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Application of a Knowledge-Based Expert System for Intersection Improvement

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***Abstract*— The KBES developed is a menu-driven type using open source programs with three very important web development tools: The Apache for web server, MySQL for database management, and PHP (Hypertext Preprocessor) for scripting "C" program language. The system guides the user in selecting exact location of congestion or road crash prone areas through an interface. The user deals with series of questions in identifying the cause of the problem which leads to potential traffic control alternative solutions. The KBES was tested at two local isolated intersections in Quezon City, Philippines for validation. The intersections validated are signalized and unsignalized three-legged intersections. The KBES recommendation for the signalized intersection is to increase right turning radius of the corner pavement for trucks to avoid conflict and delay with other vehicles. For the unsignalized intersection, KBES recommended a left turn prohibition at major approach to avoid delay and collisions at such approach.**

Keywords*— *Knowledge-Based Expert System, Traffic Congestion, Traffic Accident, Intersection

1. BACKGROUND OF THE STUDY

Traffic congestion, as well as traffic accidents, is an ensuing problem that usually occurs in fast-growing cities like Metro Manila and Baguio City due to the constant mobility of people and goods. With the increase of automobile usage each year, an evaluation of this demand is needed in order to balance the capacity of urban road as well as rural road networks. Thus, traffic alleviation and road safety programs are now properly implemented for present and future scenarios. To put this program into reality, a methodology for traffic management must be developed. Expert systems offer a practical means to assess traffic conditions so as not to waste resources (i.e. time, mobility and money) and eventually save lives and properties.

Different kinds of traffic simulation software were developed the past years. A software has the capability to simulate traffic situations and validate (and if necessary, modify) if the traffic control used is appropriate. However, other real-life problems in an intersection such as parking, loading and unloading of passengers, street vendors encroaching on sidewalks, etc. cannot be simulated in the software. Traffic accidents such as vehicle collisions were also not included in the simulation scenario. Another disadvantage of using simulation software is that users are assumed to have a thorough knowledge of traffic engineering concepts as well as computer skills in order to calibrate and validate the system to local conditions. Otherwise, users undergo training for software use and this poses an additional expenditure. Simulation software is also expensive with restrictive license. While it is worthwhile to study intersections with traffic congestion and traffic accidents occurrence and how to alleviate these problems, the calibration and validation of software are tedious and time consuming.

1.1 Objectives

The objectives of this study are the following:

a.) To apply the Knowledge-Based Expert System (KBES) to diagnose traffic congestion and accident problems within an intersection and apply corrective strategies with potential traffic control alternatives.

b.) To illustrate how the Expert System will show the best possible alternative solutions to ensure an efficient traffic congestion and accident control alternative for the intersection.

c.) To cross-classify studies on the potential alternatives between congestion and accidents on which is to prioritize in terms of finalization in the event that both problems occurred in the intersection.

d.) To test pilot the expert system to local intersections.

1.2 Scope and Limitations

Intersections will be the focal point of this study since it has a higher collision rate and causes more delay than mid-block segments [1]. In addition, the following are the scope and limitations set forth for this study:

a.) It is assumed that the user is knowledgeable on basic intersection-related problems upon observing congestion and accident location patterns based on pre-evaluation diagrams as well as historical data;

b.) Vehicle malfunction will not be considered in the study as a result to movement delays;

c.) Grade-separated intersections and work-zone related intersections are not considered in the study; Highway Capacity Manual (HCM, 2000), Akcelik method, and other traffic engineering concepts will be incorporated to further enhance the accuracy of the selection process;

d.) The study deals with 4-legged, T-intersections and skewed intersections; and The KBES will show screened summary of potential alternatives. The task for selecting the best alternative/s is given to traffic engineers and planners as users to have the final judgment regarding the traffic control solution as suggested by the KBES.

1.3 Significance of the Study

Ill-structured problems are real-world problems such as designing an optimal transit route structure, rehabilitating a major highway, repairing a retaining wall, etc. Generally, there are experts in every field who are well-experienced and knowledgeable to solve these ill-structured problems. The transportation field is mostly concerned with problems where human behavior, social and political considerations and decision-making are involved. Thus, basic transportation-related problems that are worth exploring will be traffic congestion and traffic accident problems specifically in intersections. The data needed for the solution of the problem do not only include engineering concepts but environmental factors, geometric properties, obstructions, etc. To solve this, the knowledge of experts from different traffic engineering practices will be incorporated as a database of solutions since derivation of past experience and theoretical concepts can be utilized for solving ill structured problems.

The formulation of a diagnostic methodology like a Knowledge-Based Expert System (KBES) for alleviating traffic congestion and traffic accidents is a probable answer to both problems. It is a simplified system wherein the occurrence of these problems can be worked out with a research of countermeasures that were provided by experts on well-documented traffic engineering references in the past years. Collecting the ideas of the experts can be transformed into a computer-based knowledge system that end-users can consult on. Using the physician-patient analogy, the problem is similar to a person who is being diagnosed by a physician of a certain kind of sickness that is yet to be identified. The physician now asks the patient series of questions that may lead to a conclusion on the patient's probable sickness. Accordingly, the Expert System in a form of a computer program will now ask the user series of questions that may lead to the most practical solution in alleviating traffic congestion and reducing if not eliminating accidents. The computer program was based on KBES, which is a collection of Artificial Intelligence (AI) techniques that enable a computer to assist people in analyzing specialized problems. A KBES provides human expertise through both the knowledge in engineering language and the program-supporting environment. The KBES will be beneficial to traffic and transportation professionals, local government units as well as civil engineering students for a more viable decision making on the selection of traffic and accident control alternatives as shown in Figure 1.

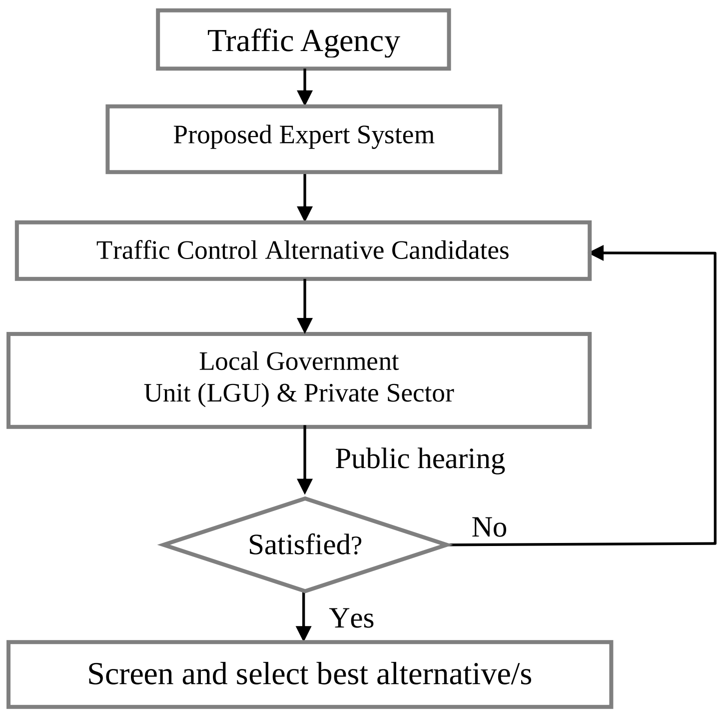

Figure 1. Proposed Expert System for Decision Making

2. REVIEW OF RELATED LITERATURE

In the mid-1970s one of the most significant accomplishments in the field of artificial intelligence (AI) has been the development of the Knowledge Based Expert Systems (KBES). These systems are interactive computer programs that employ a collection of judgment, experience, rules of thumb, intuition, and other expertise in a particular field, coupled with inferential methods of applying this knowledge, to provide expert advice on the variety of tasks according to Gevarter [2].

