Intersection Advisor: An Expert System Application*

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ABSTRACT

An experimental knowledge-based expert system(KBES) applied to solving problems at an isolated signalized intersection has been developed. This is one area in which the potential of artificial intelligence may be utilized since there is no well established algorithm that may be followed. The production rules which consist the knowledge are largely based on rules of thumb and on some standard practices of traffic engineers in solving traffic problems. Solution sought ranges from simple operational changes in the signal parameters to possible widening of approach and regulating or prohibiting some practices commonly observed to cause congestion at the approach of the intersection. The author hopes that with further improvements, the system could be used in solving actual problems and as a training tool for young traffic engineers, planners, and traffic enforcers.

Keywords: Knowledge-Based Expert System, Artificial Intelligence, Signalized Intersection, Design and Control

I. Introduction

This paper presents a KBES for solving problems commonly encountered in signalized intersections. Expert systems are well recognized in problem areas that lack explicit algorithms, i.e., problems for which no numerical model exists. Considering that there are human experts in this field whose experience could be tapped and stored electronically, then similar problems that may be encountered later could possibly be solved as if these experts have been consulted. At present, many KBES have been designed to solve real world problems and may be considered to reach the level of performance of a human expert in a specific professional domain[1].

The KBES developed is called the **Intersection Advisor**. It aims to:

1. solve traffic congestion problems at signalized intersections, and;

2. train novice traffic engineers, planners, and traffic enforcers engaged in the management of signalized intersections.

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II. Structure of the Intersection Advisor

The **Intersection Advisor** follows the general structure of a KBES shown below:

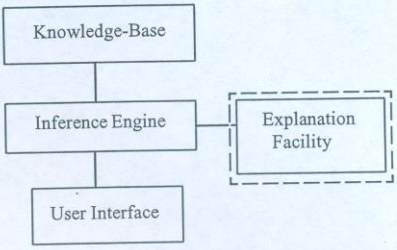


Figure 1. General Structure of a KBES

In a great deal of expert system work, there has been a conscientious effort to divide the program into two parts, namely: the inference engine and the knowledge-base. The idea is that the inference engine(also called the inference machine) is the general purpose 'thinking machine' and the knowledge-base is that which the engine shall 'think'[2].

Inference Engine

The inference engine serves as the controller of an expert system. It seeks to find a conclusion for a subgoal or the answer to an entire problem. It searches for facts through the knowledge-base and identifies new facts for subsequent inferencing[3].

Knowledge-Base

The knowledge-base represents the power of the expert system. It contains all relevant information, facts, or causal knowledge of the domain, and rules for problem-solving activities to determine what actions will be executed if certain situations are met[4]. **Intersection Advisor**'s knowledge-base involves production rules[5] in the **if-then** format.

Explanation Facility

The explanation facility is optional but aids the user in answering why a particular data is required; why such question is asked; what type of answers are expected, etc.

User Interface

The user interface serves as the link between the user and the machine. It is programmed to accept inputs and give back necessary information to the user.

All the components of the **Intersection Advisor** are written in Pascal language.

III. Hierarchy of Solutions

The Intersection Advisor attempts to seek solution to problems in the following hierarchical order:

1. Operational Solutions
2. Geometry Modifications
3. Regulations/Enforcement

1. Operational Solution

This consists of modification of signal timing - cycle length, green split or phasing. However, phasing may be difficult to modify because it usually entails hardware change. In countries like ours where such hardware is not locally manufactured, acquisition poses a big problem.

a. Cycle

Cycle time is one of the most important variables used in traffic signal control. Based on numerous studies, cycle time should neither be too short nor too long. Improper cycle time would lead to excessive delays, not only to vehicles, but to pedestrians as well. Long cycle often causes irritation to roads users and may even lead to disrespect of the signal control. On the other hand, too short a time may give the same bad effects.

