A Dynamic Intersection Traffic Control System Simulation Model

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Abstract. Traffic control at road intersections is an old and ever growing problem in cities all over the world. In many cities, intersections represent bottlenecks in the traffic flow. Evaluating and managing intersections are complex, difficult, costly, and time consuming. The existing methods for traffic management, surveillance and control, are not adequately efficient in terms of performance, cost, maintenance, and support. In this paper, a framework of an approach for the Dynamic Intersection Traffic Control (DITC) system simulation is proposed, and an intersection design that would benefit from the proposed DITC is also presented. The proposed strategy reduces conflicts through geometric design and a specific traffic control system. The proposed DITC system has no waiting time, no stages to follow, and has a specific configuration. Keyword: Traffic congestion, fixed-time traffic light control system, modified continuous flow intersection system simulation, DITC system simulation

1. Introduction

Traffic congestion is one of the worst problems in many countries. It wastes a huge portion of the national income for fuel and traffic-related environmental and socioeconomic problems. It also creates multiple problems, such as air pollution, noise pollution, slow vehicle movements, and economic problems (Hewage & Ruwanpura, 2004). Wen (2008) claimed that traffic congestion occurs when the volume of traffic is greater than the available road capacity, and is termed as saturation. It reduces the capacity of a road at a given point or over a certain length, or increases the number of vehicles in a given volume. Traffic congestion is a recurring problem, and is attributed to sheer weight of traffic, and most of the rest is attributed to traffic accidents, work zones, weather, and special events.

In general, a simulation is any model that uses random numbers. There are several reasons why ones would construct a simulation model and some of them are that the system is far too complex to model analytically, it may be difficult, costly, or dangerous to collect data for creating empirical model, and the system may not yet exist, and system may contain random events that we do not want to oversimplify (Albright, 2010).

There are so many intelligent approaches of intersection’s traffic control model and simulation studied today (Sanner, 2010), (Wiering, M., Veenen, J., Vreeken, J., & Koopman, A., 2004). But, there are still no research that study how to maintain the continuity of service of the traffic control system itself. So, this study tries to do that.
2. Proposed Framework of DITC System Simulation

The proposed DITC System framework consists of three blocks i.e. block A (Signalized intersection), block B (Unsignalised Intersection), and block C, the control module block, as shown in Figure 1.

![Proposed Framework of the DITC system](image1.png)

Figure 1: Proposed Framework of the DITC system

This DITC System is divided into several modules in its implementation. Module A contains a simulation model of 4-way intersection time-based traffic light system, module B contains a simulation of modified 4-way continuous flow intersection system, and module C represents a control module of simulation model of Dynamic Intersection Traffic Control (DITC) system.

3. 4-way Intersection Time-based System Modelling

In this paper, there are some patterns in traffic light control system, they depend on traffic condition, policies of the government and others. Juanda Street/ Katamso Street intersection (an intersection in the city of Medan, Indonesia) has the patterns as given at Figure 2 with sequence of stages as in Figure 3 and Figure 4.

![Traffic Flow of 4-way Intersection (with traffic light)](image2.png)

Figure 2: Traffic Flow of 4-way Intersection (with traffic light)

In 4-way intersection, a four-stage sequence is implemented, i.e. Stage A, Stage B, Stage C and Stage D, with special patterns, and all controlled by three signals, red, yellow, and green coding lights. Stage A and Stage B have slightly different pattern. In Stage A, Stage C and Stage D vehicles may turn to the
right, while in Stage B, vehicles may not turn to the right permanently. These patterns are made by the government to reduce the density of vehicles approaching the intersection, and also to minimize the complexity of the system.

In Stage A, only vehicles from the North side are allowed to cross the centre of the intersection. In Stage B, vehicles from the North side, and also from South side are allowed to cross the centre of the intersection to the South side and the North side respectively.

In Stage C, vehicles from the East side are allowed to cross the intersection to the West side and the South side while in Stage D, vehicles from the West side are allowed to cross the intersection to the East side and the North side. Except in Stage B, in each stage, only vehicles from one side are allowed to cross the centre of intersection. The sequence starts from Stage A, Stage B, Stage C, Stage D, and back to Stage A again, and so forth.

