Determination of the Optimum Distance of Continuous Flow Intersection Using Traffic Micro-simulation

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Abstract: Continuous flow intersection is one of the unconventional intersections, which are displaced the right turn bay to the opposite side of the oncoming through traffic called "CFI Leg". The signals at the main intersection and the sub intersection are operated by two-phase fixed time signal controllers with a proper signal coordination to provide smooth traffic flow. The distance between the main intersection and the sub intersection is one of the main factors that influences to the capacity of CFI. Using VISSIM micro simulation, distances between main intersection and sub intersection for different traffic conditions were explained. Specifically, it indicated that more entering intersection traffic volume created more traffic delay at the intersection and that needed more distance on the CFI right turn crossing point from the main intersection. In addition, based on the case study at the Khon Kaen City Gate intersection, it clearly showed that both two – legs and four – legs CFI options are a good solution for traffic congestion relief at this intersection. This therefore needs a further study to solve this issue.

Key Words: CFI Continuous Flow Intersection, Unconventional Intersection, Optimum Length of CFI Leg, VISSIM

1. INTRODUCTION

An unconventional intersection is a solution of traffic congestion at intersections. It aims to avoid conflicting between right – turning and through – straight vehicles at intersections based on the concept of moving or distributing the turning areas of a right-turning vehicle away from the formal point (Hummer, 1998). Various types of unconventional intersections have been introduced, however the mostly accepted and used one is the continuous flow intersection (CFI) (Hildebrand, 2007, Cheong et al., 2008). Research studies indicate that CFI can decrease delays and queue lengths during the evening peak hours at 64% and 61%, respectively (Pitaksringerkar, 2005). The construction and operating costs are two to three times higher than a conventional intersection; however, they are five to six times lower than.
flyovers and tunnels (Grade separation) (Berkowitz et al., 1996). According to these reasons, CFI is therefore proposed as an interim solution to handle congestion problems at intersections before flyovers, tunnels, or interchanges are built in the future (Community Planning Association of Southwest Idaho [COMPASS], 2008).

The unconventional characteristic of CFI is that the right turn bay is moved to the other side of the road, next to the through traffic lanes of the opposite direction (so called ‘living lanes’). The lane of right turn bay is technically called “CFI Leg”, as shown in Figure 1. This means the right-turning vehicle has to cross the living lanes towards the CFI leg at a 100 m distance before the intersection (Pitaksringkarn, 2005). Then drivers can turn right on CFI leg. This new intersecting point is called as a sub-intersection of CFI. Both the main (formal) intersection and the CFI sub-intersection will be monitored by 2-phase compatible regular-cycle traffic lights systems that will allow a continuous flow of traffic at the intersection.

The distance between the main intersection and CFI sub-intersection is an influential variable on the capacity and efficiency of CFI traffic operation. In fact, the distance directly impacts on approaching area surrounding the intersection and also on the cost of construction of CFI. At present, the criteria and instructions in designing this distance are not adequate, with only indications from past research studies for a 100 to 120 m (Berkowitz et al., 1996, Cheong et al., 2008, Community Planning Association of Southwest Idaho [COMPASS], 2008, Hildebrand, 2007, Hummer, 1998, Pitaksringkarn, 2005, Bruce, 2004). Hence, this research is aimed at analyzing and comparing the efficiency of traffic operations of three patterns of CFI with different lengths of CFI legs; namely short, medium, and long in order to determine the distance between the main intersection and CFI sub-intersection based on different conditions of traffic flowing towards the intersection. The outcome of this study will provide some clearer recommendations on the design of the distance between the main intersection and the CFI sub-intersection of each traffic condition towards the intersection and ultimate achievements in the use of CFI, especially in Thailand.

![Figure 1: Intersection Geometry of CFI](image)

2. CONTINUOUS FLOW INTERSECTIONS (CFI)

As mentioned earlier, CFI has been introduced by aiming to reducing the phase number at an intersection. Therefore, right-turning point at an intersection is moved to the left side of the opposite-direction living lanes which make both the through cars and right turning cars
becoming in the same phase whereas the opposite direction ones could be able to move during the green light without any trouble. Both the main intersection and CFI sub-intersection also require only two phases of traffic cycle, resulting in decreased total traffic light cycle. Meanwhile, the green traffic light length at each intersection is extended, speeding up the flow through the intersection and increasing its capacity (Reid, 2004).

The introduction of CFI embedded into the main intersection positively interrupts traffic around the main intersection. Therefore, the design of compatible traffic light cycles at the main intersection and CFI sub-intersection in order to achieve continuous flow of traffic at the intersection is an important factor for the efficiency of CFI traffic operation. Both the main and CFI intersections are controlled by regular-cycle traffic lights. This is because the use of varying cycle traffic lights with CFI will not reduce the slowness at an intersection during the rush hour, but will increase it at 24% (Pitaksringkarn, 2008).