The absolute maximum cycle length is ordinarily assumed to be 180 seconds. The minimum cycle is also determined as 40 seconds under the constraint of minimum green time requirement for vehicles even if the intersection is small. The cycle length, therefore, should vary from 40 to 180 seconds[6].

b. Phasing

The control of traffic in at-grade signalized intersections is done by separation in time. The way in which this is achieved is called phasing. A phase is defined as the sequence of conditions applied to one or more streams of traffic, which receive simultaneous identical green indicationsduring the cycle [7]. The number of phases utilized depends on the major traffic flow conflicts and geometry of the intersection. If there are two major traffic conflicts then they may be resolved by two phases.

In many instances, there are more than two major traffic conflicts and therefore, it is necessary to provide more than two phases. In practice, the number of phases should be kept to a minimum commensurate with safety. The primary reason for this is that, as the number of phases increases, the total lost time per cycle also increases.

Without a phase, it is apparent that the left turners have to depend on the available gaps in the opposing traffic and/or on the duration of the clearance interval . When there is a high volume of opposing traffic, the clearance interval serves as a main source of left turn capacity. In a previous paper by the author [8], it was found out that about 2 to 4 left and U-turners could make use of the clearance interval per cycle assuming there is queue of left turn traffic in the left turn lane. If this is so, an effective way of increasing the capacity of left turn traffic is to use shorter cycle as this will give more clearance intervals per unit time.

c. Green Split

Modification of green split can be applied to the case when only some phases are saturated. It attempts to optimize the usage of the total available green time. In practice, green time allocation of each phase is achieved in proportion to its saturation degree[9]. Hence, the greater the saturation degree of a phase is, the longer its required green time. However, giving a very short green to an uncongested phase is not a good practice either, as this would lead to confusion and irritation of the road users. A limiting value of the minimum green is thus necessary. The major phase, usually composed of through traffic or main traffic, should be given at least 15 seconds while the minor phase, consisting of left movements, should be given at least 5 seconds [10].

Aside from the vehicular requirement, the time necessary for pedestrians to cross must also be taken into account. It may be estimated by considering the width of road to be crossed in the given phase and the walking speed of the pedestrians.

The minimum green time is thus governed by either of the two requirements. The one requiring a longer green must be used in practice.

d. Pedestrian Treatment

Pedestrian Signals

Normally, traffic signals (for vehicles) are accompanied by separate pedestrian signals, especially at built-up locations where pedestrian overpasses or underpasses are not provided. There are signalized intersections, however, which do not have separate pedestrian lights. When the number of pedestrians increases, conflict between them and the vehicular traffic arises. Congestion occurs, coupled with high rate of pedestrian accidents. It is therefore imperative to provide or install pedestrian signals to eliminate such conflict thereby reducing accident rate.

Pedestrian Green Time

If pedestrian signals do exist, it may be possible to shorten pedestrian green to give more time to right turning vehicles blocking the through traffic. Minimum green for pedestrians is estimated based on their walking speed and the total width of roadway they have to cross. When pedestrian green can no longer be reduced, other measures have to be considered. If some phases are not congested, pedestrian green time may be maintained while the green time of the phase in which the right turn vehicles have the right of way, may be increased. Otherwise, provision of an additional lane for right turn traffic may be examined.

Scramble Phase

The provision of a scramble phase is another option to consider. In this phase, vehicular traffic is called to a stop in all the approaches of the intersection and pedestrians are allowed to cross in all directions. This kind of phase may be helpful at large intersections with very high pedestrian demand particularly involving diagonal movements. The scramble phase, however, may cause undue delay to vehicular traffic since this is considered to be an all-red period and therefore, a lost time.

2. Geometry Modification

This involves the utilization of the median to provide an additional bay for left turn traffic, adjustment of lane width for a possible extra lane, or reassignment of lane usage. In some cases, such modification may not incur much cost especially if only repainting of lane markings are needed.

a. Extra or Additional Lane

An extra or additional lane may be achieved by considering any of the following :

i. Provision of an extra lane by adjusting the widths of the individual lanes plus the utilization of the median ;

ii. Provision of an added bay by utilizing the median of adequate width ;

iii. Reassignment of lane usage, i.e., the number of lanes of the uncongested movements is reduced while the number of lanes of the congested ones is increased at the same time.

Adjusting the width of individual lane widths can be done on the approach or by considering the whole width of the roadway. Adjustment of width on a single approach will not affect the width of lanes of opposing approach. However, if an extra lane cannot be obtained by adjustment in a single approach, the whole roadway may have to be considered.

