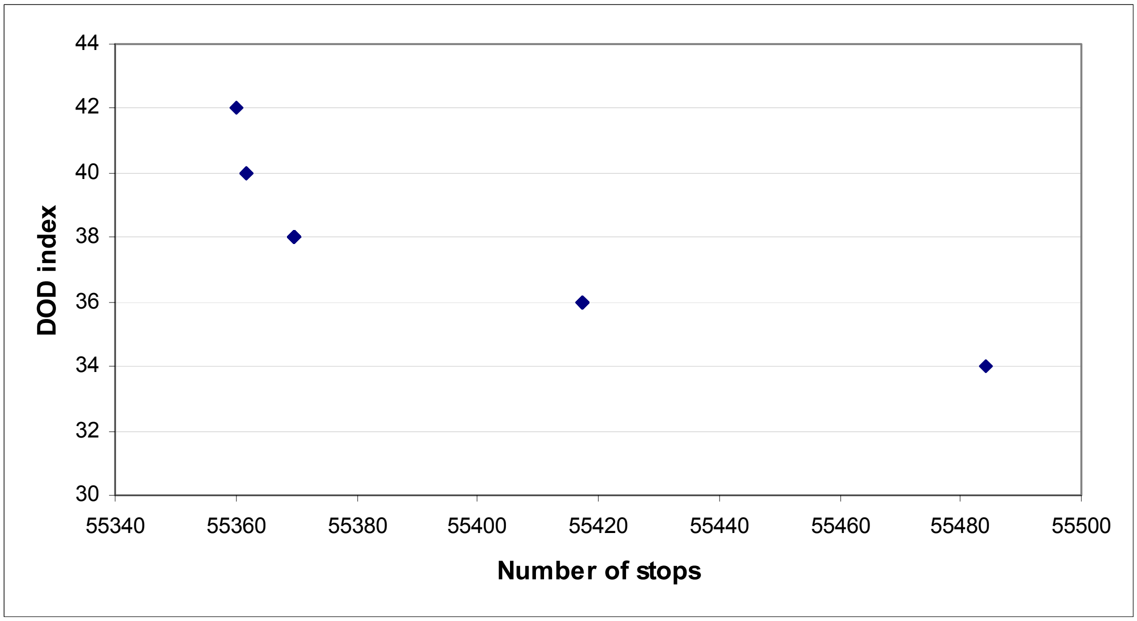

FIGURE 3 The Pareto Front.

It was interesting to note that the five solutions included in the Pareto front all agreed on the selection of exactly same five timing plans. The solutions differed only in the schedule by which these timing plans were activated during the day. Figures 4 and 5 show two solutions to illustrate how a high DOD is associated with more frequent plan changes.