Knowledge-Based Expert Systems provides human expertise through both engineering-knowledge language and the program-supporting environment [3]. The AI/KBES application requires development of a generalized knowledge base that permits traffic engineers to interact with the following components: the traffic characteristic data, the theoretical or simulation results, and the specific hypothesis for measuring the effects of traffic control measures. KBES has high potential for solving problems that lack explicit algorithms (e.g., problems for which a numerical model does not exist). According to Edmon Chin-Ping Chang [4], "The structured guidelines for traffic engineering problems are suitable for KBES applications because explicit algorithms do not exist and the traditional programs can provide only restricted problem-solving capability."

A text graph is shown in Figure 2 to summarize past studies from 1983 to 2006. The first phase of the development of the expert system in transportation from 1983 to 1986 dealt with the maintenance, scheduling and traffic control on some aspects of transportation modes such as the locomotive trains, space shuttles, and airplanes. Other developments are the design of noise barriers, traffic signal setting assistance, post-disaster traffic recovery strategies, and traffic network design. It is observed that in the first phase, the traffic network design leads to the development of an expert system in alleviating traffic congestion. In the second phase, intersection improvements start the development of left turn signal treatment and intersection design which are both essential in congestion alleviation. The third phase of the development of the expert system for transportation is focused on measures of performance and traffic congestion engineering evaluation particularly at intersections with the development of the HCS (Highway Capacity Software), IDRM, and SIDRA. A study was made by Yeh, Ritchie, and Schneider [5] entitled "Potential Applications of Knowledge-Based Expert Systems in Transportation Planning and Engineering." Their significant suggestions include the development of an expert system for both traffic congestion diagnosis and road safety diagnosis Traffic congestion is highly dependent on a variety of factors such as physical, environmental, operational, geometric, land use, human, etc. Hence, a series of traffic engineering experts would be needed to diagnose the problem but they are scarce and expensive for consultation. Road safety is an important issue since accidents are caused by poor design. It is not possible, in practice, for every accident to be reviewed by an expert. Past studies were not able to develop an expert system for traffic congestion with traffic accident problems particularly on an intersection. The study by Yeh, Ritchie, and Schneider [5] suggested traffic congestion diagnosis and road safety diagnosis expert system. But it would be more significant if we combine traffic congestion and road safety diagnosis especially at intersections where congestion and accidents are inevitable. The expert system is intended for improving intersections at minimal level in terms of resources and efficiency. The expert system will also provide a systematic user-friendly procedure for a more viable accurate decision-making.

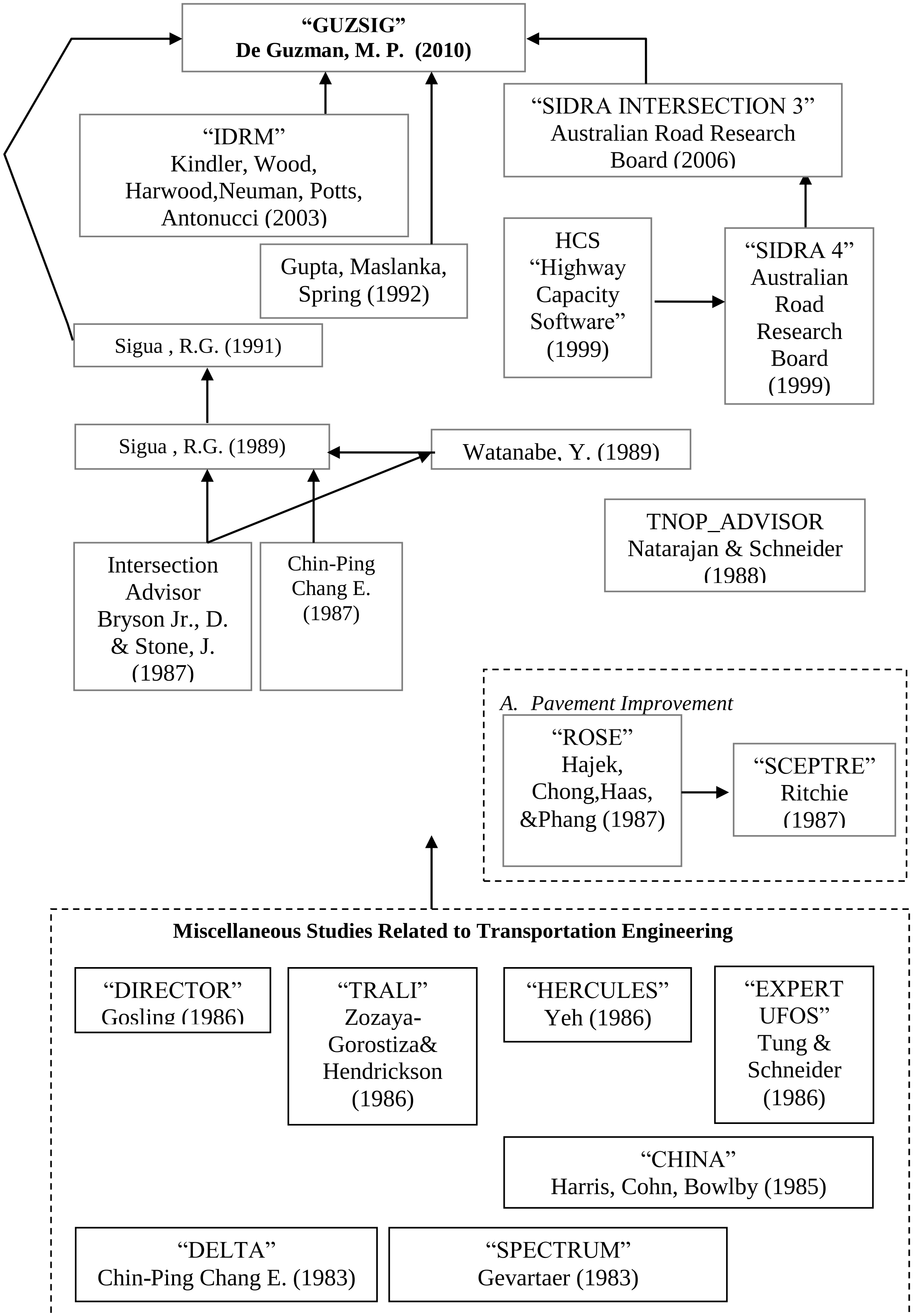

Figure 2. Review of Studies on Expert System in Transportation Engineering

3. FRAMEWORK OF THE STUDY

In this study, the expert system developed will investigate the relationship between traffic congestion vis-à-vis traffic accidents on intersection improvement that is not studied at present. The intersection to be observed and investigated will cover all traffic congestion problems and traffic accident incidents that took place. Traffic control measures will now be analyzed by using rules for inferencing by forward chaining to achieve potential alternatives. The general framework is shown in Figure 3.1.