As to reassignment of lane usage, it is deemed necessary to check if such reassignment will work for different time periods. Oftentimes, at intersections within an arterial that happens to be a radial road, tidal flow may occur. Reassignment may not work even if it is possible in this case.

b. Length of Storage Bay

One of the factors that cause blockage or spill over of right or left turn vehicles is the length of storage bay or exclusive lane. As much as possible, adequate length should be provided in order to avoid such problem. The cycle length, phasing arrangement, and the rate of arrivals and departures have to be taken into account in designing its length.

3. Regulation/Enforcement

This considers measures, such as parking or waiting prohibitions on curb lanes, stopping regulation of buses or jeepneys near the intersection, or turning regulation.It is the opinion of the author that such measures should be looked into after solutions related to operation and geometry modifications are first exhausted. Regulation or enforcement would be appreciated by the road users if efforts are made to improve the intersection in a nonrestrictive sense.

Parking on curb lanes near the approach definitely leads to underutilization or nonutilization of a lane --- a great loss in the capacity of the approach. Unreasonable stopping of buses or jeepneys near the approach even during green time should be checked. Left turn or U-turn maneuvers at an intersection may be prohibited to minimize blockage of through traffic

specially at locations where it is not possible to provide exclusive bay and/or exclusive phase. However, turning prohibitions should be implemented only if there are alternative routes available.

IV. Methods of Solving Problem

The following methods are utilized in the development of the **Intersection Advisor**:

1.Trial and error, which generally involves :

i. modification of traffic parameters or variables;
ii. observation of the 'new' situation to see if it turns okay;
iii. further modification if situation is not yet satisfactory.

2.Giving final recommendation after fully analyzing the quantitative description of the problem.

Trial and error can be best implemented for signal timing changes, such as cycle and green split modifications.

Giving final recommendation is best suited for problems which require phase modification, geometry modification, or involving regulation or enforcement.

V. Basic Policies

In connection with the hierarchical order mentioned above, some basic policies may be considered to serve as guide in searching for solutions, as follows:

1. Recommendations should follow current traffic engineering practice.

2. Priority should be given to signal retiming.

3. Cycle must be within normal range in all cases.

4. When blockage occurs, cycle reduction should be considered first.

5. More green time should be given to more saturated phases.

6. The need of left turn lane must be given due importance.

7. Substandard lane width should be provided rather than to have no lane at all.

8. Regulation or enforcement, such as parking or turning prohibition, should be considered as a last measure because it is usually 'unacceptable' to road users.

VI. Description of the Intersection Advisor

This expert system has been developed using NEC PC9801 although conversion to IBM PC is now underway. It incorporates graphics and most steps at data input stage are of selection type using mouse. A brief discussion is given on the following initial data input stages:

1. Intersection type selection
2. Phase selection, creation, or modification
3. Information on congested movements

1. Intersection type selection

The system deals only with 3 and 4-leg intersections. The selection of a particular type is done by using the mouse(Figure 2).

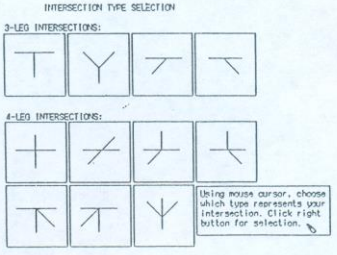


Figure 2. Intersection Type Selection Menu .

2. Phase Selection, creation, or modification

The number of phases is asked after selecting the type of intersection(Figure 3).

Figure 3. Number of Phases Menu

The system stores a number of phase patterns for every type of intersection. For a normal 4-leg intersection , for example, phase selection is shown in Figure 4. If a phase cannot be found in the menu, the user may either create his own phase or select one from the given phases and then modify by omitting or adding movements.

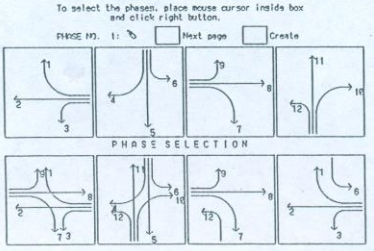


Figure 4. Phase Selection Menu

3. Information on congested movements

Once the input on phases is completed, the system asks about those movements which are congested. This is the last of the initial inputs before the system can proceed with the analysis(Figure 5).

