論文内容の要旨

Further Improvements at Signalized Intersections: Solutions with Auxiliary Signals

（信号交差点性能の増強方策に関する研究 ー 付加的信号機の適用 ー）

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Alleviating traffic congestion continues to be one of the biggest challenges faced in many cities. The increase in motorization especially in urban areas has escalated in recent years, resulting in the need to increase the capacity of increasing infrastructure. In general, this problem is dealt with by either a) decreasing vehicle demand via improving mass transportation or congestion pricing schemes and b) increasing infrastructure capacity by the construction of additional lanes or paths. This research focuses on the latter approach.

Innovative approaches to increasing infrastructure capacity are important because the construction of additional lanes or paths often entail high capital costs and the required right-of-way may not always be easy to obtain. This dissertation focuses on the improvement of existing infrastructure, specifically on the level of a regular signalized intersection (RSI). Two alternative approaches are explored, these are: the Tandem Sorting Strategy (TSS) and the Median U-Turn (MUT). Both approaches provide additional capacity by relaxing the conventional practice of assigning one lane to one vehicle movement. By allowing the lanes to be used by different vehicle movements, intersection capacity and travel times are improved even without providing additional lanes. Another feature of both approaches are that they both utilize auxiliary signals which are placed upstream of the main intersection stop line.

TSS uses auxiliary signals (or pre-signals) to separate vehicle movements of different phases (e.g., through phase and right-turn phase, assuming left-hand side traffic) at the main intersection stop line. The space between the pre-signal and main signal stoplines, called the storage area, can be used by vehicles from two phases. The pre-signal first releases the vehicles belonging to the leading phase only so that they can occupy most, if not all, of the storage area lanes. Dynamic signs are provided in

order to guide the vehicles on which lanes can be used for queuing. The same principle is then applied to vehicles in the lagging phase.

Meanwhile, MUT provides capacity enhancement by prohibiting direct right-turns at the intersection and diverting vehicles to a downstream U-turn crossover instead. Auxiliary signals are utilized to manage conflicts between the merging streams at the U-turn crossover that want to approach the main signal stopline. The operational performance of the two approaches were assessed with respect to delay and capacity. To this end, delay models and corresponding signal optimization problems were developed.

To evaluate the benefits and limitations of both TSS and MUT, delay analysis was conducted for each and compared to that of the RSI. The comparisons were conducted assuming the same available road space and zero-conflict phasing plans, thereby assuring fairness.

For Tandem Sorting Strategy, a thorough discussion of the spatial and temporal constraints were conducted. Temporal constraints refer to limitations in available time for vehicles to enter and sort themselves on the storage area due to limited cycle length. Spatial constraints refer to the limitations imposed by inadequate storage space both upstream and downstream of the pre-signal. Considering these constraints, a delay estimation model was developed and a corresponding signal optimization program was formulated.

The optimization program consisted of two steps. The first step dealt with signal parameters on an intersection level, called the "Intersection-Level" problem whose objective function was to minimize expected delay for the whole intersection. The second problem dealt with the coordination problem between pre-signal and the main signal, called the "Link-level" problem and its objective function was capacity maximization at the pre-signal. The link-level problem took into account the effects of storage limitations and maximized the discharge capacity despite inadequate length of the storage area. Finally, to consider the negative effects of non-uniform discharge headways, green time adjustments were applied to the pre-signal green times to reduce the probability of discharge failures at the storage area.

The delay evaluation of TSS revealed that delay benefits and not just capacity enhancements can be derived from turning on the pre-signal. Contrary to the suggestion of Xuan (2010) where pre-signals should only be turned on when extra capacity is needed, it was found that turning on the pre-signal even when the intersection is undersaturated can retard the intersection's approach to an oversaturated state as demands increase.

Compared to TSS, the flows of U-turning vehicles at the U-turn crossover depend on upstream signal conditions. As such, the exact volumes and queues lengths of U-turning vehicles are difficult to determine. Therefore, a combination of analytical and simulation-based methods were adapted for MUT evaluation. Before conducting the analytical and simulation-based evaluations, a sensitivity analysis of different three-phase plans was conducted to select the most appropriate plan. Earlier simulation experiments also revealed a potential tradeoff that exists between the U-turning and through vehicles at the crossover. It was found that when the offset is set such that U-turning vehicle queues build-up at the U-turn approach and spillover to the adjacent lane, U-turning vehicles can block upstream vehicle flows and lead the intersection to approach a locked stated. To prevent this situation, the green duration for U-turners must be kept as high as possible to accommodate more vehicles. However, the tradeoff is that it reduces green time for the opposing through vehicles. To avoid the more drastic effect of the locked state, offset setting that provided U-turn priority was set.

For demands below capacity and assuming adequate storage space, a delay model was formulated for MUT, taking into account a zero-conflict phasing plan at the main signal and an offset setting which gave priority to U-turning vehicles at the crossover. A signal optimization problem which minimized delay was then formulated. To check if the assumptions made in the delay model were valid, the results of the delay model were compared to the delay output of the TRANSYT simulator. The model was seen to correspond well with the delays obtained from simulation for undersaturated conditions.

The results showed that despite the reduced number of lanes of the MUT compared to RSI, delays for MUT are lower especially when U-turn demands are low. This illustrates the attractiveness of the MUT as it reduces the number of signal phases. However, the results also shows that MUT performance significantly declines when U-turn demands increase to levels above 15-20%. The simulation results showed that under certain cases of oversaturation, MUT can lead to a failed state where it gives a lower capacity than the regular signalized intersection. Therefore, it is important to monitor existing U-turns in light of changes in demand patterns.

Finally, a comparison between the two approaches were conducted. The main attractiveness of both approaches is that they can process vehicles in an intersection faster, i.e., give shorter cycle lengths under high demand conditions. In general, based on operation performance in undersaturated conditions, MUT was shown to have the least delay under low right-turn/ U-turn demands while TSS is more appropriate for higher demand and higher right-turn demands. In terms of operational flexibility, however, TSS has a wider applicability because it can be reverted to an RSI by means of turning off the pre-signal. However, both have their own critical points: TSS performance can be significantly affected by variations in driver behavior (via lane failure) and MUT performance is affected by high U-turn demands.

To conclude, this study contributes to the increased understanding and implementation of approaches for improving intersection capacity and performance. As the analyses conducted focused on operational performance, further assessments of the financial and social impacts of adapting TSS and MUT should be conducted to make better judgements on their applicability. By further improving and exploring similar approaches, the introduction of innovative approaches to increasing intersection performance can be promoted.