Simulating and evaluating an adaptive and integrated traffic lights control system for smart city application

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Abstract. A city could be categorized as a smart city when the information technology has been developed to the point that the administration could sense, understand, and control every resource to serve its people and sustain the development of the city. One of the smart city aspects is transportation and traffic management. This paper presents a research project to design an adaptive traffic lights control system as a part of the smart system for optimizing road utilization and reducing congestion. Research problems presented include: (1) Congestion in one direction toward an intersection due to dynamic traffic condition from time to time during the day, while the timing cycles in traffic lights system are mostly static; (2) No timing synchronization among traffic lights in adjacent intersections that is causing unsteady flows; (3) Difficulties in traffic condition monitoring on the intersection and the lack of facility for remotely controlling traffic lights. In this research, a simulator has been built to model the adaptivity and integration among different traffic lights controllers in adjacent intersections, and a case study consisting of three sets of intersections along Jalan K. H. Hasyim Ashari has been simulated. It can be concluded that timing slots synchronization among traffic lights is crucial for maintaining a steady traffic flow.

Keywords: economic cost of congestion, smart city, smart traffic light control

1. Introduction
The introduction of Indonesia Smart City index in 2015 has created a national standard to measure how major cities in Indonesia are developing, in terms of smart city achievement [1]. A city could be categorized as a smart city when Information Technology (IT) has been developed to the point that the administration could sense, understand, and control every resource to serve its people and sustain the development of the city [1]. Several cities in Indonesia have geared up toward the smart city concept, such as Jakarta Smart City [2], and 98 cities have been surveyed in a national competition including Depok, Bandung, Semarang, Surabaya, and Tangerang as the champions [3].

One of the smart city aspects is transportation and traffic management. As the economic cost of congestion in major cities (Jakarta and Bandung) is estimated as high as IDR 35 trillion (28 trillion in Jakarta and 7 trillion in Bandung) every year [5], a coordinated effort which may alleviate a city’s congestion is deemed necessary, especially in tackling busy and complex intersections at the center of the problem to reduce losses.

One stream of four focuses in Trisakti University’s Research Strategic Plan [4] is “Eco-region” with one of its sub focuses of “City Transportation” covering “infrastructure and transportation as well as transportation integration and economic cost of congestion”. Based on this focus, a research project has been initiated to design an adaptive and integrated traffic lights control system as a part of the
smart system for optimizing road utilization and reducing congestion. Therefore, the purpose of this research is to design a simulator for the traffic lights control system with the adaptivity and integration as its core characteristics.

In each intersection/crossroad, traffic lights are installed to direct all the vehicles going through that intersection from all directions. The purposes of those traffic lights are (1) to prevent accidents from happening, caused by uncoordinated traffics from all directions, and (2) to prevent congestions that might happen because of the substantial number of vehicles or traffic density. Although adequate traffic lights have been installed, heavy congestion may still occur due to the incorrect timing setup compared to the traffic volume at different time of the day, e.g., the duration of green light is too short at busy time yet the traffic is heavy, therefore causing a long queue in one direction, while at vacant time the duration of green light is too long, causing non-optimal utilization of lanes/direction.

Nowadays, to monitor and coordinate traffic in multiple sites of the city, a traffic management center (TMC) has usually been established. The purpose of this TMC is to monitor the controller status in each intersection and is equipped to overwrite the timing cycle in each local controller. Also, to improve the effectiveness and coordination among multiple controllers, TMC can synchronize the timing of nearby controllers in the adjacent intersections [6], [7].

According to the design framework described above, the literature reviews for different controller implementation regarding adaptivity and integration features have been conducted. Several local controller designs using sensors to provide adaptivity [8], [9], [10], [11] equipped with a programmable logic controller (PLC) for a convenient change timing [8], [9], [10] have been implemented. However, they did not provide flexibility for testing out a different configuration of intersections. Several monitoring systems for remote controllers in intersections have been implemented [12], [13]. However, they did not provide synchronization among different local controllers in the adjacent intersections.

2. Research Method

2.1. Research problems, aim, and scope
This study focuses on three (3) research problems as follows: (1) Congestion in one direction due to dynamic traffic conditions from time to time during the day, while the timing cycles in traffic lights system are mostly static; (2) No timing synchronization among traffic lights in adjacent intersections, causing unsteady flows; and (3) Difficulties in traffic condition monitoring on one intersection and the lack of facility for remote controlling of traffic lights.

Specifically, this research aims to build a simulator, combining hardware and software as a tool to assist in the analysis and design process of the traffic lights control system. Thus, all kinds of traffic lights configurations and timings can be simulated before the actual implementation.

This simulator design process follows the system engineering methodology consisting of the following tasks: requirements analysis, design and modelling, implementation, testing and verification, and finally, system deployment. All these tasks can be carried out in multiple cycles (iterations) which produce a gradual progress of completed system. In this paper, the discussion is limited to the first two tasks which are the two dominant stages in producing the simulator: (1) requirement analysis and (2) design and modelling.