Definitions and notations of the simulation model are given in Table 1.
Table 1: Definitions and notations of the simulation model

| Variables        | Description                                                                                     |
|------------------|-----------------------------------------------------------------------------------------------|
| Cross EW, Cross WE | The mean time of cars passing the intersection zones from East to West and from West to East |
| Cross NS, Cross SN | The mean time of cars passing the intersection zones from North to South, and from South to North |
| Cross NE, Cross ES | The mean time of cars passing the intersection zones from North to East, and from East to South |
| Cross WN         | The mean time of cars passing the intersection zone from West to North                          |
| Clock A, Clock B, Clock C, Clock D | Simulation clock time for Stage A, Stage B, Stage C, and Stage D respectively |
| Green A, Green B, Green C, Green D | Green light duration at Stage A, Stage B, Stage C, and Stage D respectively |
| Red A, Red B, Red C, Red D | Red light duration at Stage A, Stage B, Stage C, and Stage D respectively |

**Resources**

| switch A, switch B, switch C, switch D | Resources for controlling traffic light signal (permits or not) to pass the stop line at Stage A, Stage B, Stage C, and Stage D respectively |

**Queues**

| Queue East, Queue North, Queue West, Queue South | Queues at the intersection to store all waiting cars, which do not have the right to pass the intersection in East, North, West, and South paths respectively. |

Operating conditions for this 4-way intersection are shown in Table 2 with its specific patterns.

Table 2: Operating conditions of 4-way intersection (time-based system)

| Stage/Sequence | Departure | Direction          | Average Green Light Duration (Observation) |
|----------------|-----------|--------------------|------------------------------------------|
| A              | North     | West, South, East  | 25 seconds                               |
| B              | North     | South              | 65 seconds                               |
|                | South     | North              | 65 seconds                               |
| C              | East      | West, South, North | 98 seconds                               |
| D              | West      | East, North, South | 76 seconds                               |

4. Modified 4-way Continuous Flow Intersection System Modelling

In reducing or mitigating traffic jam, or to overcome power failure at intersection zone, this study will use the optimal configuration of lane closure strategy by completely closing four lanes in the middle of an intersection zone of one road or street (with four lanes, and a divider), diverting all vehicles to the left side of that direction and then detouring some of them by means of U-turn rotation, following the rest of the road and then at the intersection zone, turning to the left to continue their movement in the previous direction. The proposed strategy is shown in Figure 5 and an illustration of Intersection’s lane closure is given in Figure 6.
Figure 5: Proposed Strategy for 4-way Intersection

The flow patterns for this intersection is depicted in Table 3 where there will be no more stages, no more waiting time, and no more stage sequence.

| No. | Departure | Direction | Average Time Duration (in Minutes) |
|-----|-----------|-----------|-----------------------------------|
| 1   | East      | North     | .....                             |
|     |           | West      | .....                             |
|     |           | South     | .....                             |
| 2   | North     | West      | .....                             |
|     |           | South     | .....                             |
|     |           | East      | .....                             |
| 3   | West      | South     | .....                             |
|     |           | East      | .....                             |
|     |           | North     | .....                             |
| 4   | South     | East      | .....                             |
|     |           | North     | .....                             |
|     |           | West      | .....                             |
Figure 6: Illustration of intersection’s lane closure

This proposed model only has 4 variables, i.e. cross EW, cross WE, U-turn WE, and U-turn EW, and there are no resources and queues. Implementation of its model (using Arena software) is depicted in Figure 7.

Figure 7: Module of modified 4-way continuous flow intersection simulation model

5. Control System of the Dynamic Intersection Traffic Control (DITC) Modules

By applying lane closure strategy (Hwang, 2009), continuous flow treatment in intersection zone (Bared, 2005) and the amazing idea to design a reliable intersection traffic control, the signalized intersection can be treated as unsignalized intersection for certain condition. Figure 8 shows the proposed DITC main algorithm which controls its operating condition. The intersection normally is a signalized intersection, but in specific situation when the traffic control system is out of order (control system failure or electrical power supply failure) or when traffic jam occurs at the intersection, then it acts as an unsignalized intersection with special treatments. If the situation goes back to normal again, i.e. traffic control working as usual or the jam was hang loosely, the intersection reverts to a signalized intersection again.
This study focuses on finding and developing a method to reduce or mitigate traffic congestion in a single or isolated signalized intersection. A method is to be developed to interchange the intersection zone condition in which in a temporary situation, it acts as if it is as an unsignalized intersection when traffic jam occurs and if traffic jams flows away, then the control is given back to the signalized traffic control system environment.

6. Conclusion and Future Work

The strategy used in this study is by reducing conflicts through geometric design improvement, operating speeds on approaches, choosing appropriate traffic control, and improving management access by using lane closure (in the middle of the intersection), U-turn, and continuos flow intersection treatment. The proposed DITC system has no waiting time, no phase (stage) movement to follow and has specific configuration when acting as unsignalized intersection. In this study only two lanes are considered, it could be expanded into multi-lane in a future work.

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