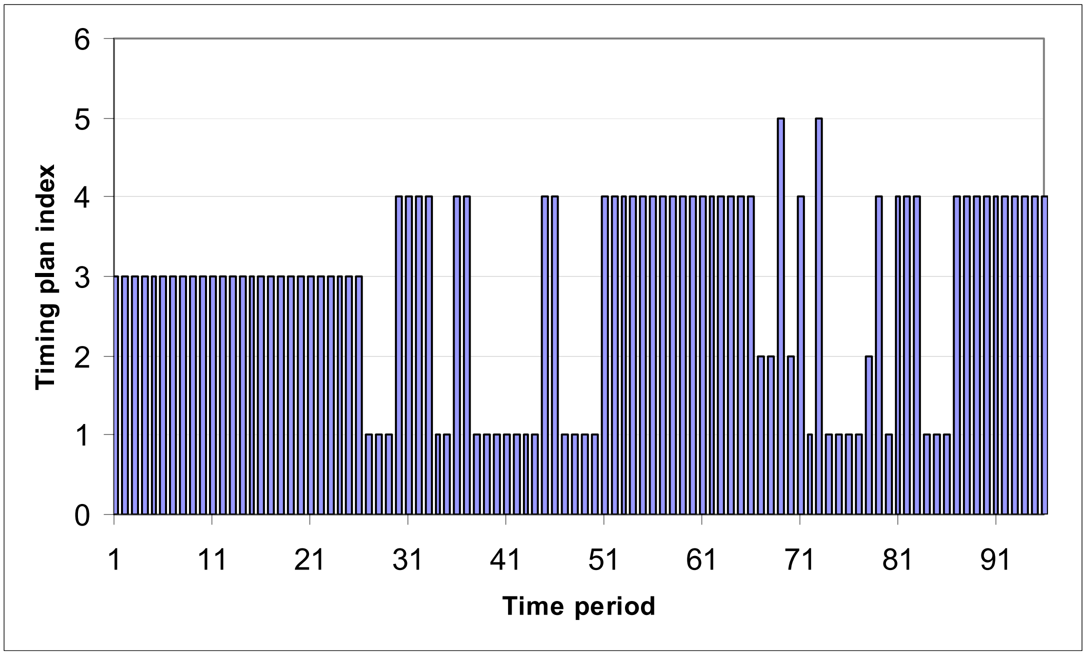

FIGURE 4 TOD Plan Schedule Pareto Solutions with DOD = 42.

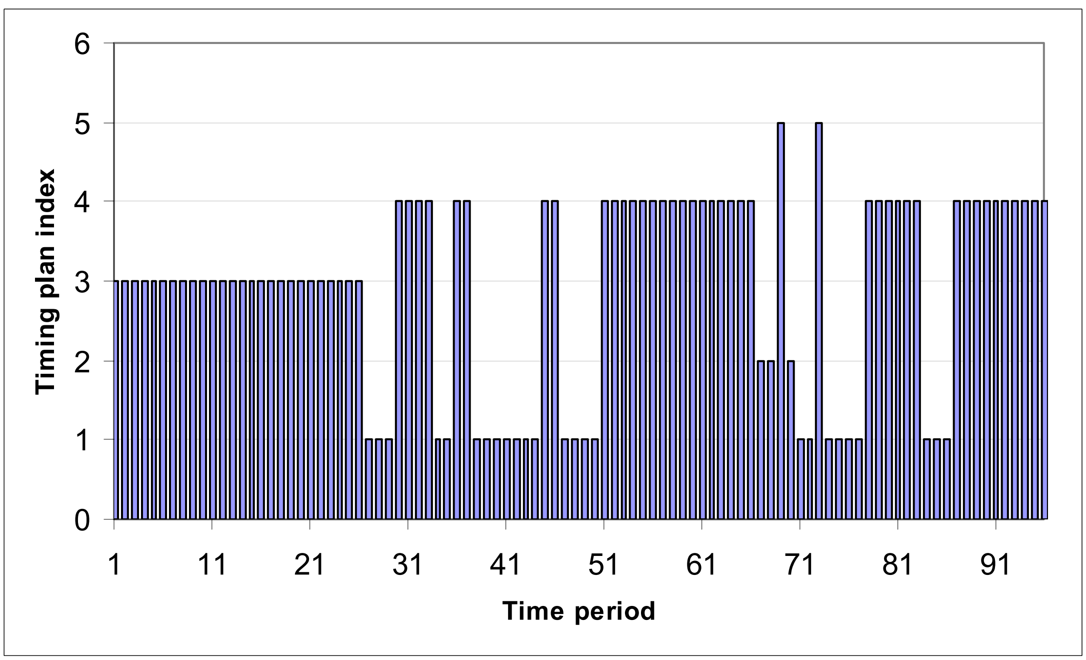

FIGURE 5 TOD Plan Schedule Pareto Solutions with DOD = 34.

CONCLUSION

This paper proposed the use of a multi-objective evolutionary algorithm to optimize the TOD plan scheduling. The paper defined a new measure of performance (the DOD) to provide a clustering mechanism of traffic patterns. The DOD was able to provide a clustering procedure that does not suffer from drawbacks encountered by previous research methods. The paper illustrated the integration of a non-dominated sorting genetic algorithm with the DOD measure to optimize the TOD scheduling. Using sample field data from a coordinated system in Texas, the developed algorithm was able to produce a Pareto front with five solutions. Each of the five solutions used the same plans (five plans) and differed only in the frequency of timing plan changing. Solutions with more frequent timing plan changing exhibited the lower number of system stops.

The multi-objective evolutionary algorithm with DOD was successful in finding optimal selection of timing plans. In addition, it provided several options for the analyst to choose from. All options being optimal, but different in the preference levels they assign to each of the two objective functions. The authors recommend the use of the multi-objective evolutionary algorithm to determine the TOD plan schedule. However, the author recommend including system delay as a third objective function in the optimization process.

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