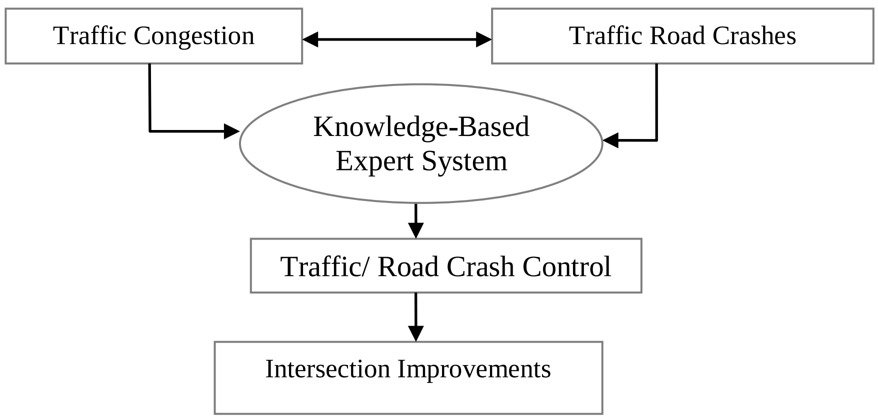

Figure 3. Framework of Proposed Expert System

3.1 Hierarchy of Solutions

Traffic control measures will be in the form of hierarchy of solutions as follows: (i) Operational solution, (ii) Geometric modifications, and (iii) Enforcement.solution

3.1.1 Operational solution

Operational solution consists of the following procedures such as modification of signal timing-cycle length, green split, or phasing. This also includes removing sight obstructions that may cause accidents to drivers, overlaying slippery pavements, etc. It entails the priority of all solutions since it is easy to manipulate and lesser monetary cost is achieved.

3.1.2 Geometric modification

Geometric modification involves the following strategies such as the utilization of the median to provide an additional bay for right left turn traffic, providing right turn lanes, increasing right turn radius, channelizing intersections, adding extra lanes, constructing flyovers, etc. This solution is the most expensive of all the three solutions.

3.1.3 Enforcement

Enforcement solution considers measures such as parking and waiting prohibitions, turning regulations, speed limits, installing barriers for unloading zones, installing barriers for non-pedestrian crosswalks, etc. This may not be appealing to drivers and pedestrians since they are compelled to follow regulations. To incorporate these hierarchies of solutions in the general framework of Figure 3, a conceptual framework is shown in Figure 4.

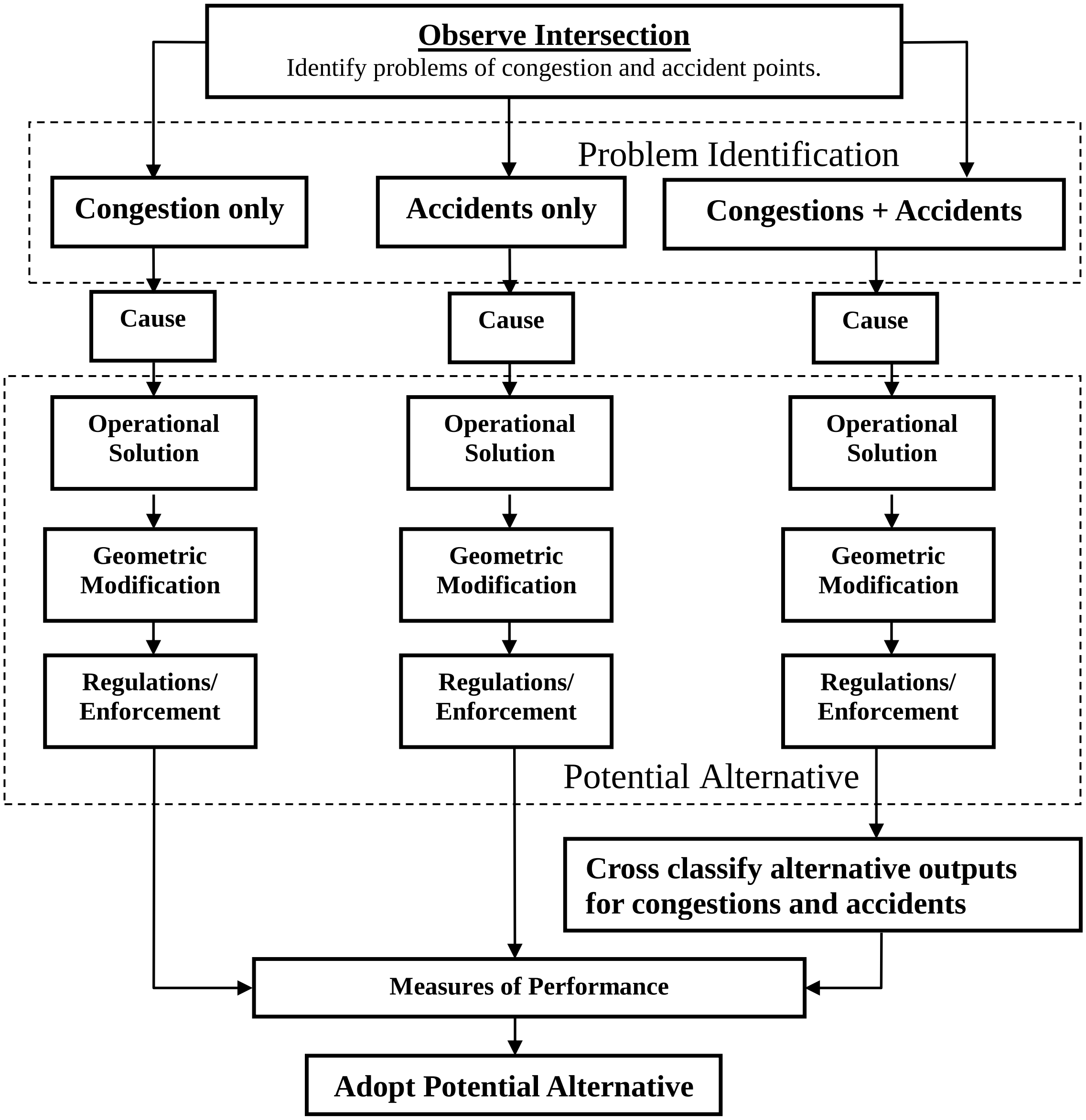

Figure 4. Conceptual Framework

3. APPLICATION OF KBES TO INTERSECTIONS

University Avenue-C.P. Garcia Avenue intersection and C.P. Garcia Avenue-Maginhawa St. are analyzed using the expert system as shown in Figure 5. The distance between the two intersections is approximately 0.87 kilometers. The intersections are categorized as suburban area. It is noted that these intersections are not linked to each other since the route for right-turning vehicles from University Avenue towards the Maginhawa St. intersection is continuous with reference to RTOR (Right-turn on Red) principle. Likewise, left-turning vehicles with signal phasing merging with RTOR (Right Turn On Red) are minimal from University Campus proceeding to Maginhawa St. intersection. The problem is on C.P. Garcia-Maginhawa St. intersection itself because of the gridlock and road capacity problem.