2.2. Case study selection
As a case study for simulating adaptivity and coordination among traffic light controllers in adjacent intersections, a series of intersections along Jalan K. H. Hasyim Ashari nearby Trisakti campus in West Jakarta was selected, started from Jalan Gajah Mada to Grogol intersection. A modeled map is presented in Figure 1. This location was chosen based on certain criteria as follows:
1. One intersection along this road has enough complexity for modeling adaptivity in traffic management, i.e. the Cideng intersection which has four directions of traffic.
2. Alongside this road, there is a busway lane that adds one extra traffic to manage which contributes to merging traffic on the flyover bridge which may slow down traffic leaving Roxy intersection.
3. The distance between adjacent intersections (Cideng and Petojo) is relatively short which may need
coordination in case of priority traffic request, e.g., an important government official convoy or emergency vehicles (ambulance, fire department, or police) demanding to travel along without disruption.

4. With this condition, a total deadlock has frequently happened in the intersections along this road especially at Cideng and Petoho during busy hour, caused by static timing (no adaptivity to traffic changes on different time of the day) and uncoordinated traffic light timing (see Point 3) as well as undisciplined drivers who did not want to wait before entering the intersection while traffic was heavy and still stuck in the middle of intersection.

![Figure 1. Modeled map of Jl. KH. Hasyim Ashari from Jl. Gajah Mada to Grogol for simulation purpose.](image)

3. Results and Discussion

3.1. Analysis phase

In the analysis phase, timing sequence analyses of current condition for all traffic lights in each intersection alongside Jl. K. H. Hasyim Ashari were conducted as a basis for local traffic controller design. A sample timing sequence for one intersection is provided in Figure 2.

![Figure 2. Traffic light timing sequence at Cideng intersection](image)
Legend for Figure 2:

MP2 BS, KP2 BS, HP2 BS: Traffic light timing sequence alongside Jl. K. H. Hasyim Ashari from Roxy direction turning to Jl. Cideng Timur.
MP2 BT, KP2 BT, HP2 BT: Traffic light timing sequence alongside Jl. K. H. Hasyim Ashari from Roxy direction straight to Jl. Cideng Timur.
MP1 TB, KP1 TB, HP1 TB: Traffic light timing sequence alongside Jl. K. H. Hasyim Ashari from Jl. Gajah Mada direction straight to Roxy.

For each intersection, currently, there is a local controller in which the sequence can be set and can be over-written manually. The sequence is synchronized to prevent race condition which can cause an accident. Once it is set, the sequence will run automatically, but if a timing change is needed for one lane, for example, it needs to be arranged manually on the spot. There is an indication of timer use for establishing discrepant timing sequence at a different time of the day. However, a manual set up of the operation is still needed whenever there is a new sequence. There are also no functions of synchronizing adjacent controllers, sending new sequence remotely, or automatically detecting current traffic.

Based on this analysis regarding the adaptivity and integration, means to address all these limitations are needed. To be able to provide adaptivity to cater the dynamic traffic change, a traffic sensor is required for detecting traffic changes and determining at what threshold level the sequence needs to be altered. Therefore, a statistical evaluation is necessary to serve as a basis for the dynamic sequence change calculation.

To be able to provide integration among multiple intersections, a centralized controller is required to monitor the status of each intersection and to define which can remotely synchronize and overwrite the sequence in each intersection. An analysis and rearrangement of timing slots in each intersection need to be conducted to attain synchronization among controllers. Several steps of rearrangement that have been carried out in this study are as follows:

1) Combining the timing diagrams of multiple intersections in one place for the ease of rearrangement
2) Identifying continuous timing slots which can be forwarded from an intersection to the next one
3) Rearranging timing slots and relabelling timing variables to facilitate the synchronization
4) Performing the adaptive and synchronized change just by changing one timing variable (the rest of timing slots will alter accordingly, and synchronization could be maintained) once the timing slots are continuous (correspond to counterparts from other intersections or other directions)

The results of this rearrangement are depicted in Figure 3, showing that all corresponding time-slots are put together in the same order and with the same label. Changing one timing sequence, e.g., extending a green light duration in one direction in case of priority traffic, requires only a change of the corresponding variable.

3.2. Design phase

Based on all factors described in the analysis phase, a high-level System Block Diagram with an indication of technological components have been defined as guidance for detailed design as depicted in Figure 4. It shows the role of the central traffic controller which may reside in TMC which can synchronize multiple intersections by sending out synchronizing command based on the synchronized timing diagrams discussed in Section 3.1. It is also capable of sending out those commands remotely through the utilization of Internet of Things (IoT) platform in which every controller is linked to each other in a loosely coupled manner through the Internet.
Figure 3. Integrated and synchronized timing sequence diagram to facilitate synchronization and flexibility of change in the sequence.

Figure 4. High-level system block diagram of an adaptive and integrated traffic lights control system.
4. Conclusion
The high economic cost to solve congestion in critical intersections will lead to the losses in productivity. A case study has been carried out regarding how to tackle frequent congestion due to the complexity of the intersections and uncoordinated traffic lights controllers. Integration and adaptivity among intersections can be facilitated by performing an analysis of the timing diagrams of related intersections as well as a rearrangement of timing slots. This synchronized timing has been simulated in a simulator in this study and can be implemented and deployed in real world scenario.

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