In operation process, right turning of cars at a CFI can be operated in three steps as follows:

- Moving into the slow lane and pausing before making the right turn at the sub-intersection. This has to be done if there is the red light.
- Crossing the opposite straight lanes and entering the CFI leg under the green light. This will not be long after the straight and right-turning cars on the cross street get the green light.
- Moving on the CFI leg towards the main intersection. If the traffic light is green, the car is able to turn right without any more pausing.

Figure 2 shows a concept of the Continuous Flow Intersection on the north-south direction (on Street B) considering a right-hand side driving only.

![Figure 2: Concept of Continuous Flow Intersection on North-South Direction or on Street B (Right Hand Side Driving)](image)

3. TRAFFIC MICRO - SIMULATION

Traffic micro-simulation is a simulation of dynamic and stochastic moving characteristics of an individual vehicle in the transportation network. It is based on the information related to the vehicle, basic laws of moving (e.g., speed x time = distance), and laws governing driving behaviors of the driver, e.g. the car-following rules and lane-changing rules stipulated for each individual vehicle before entering the system (California Department of Transportation [Caltrans], 2002).
Advanced computerized technology at present has led to development of a number of highly accurate traffic micro-simulation software programs with different objectives. The famous and widely used programs are CORSIM PARAMICS and VISSIM (Transport for London, 2003, Choa et al., 2003). However, VISSIM is accepted as a program suitable for developing micro simulation of transportation infrastructures as well as complex geometrical traffic (Choa et al., 2003). Furthermore, VISSIM can appropriately and accurately simulate traffic behaviors of motorcycles and bicycles (Matsuhashi et al., 2005, Elshafei, 2006). Thus, VISSIM was selected as the tool to develop traffic micro simulation of this research.

4. METHODOLOGY

4.1 Model Design

In order to develop Continuous Flow Intersection, CFI, not only case study is considered, but also VISSIM, one of micro traffic simulation software, will be used a tool in developing for making decisions in alternatives. In this research, the case study was selected from intersections in urban and sub-urban areas where the number and directions of traffic lanes matched the designed CFI, and where there is a tendency to be developed to flyovers or tunnels in the future. Following sections will describe in details of model developing in this research.

4.1 Conceptual design and CFI existing traffic conditions

The procedures involved in this step comprised:

- CFI traffic efficiency would indicate the influence occurred from the distances between the main intersection and sub-intersection only. Indeed, consideration of the distances could be divided into two parts; (1) the distance from the center of the main intersection to the stopping line on the CFI leg and the distance from the center of the sub-intersection to the starting point of the through lane of the CFI, both of which were constant, and (2) the length of the CFI leg, which varied with the traffic patterns, physical characteristics, and land use pattern of the ground around the CFI leg; therefore, this research applied the CFI leg’s length as the variable value in the design.
- To avoid influence from the difference of the traffic pattern, traffic conditions are similarly simulated on all intersection legs in order to test the efficiency of CFI traffic operations. The test began when the traffic was light and was increasingly dense until it exceeded the capacity of the joint. The test was conducted on all cases of right turning, i.e., when there were not many right turns, when they were balanced and when there were a lot of right turns.

4.2 Developing the traffic micro simulation

The simulation consisted of three steps:

- Building an intersection in the simulation model, by adding links and connectors of each of the intersection leg and compiling them into an intersection in the model.
- Calibrating the simulation by adjusting the values of vehicles in the simulated traffic so that they were the same as the developed traffic micro simulation. This enabled us to develop the micro simulation model according to the traffic engineering principle and similar to the actual traffic operation.
Validating of the simulation, seeing that the objectives were right, in order to reaffirm the accuracy of the developed simulation. The procedures and methods were the same as in the calibration step but with a new set of data.

4.3 Designing and analyzing the most appropriate traffic signal cycles of CFI for each traffic condition

This research employed the Synchro 6, a program based on Highway Capacity Manual, to analyze the cycle length of traffic light and offset in the optimum coordination for the intersection. Synchro 6 is the most effective tool for the design and analysis of traffic lights of CFI of each traffic condition. The steps involved consisted of:

4.4 Analysis of the optimum distance between main intersection and sub-intersection for CFI

The analysis of the optimum distance from the main and sub intersection of CFI was based on the least required length, the real CFI leg length and the level of service of the intersection as the criteria. The optimum pattern is when CFI with the least required length shorter than or equal to the real length is closest to the real length of the CFI leg from the group of CFI with the highest LOS at the intersection. The shortest length of required CFI leg is 2.5 times greater than the length of the waiting lane (Florida Department of Transportation, 2007) of the right-turning vehicles at the main intersection or of the straight vehicles at the sub-intersection, based on the higher values as the computation representative.