Adopting the procedure suggested by NCHRP Report No. 457 (Bonesson and Fontaine [1]) in improving intersections may possibly cause comprehension difficulties for the user. d. Moreover, copies of the report are limited but it can be downloaded online. The user must be well familiarized with the guidelines by repeated evaluation of the article to understand how the procedure is executed. The user also needs to see other references suggested by the NCHRP Report No. 457 for other solutions to the problem. The aid of the KBES eliminates these types of problems and makes the procedure user friendly. It analyzes the intersection whether the selected alternative is warranted or not. The user can also test an alternative if it is geometrically viable on the intersection. Table 1 shows a description of the intersections to be analyzed for validation.

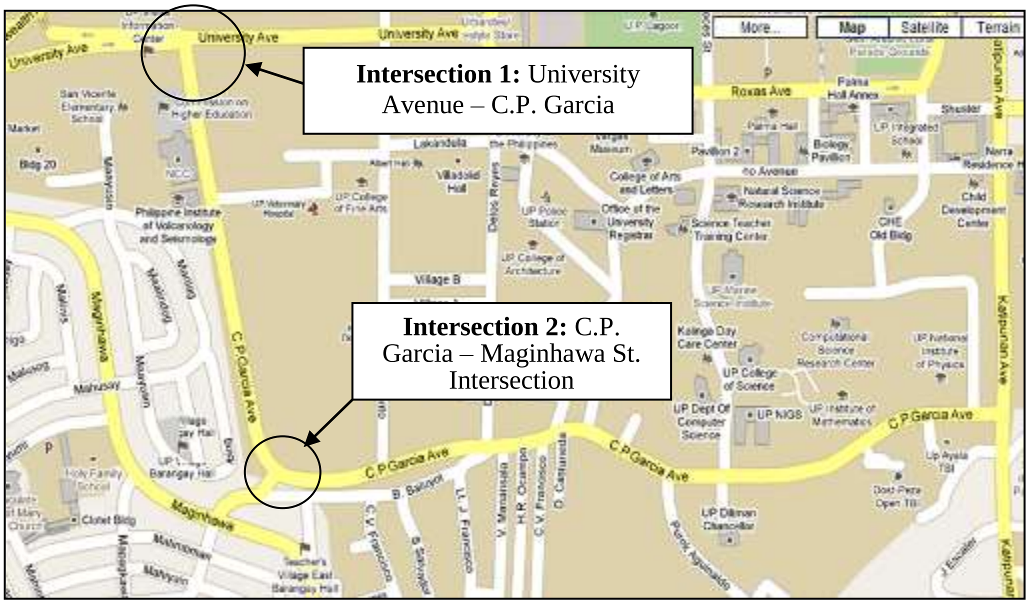

Figure 5. Survey intersection (Google Map 2010)

Table 1 Description of problem intersections

Intersection No.	Type of Control	Intersection Type	Intersection Classification	Problem	Problem Cause
1 (Local)	Signalized: Traffic signal control	T-Intersection	Isolated: Suburban	Delay and conflict of right-turning vehicles on major approach	High percentage of right-turning vehicles from major arterial to minor road.
				Delay of vehicles on minor approach	High percentage of left-turning vehicles from minor road to major arterial road.
2 (Local)	Unsignalized : Flashing beacon	T-Intersection	Isolated: Suburban	- Delay of vehicles on all approaches - Right angle collisions	High percentage of left-turning vehicles from major road

4.1 Intersection 1: University Ave- C.P. Garcia Ave intersection

Figure 6 shows geometric measurements and features of the intersection. CP Garcia approach originally has two lanes approximately 5.5 meters each but with high percentage of left-turning vehicles from C.P. Garcia going to Commonwealth Avenue via University Avenue, the approach lane was divided into three. The outer lane approach was converted to a shared lane of 3.40 meters while the inner lane approach was converted to an exclusive left-turn lane. The number of pedestrians crossing C.P. Garcia approach was very minimal. The amount of non-stop right-turning vehicles is tremendous which could even make it difficult for a pedestrian to cross.

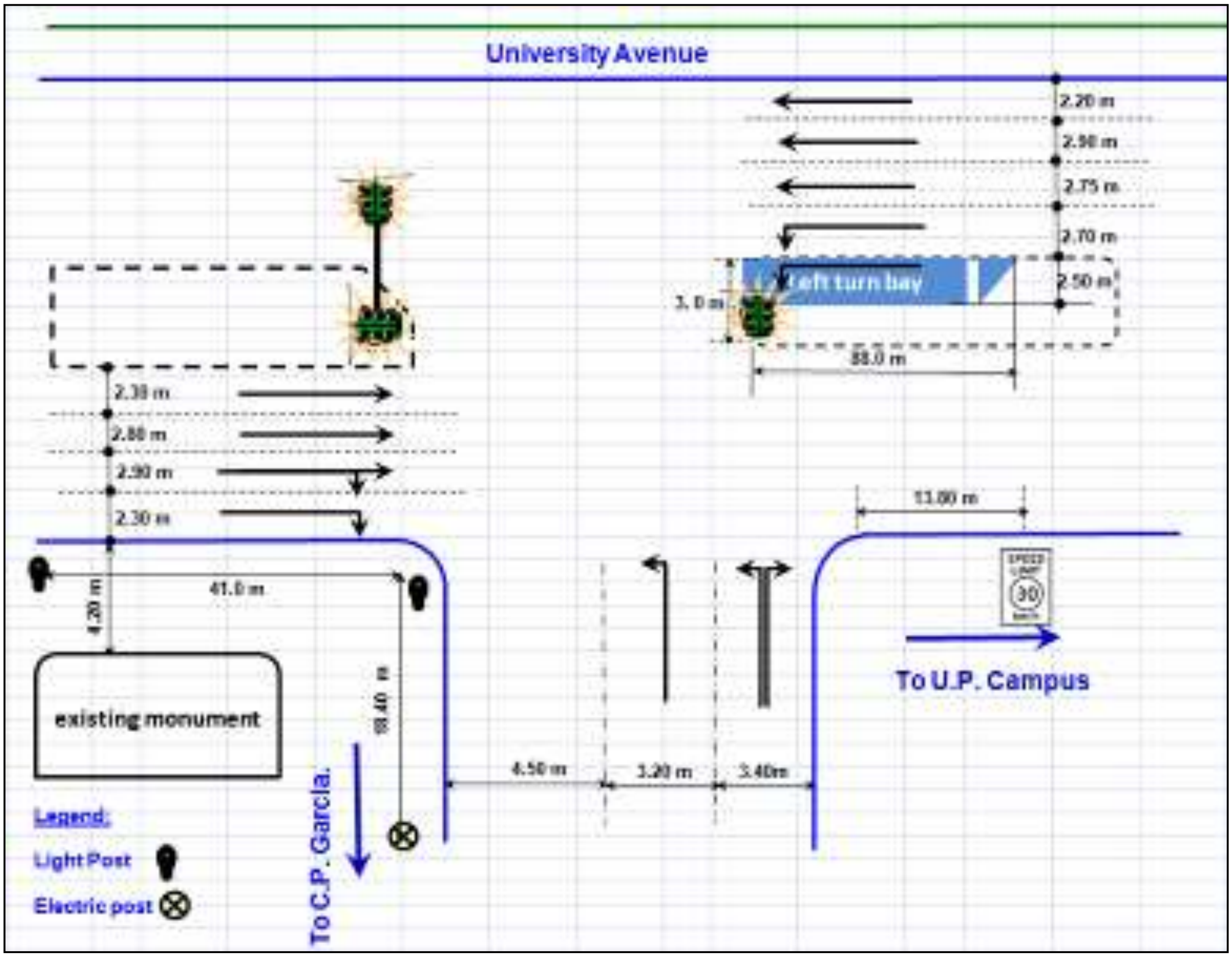

Figure 6. Geometric features of the intersection

Moreover, delay usually took place for right-turning movement because of too much right-turning volume that created diverging conflict with through movements and merging conflict with left-turning movements that created possible road crashes as shown in Figure 7. To solve this possible road crash conflict, the KBES road crash interface is used.

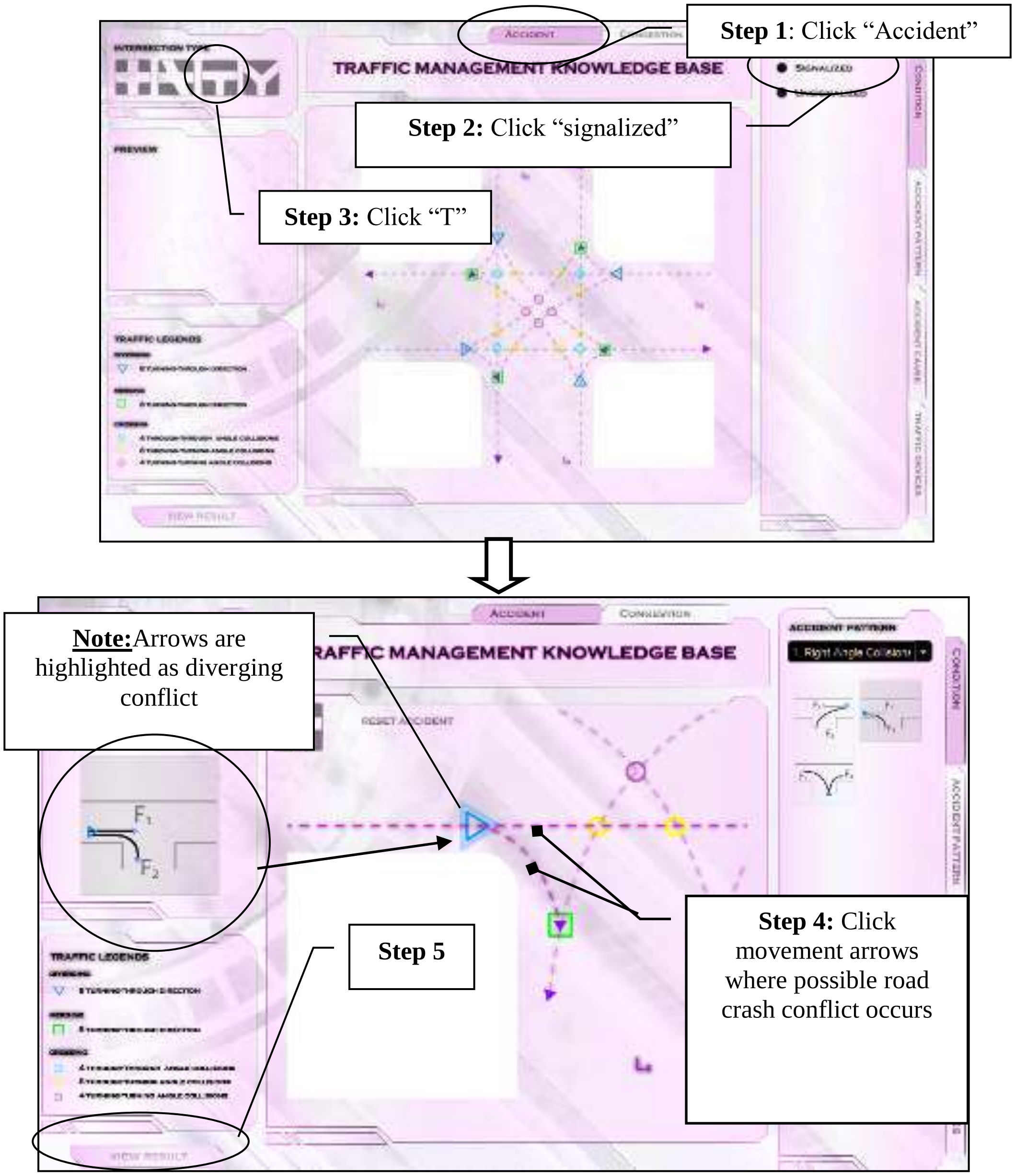

Figure 7. Possible road crash conflicts

Problem identification using road crash analysis at diverging conflict

Click step 5 "view result" will lead us to the next interface titled "POSSIBLE CAUSE" as shown in Figure 8. Selecting "Large turn volumes" will lead to possible solutions. There are two possible solutions namely "providing right turn lane" and "increasing right turn radius." The KBES recommendation is to provide a right turn lane. A right-turn lane that is excessively long may be mistaken by the driver as a "through" lane. A dividing length to a double right-turn lane of 94 meters is not also possible since it is still quite long and receiving lane at minor approach has one lane only. Thus, a right-turn lane is not possible. The other solution is increasing the right turn radius. The existing radius is 8 meters as shown in Figure 9.