4.5 Application of the research results to recommend the solution to traffic problems in the studied sites

This step involved the application of knowledge from the research to design suitable CFI for the traffic pattern, physical characteristics and land use pattern in the area surrounding the junction of the studied site. This is in turn used as the recommendation for solution in the studied area.

5. RESEARCH RESULTS AND DISCUSSION

5.1 The mostly applied CFI pattern

The study of CFI geometry shows that (1) CFI was mostly applied on the intersection where the major arterial crossed the minor arterial in a 2-legged pattern. The CFI on the major arterial with the left-turn traffic/straight traffic/right-turn traffic on the junction leg were 1/3/2 and 1/2/2, (2) The flow of the right-turning vehicles took the pattern of the right-turning car from the CFI leg turn into the straight lanes of the cross street, (3) the mostly applied length of CFI leg was 100 m. The least and the greatest applied lengths used were 50 and 260 m respectively, and (4) The length of the slowdown and waiting lane at the sub-intersection was between 1.2 to 1.3 times more than the length of CFI leg.

5.2 Concept and CFI traffic test condition

The CFI concept used in this research was a 4-legged CFI with 1/3/2 lanes of left-turning/straight/right-turning vehicles on the junction leg. Eight patterns were designed consisting of CFI-30 (where the 30 is the length of CFI leg and is the shortest length of the pocket lane for
turning recommended by the Highway Department, Thailand), CFI-60, CFI-90, CFI-120, CFI-150, CFI-180, CFI-210, and CFI-240). Examples of the designed CFIs are shown in Figure 2.

The testing traffic condition began when the traffic on each lane leg measured 500 PCU/h, and increased at 500 PCU/h each time until it exceeded the capacity of the intersection. The proportion of the traffic amount on each intersection was considered from the proportion of the lanes of each direction on the joint legs. Three different cases were involved: (1) the case where right-turning cars were not many. This means the percentage of left-turning cars/ straight cars/ right-turning cars were 10/65/25, (2) a balanced case of 10/60/30, and (3) the case where there were many right-turning cars, or 10/55/35.

Figure 3: CFI – 90

5.3 Study area

From the study conducted on the construction of flyover bridges and tunnels at intersections of the Bridge Construction Office, Royal Highway Department, there were two construction projects on road crossing tunnels on Mitraparp Highway, namely, Nakhon Ratchasima Junction and Khon Kaen Sam Liam. The researcher therefore carried out a preliminary physical survey of the intersections on the Mitraparp highway adjacent to both projects. It was found that at Khon Kaen City Gate, the number of traffic lanes on the legs of the intersection towards the north was equal to the designed CFI. In addition, at Quadrant 1 of the intersection, the Central Plaza construction project was ongoing, which means a greater amount of traffic towards the city gate. This would in turn cause traffic problems here. Thus, Khon Kaen City Gate intersection was selected as the study site.
Regarding the pedestrian traffic issues at the CFI intersection, it is understood that the pedestrian traffic would not be included in the analysis model. This is due to the reason that the Royal Thai Government will always construct a pedestrian bridge at a major intersection when high demand of pedestrian traffic occurs at this intersection. This then will not affect the traffic operation of the CFI intersection.

5.4 Calibration and validation of the traffic micro simulation at Khon Kaen City Gate intersection

Calibration of the simulation was based on the trial and error method in order to adjust the variables in terms of behaviors of drivers (Behavior parameters). This was carried out in order to obtain the difference between the surveyed results and simulation in the criteria accepted for calibration and validation of micro-simulation as recommended by Wisconsin Department of transportation and California Department of transportation (Choa et al., 2003, California Department of Transportation [Caltrans], 2002) respectively.

This research used as the indicators the traffic volume and the average queue length in the evening rush hours, which were used to calibrate the surveyed results and the simulated results as shown in Table 1. This is based a traffic micro simulation model run of 10 times to ensure the accuracy of the model.

<table>
<thead>
<tr>
<th>Intersection Leg</th>
<th>Criteria Threshold</th>
<th>% Met Target</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitraphap SB</td>
<td>Within 5%</td>
<td>0.07%</td>
<td>Pass</td>
</tr>
<tr>
<td>Mitraphap NB</td>
<td>Within 5%</td>
<td>-0.36%</td>
<td>Pass</td>
</tr>
<tr>
<td>Si-Chan WB</td>
<td>Within 5%</td>
<td>0.38%</td>
<td>Pass</td>
</tr>
<tr>
<td>Si-Chan EB</td>
<td>Within 5%</td>
<td>0.69%</td>
<td>Pass</td>
</tr>
<tr>
<td>Overall</td>
<td>Within 5%</td>
<td>0.08%</td>
<td>Pass</td>
</tr>
</tbody>
</table>

Geoffrey E. Havers [GEH] Statistic
Validation of the simulation was conducted using the traffic volume and the average queue length in the morning peak hours and during non-peak hours as indicators. The surveyed and simulated results were then compared. In terms of traffic volume, the indicators all passed the criteria (100%). With respect to the comparison of the queue length as shown in Figure 5, five indicators passed the criteria from six data compared, or 83.3% (not taking into account the lanes on Srichan Road towards the west), where the behavior parameters were different from other intersection legs. However, the data not passing the criteria of validation was the data related to the lanes from Mitraparp intersection towards the south, which were not CFI representatives. Therefore, it could be said that the designed traffic micro simulation of Khon Kaen city gate intersection was accurate and could be applied in the analysis of the efficiency of CFI traffic operation studied here.