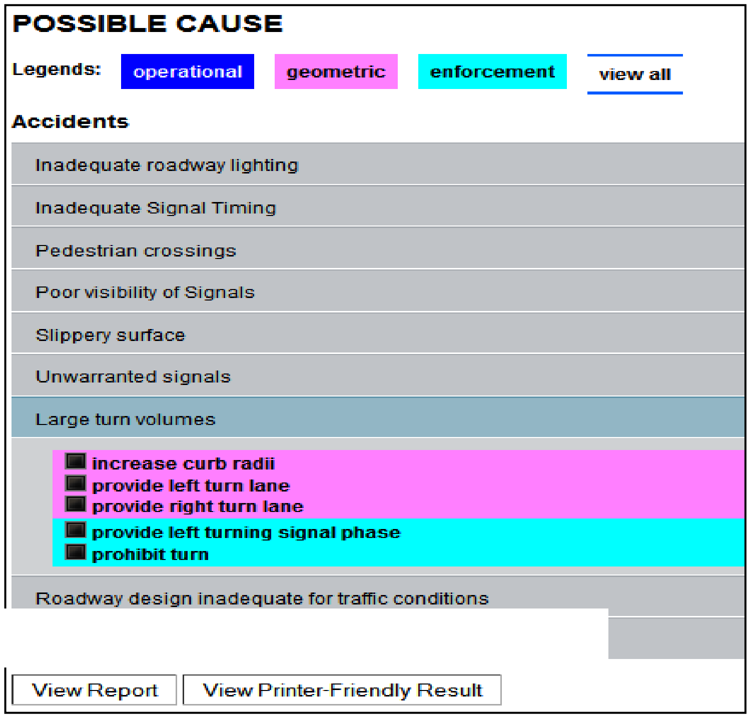

Figure 8. Interface selection

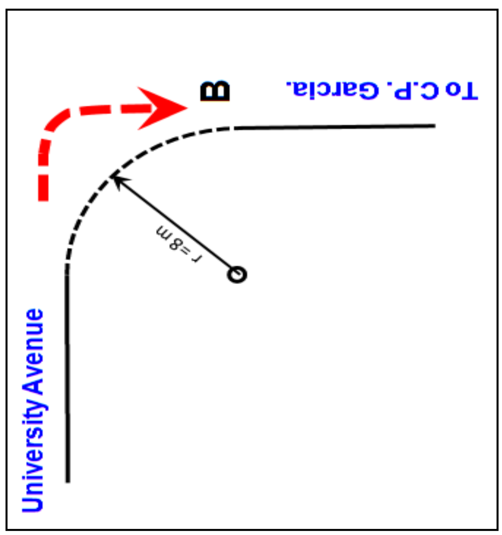

Figure 9. Existing turning radius

After selecting "increase curb radii," enter the peak number of trucks in an hour. Note that recommendation from the number of trucks maneuvering a right-turn requires a maximum radius of 15 m. The shaded area is removed to pave way for the proposed turning radius at 15 meters as shown in Figure 10. Thus, a right turning radius equal to 15 meters is proposed for the major approach.

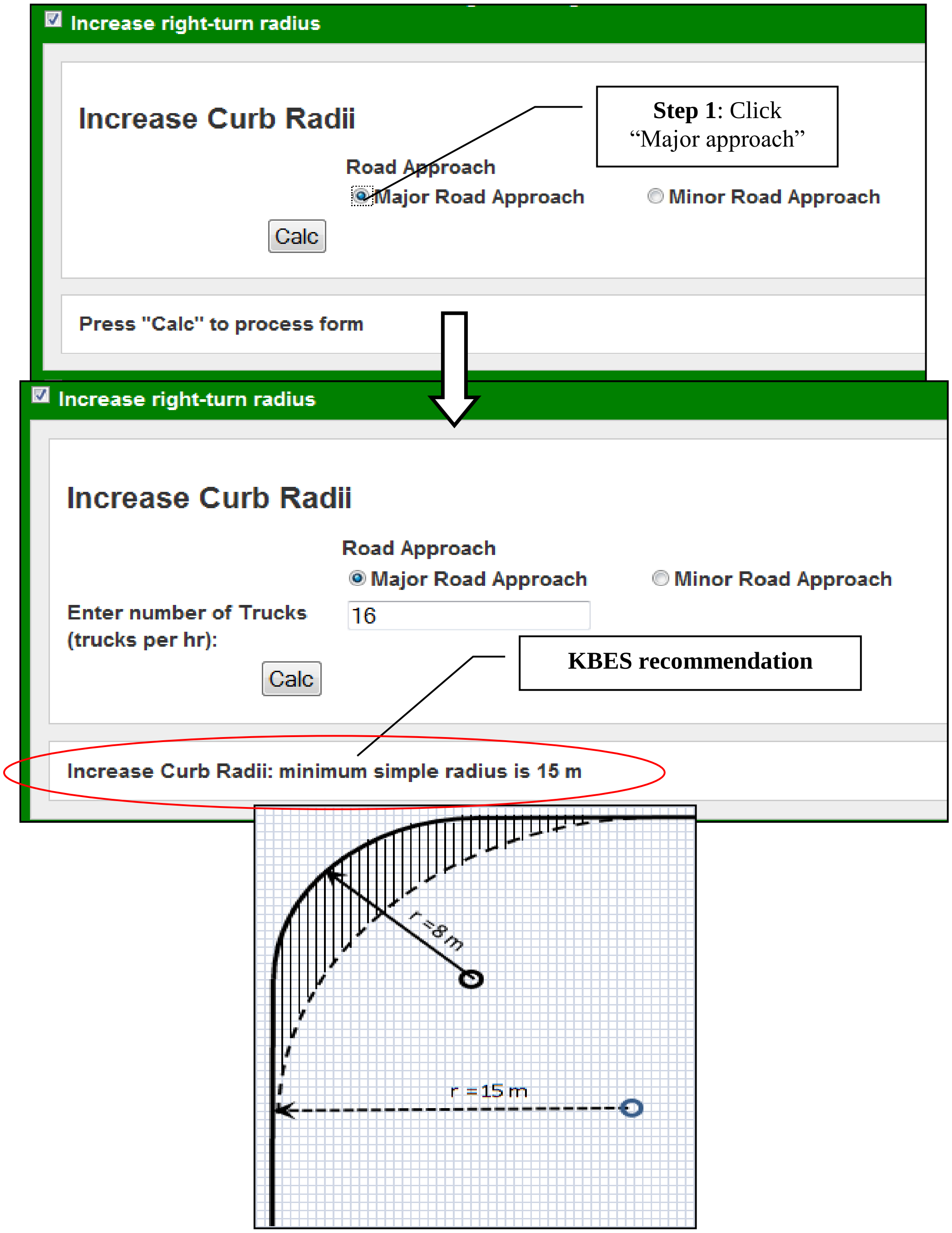

Figure 10. Recommended turning radius

A left-turn lane was not possible since a 220 -meter length is too long that may create confusion for drivers maneuvering a left-turn. A double left-turn lane of 110 meters was neither possible since the receiving lane has one lane only as shown Figure 11. Moreover, vehicles from Katipunan Avenue move towards a horizontal curve prior to entering the intersection that also creates confusion for the driver.

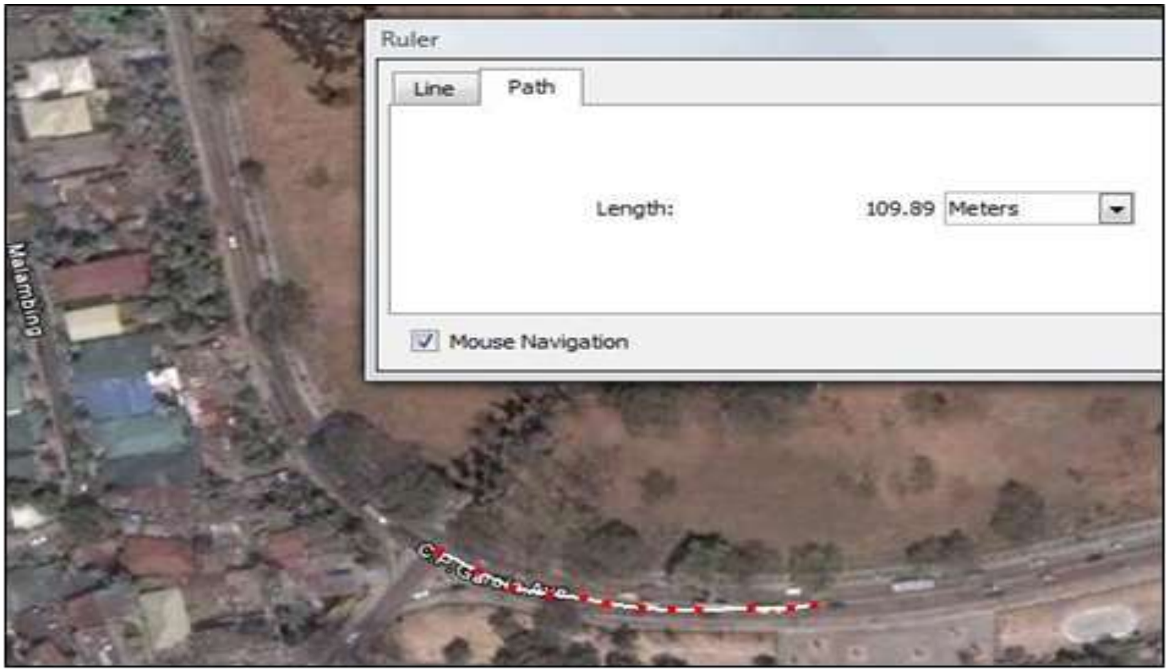

Figure 11. Proposed double left-turn bay at C.P. Garcia approach (Google Earth 2010)

Try "Converting to Roundabout"

Converting to a roundabout obviously was not possible because of the presence of "islands" for right-turning exclusive lanes. Geometric positioning of a roundabout on the perimeter of the intersection is not enough to accommodate a two-lane entry. Moreover, there was a high percentage of trucks for both "through" movements.

Try "Prohibit Left-turns permanently with channelization"

Left-turn prohibition with channelization was not possible since high volume of left-turning vehicles from Katipunan Avenue occurs during morning peak hour.

Two alternative candidates for further investigation

Three alternatives were eliminated and two alternatives are left for further investigation (Figure 12)

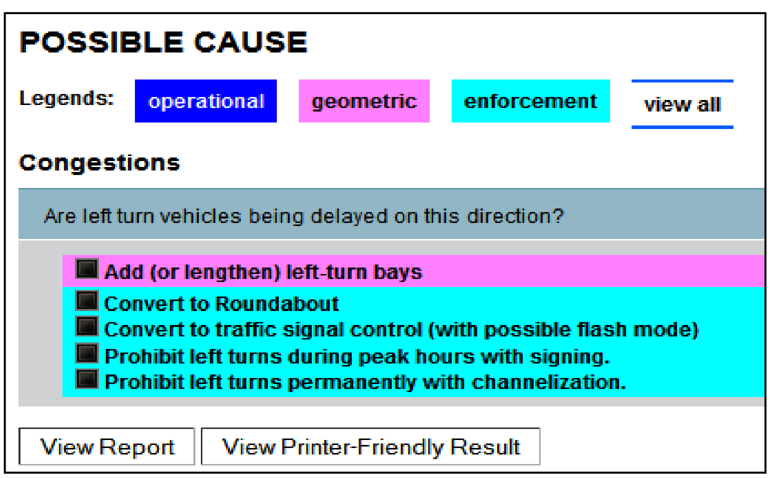

Figure 12. Possible cause

Since these two alternatives are enforcement solutions, an analysis of the left-turn prohibitions during peak hours is prioritized since the cost is minimal as compared to installing a traffic signal.

Try "Prohibit left-turns during peak hours with signing"

Prohibition of left-turning vehicles during peak hours was tested for left-turn movements from Katipunan Ave. towards Maginhawa St. There are minimal left-turning vehicles from Maginhawa St. going to University Avenue; hence, prohibition was not considered for this direction. To justify this prohibition, the following warrants must be checked:

Warrant check:

Left-turn-related delay, conflicts, or crash frequency should be at unacceptable levels: An ocular inspection was conducted on March 2, 2010 prior to the survey and it so happened that during morning peak hour, unacceptable delay was overwhelming with the collision of a left turning vehicle and a through vehicle as shown in Figure 13. Thus, warrant is satisfied.

(a) (b)

Figure 13. Through and left-turn collision

During the survey on March 9, 2010 a collision happened and the illustration of the collision is shown on Figure 14:

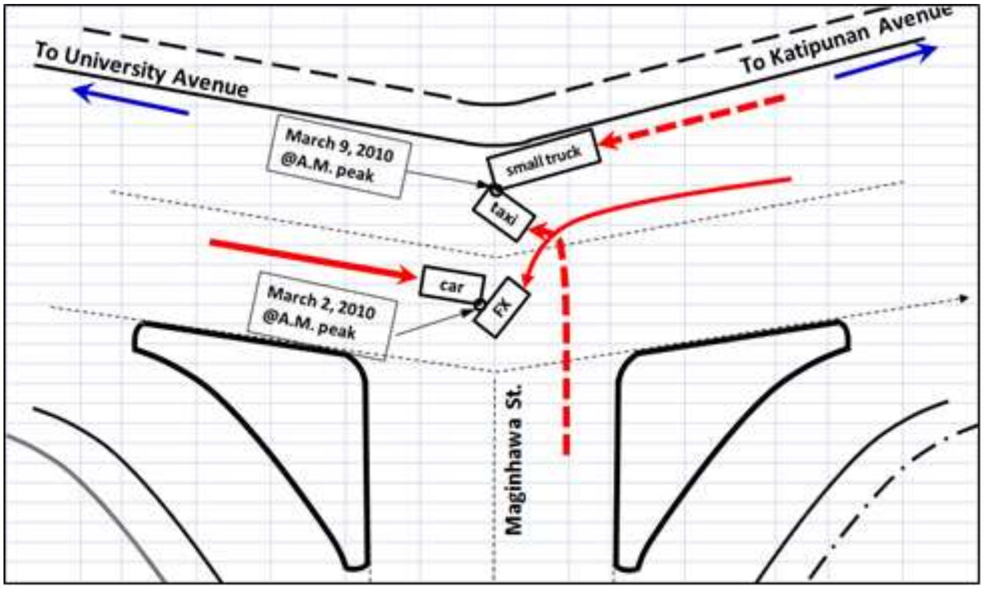

Figure 14. Collision diagram

An alternative route is available for the re-directed vehicles:

An alternative route was available using Baluyot Street as shown in Figures 15, 16 and 17; thus, eliminating left-turning vehicles on the subject intersection during the peak hour prohibition.