![Figure 5: Comparison between VISSIM results and 2004 survey data](image)

### 5.5 Optimum distance between the main intersection and sub-intersection of CFI for different traffic conditions

The most appropriate distance between the main intersection and sub-intersection of CFI for each traffic condition is shown in Figure 6. Average delays shown in this figure have been measured from the micro simulation model based on the difference between the desire travel time and the actual travel time measured from each vehicle running in the model. Then the model calculates vehicle average delay from the total vehicles running in the model.
5.6 Application of CFI at Khon Kaen city gate intersection

CFI at Khon Kaen city gate intersection was applied for both in the 2-legged CFI pattern (Figure 7) and 4-legged CFI (Figure 8 and Figure 9 for more details). The designed lengths of the CFI leg on Mitraparp and Srichan roads were 150 and 90 m. due to the limited length of lanes of the intersection leg on Srichan road towards the west.

The average delay of the alternatives for improving Khon Kaen city gate intersection, both for the traffic condition with and without the Central Plaza mall is shown in Figure 10. The alternative waiting lanes for improving Khon Kaen city gate intersection, in the case of traffic condition with the Central Plaza mall is shown in Figures 11-13.
Figure 7: Two – Legs CFI at Khon Kaen City Gate intersection

Figure 8: Four – Legs CFI at Khon Kaen City Gate intersection
Figure 9: Detail of CFI design at Khon Kaen City Gate intersection

Figure 10: Average delay for 2 – legs and 4 – legs CFI at Khon Kaen City Gate intersection (with and without Central Khon Kaen Plaza)

Figure 11: Delay from VISSIM at Khon Kaen City Gate intersection (Without Central Khon Kaen Plaza)
6. CONCLUSION AND RECOMMENDATIONS

From the evaluation and prioritization of each traffic condition towards the CFI intersection with the traffic lanes of left-turning vehicles/straight vehicles/right-turning vehicles of 1/3/2 and with different CFI leg lengths, it was found that the recommended shortest CFI length is 60 m. With this length the amount of traffic capacity on the intersection leg was 2,500 PCU/h at the LOS C and the condition of great number of right-turning vehicles. With the condition of a few right-turning vehicles, the capacity of the intersection leg was 3,000 PCU/h at the LOS C and the recommended most appropriate CFI length. In the case where there was no limitation of the length of road, and where land use on the border was 150 m the traffic capacity was 3,500 PCU/h at LOS D and E for the case with not many right-turning vehicles and many right-turning vehicles, respectively. With the condition of balanced left-straight-right turns, the traffic capacity was 4,000 PCU/h with an average delay at the intersection of 107.2 seconds per vehicle at LOS F. Meanwhile, the conventional intersection with the same size could only accommodate 1,750 cars per hour (Community Planning Association of Southwest Idaho [COMPASS], 2008). Therefore, the application of CFI with CFI legs of 60 and 150 m on the intersection legs having 1/3/2 left-turning/straight/right-turning lanes means that the capacity of the intersection legs can be extended from 43 to 71% and 100 to 129%,
respectively. The application of 2-legged CFI on Mitraparp intersection could reduce the average delay of Khon Kaen City Gate intersection at 42.8 and 69.4 %, respectively for with and without Central Plaza mall at LOS C and D respectively. The application of 4-legged CFI could speed the average delay both of with and without Central Plaza mall at 60.8 and 80.3%, respectively, for LOS C. However, the use of 4-legged CFI means higher cost than 2-legged CFI, and also accessibility to the surrounding areas became also more difficult. The 4 –legs one would not be suitable for the land use patterns on the intersection leg of Srichan towards the west, which consists of the Central Plaza and a public park. This research therefore recommends the use of 2-legged CFI on the intersection leg of Mitraparp Road as a means to increase the efficiency of traffic utilization of Khon Kaen city gate intersection before developing a different level interchanges of a flyover bridge or underpass in the future. Nevertheless, before using the CFI, a study should be conducted on the safety of road users, since CFI is a new type of intersection which is not common to road users and may lead to danger.

In addition, traffic accessibility issues due to the CFI design concept still needs to be considered and solved at this intersection if implemented. It therefore needs a further study to solve this issue.

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