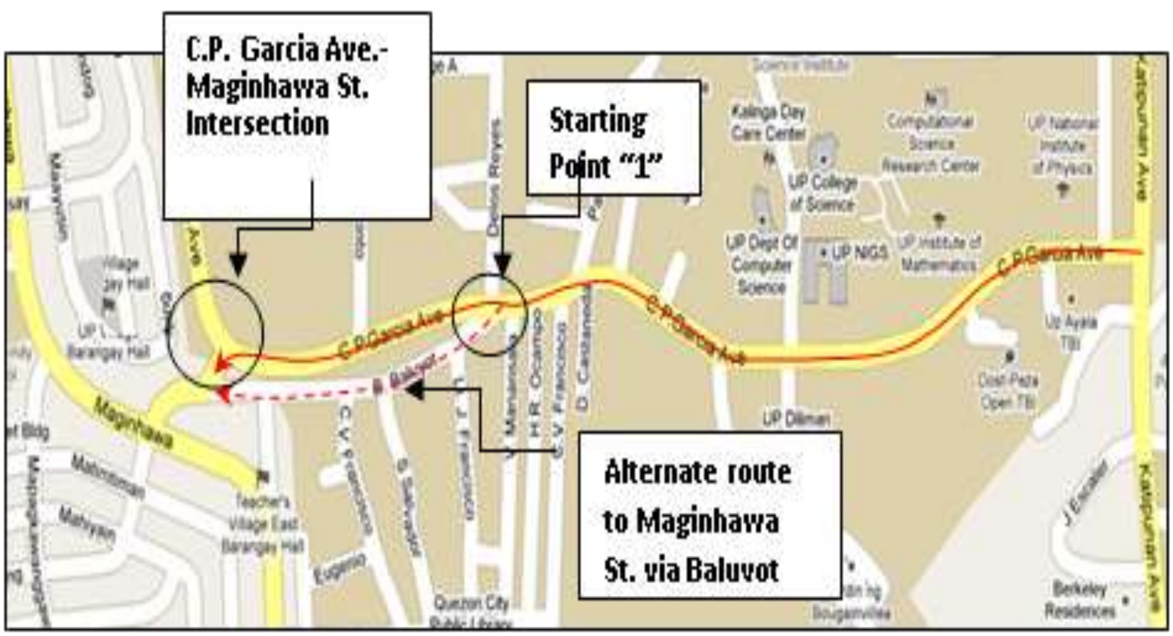

Figure 15. Base Route and alternate route (Google Map 2010)

Figure 16. Base Route (Google Map 2010)

Figure 17. Alternate route (Google Map 2010)

5. CONCLUSIONS AND RECOMMENDATIONS

Intersections was tested locally using the KBES namely University Avenue-C.P. Garcia Avenue and C.P. Garcia Avenue-Maginhawa Street. Possible traffic congestion and vehicular road crashes were observed at each approach and field measurements were made for possible geometric modifications and engineering evaluation. Driving along the proposed route gave a more accurate evaluation on the traffic delay condition. University Ave. - C.P. Garcia Ave. is a signalized "T"-intersection while C.P. Garcia Ave.-Maginhawa St. is an unsignalized "T' intersection. Tables 2 and 3 show the summary of the selected problem intersections and solutions respectively. The results shown in Table 3 particularly for Case no.1 at minor approach showed that there was no need to fine tune the traffic signal. Delays measured from the field show the present condition of the intersection while delays measured from the KBES show actual field delay from peak hour volume. Other references of performance measures were the actual travel time comparing base routes and alternate routes as discussed in Case no. 2 for the prohibition of left turning vehicles during peak hours.

Table 2 KBES problem and cause identification

Case No.	Type of Control	Type	Intersection classification	Problem	Problem Cause	Corrective strategy
1	Signalized: Traffic signal control	T-Intersection	Isolated: Suburban	Delay and conflict of right-turning vehicles on major approach	High percentage of right-turning vehicles from major arterial to minor road.	Separate conflicting flows
				Delay of vehicles on minor approach	High percentage of left-turning vehicles from minor road to major arterial road.	Separate conflicting flows
2	Unsignalized: Flashing beacon	T-Intersection	Isolated: Suburban	Delay of vehicles on all approaches	High percentage of left-turning vehicles from major road	Increase capacity or Reduce demand

Table 3 Solution of KBES for the intersections

Case no.	Solution interface	Possible Alternative	Reasons for elimination	Solution using KBES
1	At major road crash interface	Provide right-turn lanes	A right-turn lane measuring 188 was too long. A right-turn lane that is excessively long creates confusion for drivers and may be mistaken as a through lane. A dividing length to a double right-turn lane of 94 meters is still quite long and the receiving lane at the minor approach has only one lane.	Geometric: **- Increased right-turn radius to 15m with a proposed island** (See Figure 4.6)
	At minor congestion interface	Parking provisions	Parking was prohibited.	Operational: **Re-timing of traffic signal timing was not required.**
		Roundabout	- A traffic signal was present. - Presence of long trucks and high percentage of medium trucks.	
		Increase right-turn radius & add right-turn bays	Only 10% were right-turning vehicles.	
2	At major /minor congestion and road crash interface	Add left-turn bays	A left-turn lane of 220 meters was computed for the major approach which was too long even if dividing it to double left-turn lanes of 110 meters.	Enforcement: **Left-turn prohibition at major approach during A.M. peak hours (7 to 8 am)** (See Figure 4.12 and Figure 4.13) Base route = 496.58 meters Alternate route = 496.85 meters **Note**: Road crash analysis adopted the prohibition
		Convert to roundabout	- Presence of long trucks and high percentage of medium trucks. - Presence of islands for lanes exclusive to right-turn maneuvers - A two-lane roundabout did not satisfy the warrant.	
		Prohibit left-turns permanently with channelization	- High percentage of left-turn volumes at major approach only happens during peak hours.	
		Convert to traffic signal	- Is possible for implementation but too expensive as compared to the proposed prohibition of left-turns during peak hours.	
		Increase right-turn radius	- No large trucks maneuvering a right	
		Add right-turn bay	- Right-turn bay warrant was not justified	
		Convert to roundabout	It is possible but might not be effective for solving road crash collisions	

6. IMPLEMENTATION

Case 1: University Avenue-C.P. Garcia Avenue Intersection
Solution: Geometric Design: Increase right turn radius

The solution was implemented in year 2014 and accordingly, traffic flow improved and large trucks were able to maneuver a right turn with no difficulty. Figure 18 and 19 shows the increase in turning radius as indicated by the dashed line. The original turning radius represented by the solid line in year 2010.

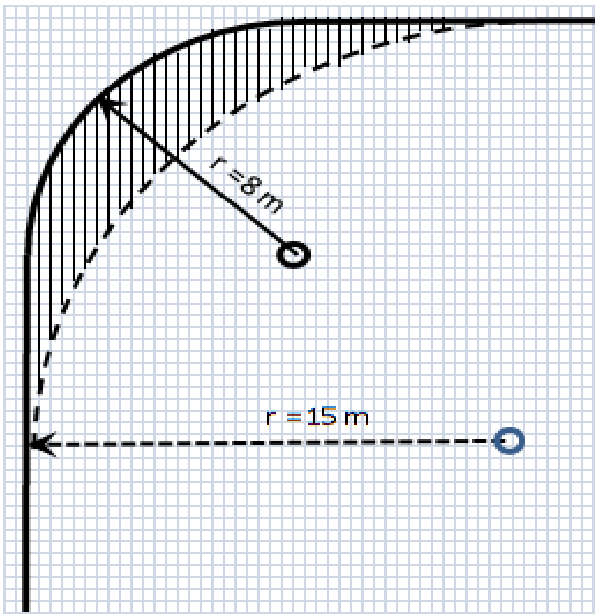

Figure 18. Increased turning radius from 8 to 15 m

Figure 19. Increased turning radius

With the increase in the turning radius, the sidewalk was transformed to an additional lane. The offset is shown in Figure 21.

Figure 20. Existing sidewalk (year 2010)

Figure 21. the sidewalk offset further to the right (year 2014)

Figure 22. Right turning geometry in year 2010

Figure 23. Increased right turn radius in year 2014

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