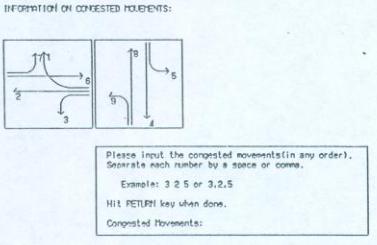


Figure 5. Information on Congested Movements

VII. Sample Runs

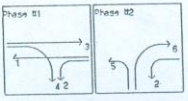
The following examples are extracted from the previous works of the author while studying in Japan[11]. Due to time constraint, left hand drive system is presented.

Problem 1: Right turn Traffic Without Phase

Problem Definition:

- T intersection

- Number of phases: 2; Phase pattern as shown;

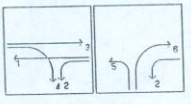


- Right turn from Approach 2 has exclusive bay but without a phase;
- Cycle time is 80 sec.
- Right turn traffic from Approach 2 has difficulty in filtering through; the only possible source of capacity is the clearance interval after green time along 1-2; queue begins to grow causing congestion in Approach 2.

Solution:

The user inputs the initial data by following the steps discussed in the previous section, namely: intersection type selection, number of phases, phase selection, and information of congested movements. The user shouldn't find this task difficult as most of these steps are selective type using the mouse.

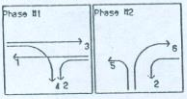
INFORMATION ON CONGESTED MOVEMENTS:



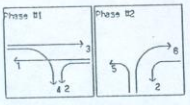

```
Please input the congested movements(in any order).
Separate each number by a space or comma.
   Example: 3 2 5 or 3,2,5
Hit RETURN key when done.
Congested Movements: 3 4
```

The system displays the chosen phases with the movements which has right of way in each phase.

```
Current Phasing:
```




```
Right turns:  4  6

Movement 4 has no exclusive phase
Movement 6 has exclusive phase

Please hit any key...


***Please input the cycle time now in use: 80

***Is there any right turn or left turn movement
   blocking through traffic (y-n)? y

***What do you think is the reason why blockage of through
   by turning vehicles occurs?

   1. Accumulation through time; right and/or left turn
      queue builds up to the point of blocking through traffic

   2. Spillover of right or left turn vehicles causing blockage
      of through; spillover is usually cleared during every cycle

   Enter Reason ( 1 or 2 ): 1
```

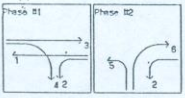



```
***In phase #1, do right turners have difficulty
   filtering thus causing congestion in the
   approach? (y-n) y
```

```
RECOMMENDATIONS:

Try to reduce the cycle time.
  This may reduce the number of right turners arriving per
  cycle and therefore relieve congestion in the approach.


  Press Any Key...
```

Assuming that the user has reduced the cycle time from 80 seconds to about 60 seconds. The situation improves but not quite. If the user further consults the system:

```
***Please input the cycle time now in use: 60

***Is there any right turn or left turn movement
   blocking through traffic (y-n)? y

***What do you think is the reason why blockage of through
   by turning vehicles occurs?

   1. Accumulation through time; right and/or left turn
      queue builds up to the point of blocking through traffic

   2. Spillover of right or left turn vehicles causing blockage
      of through; spillover is usually cleared during every cycle

   Enter Reason ( 1 or 2 ): 1
```

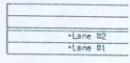



```
***In phase #1, do right turners have difficulty
   filtering thus causing congestion in the
   approach? (y-n) y
```

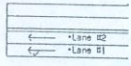
Since the cycle time cannot be reduced any further, the system tries to seek for other feasible solutions. Information on the geometry of the intersection are asked.

```
                                                    X:178 Y:54
Consider Leg # 1

Number of ENTRY lanes: 0 1 2 3 4 5 6 7 8 9

Number of EXIT lanes:  0 1 2 3 4 5 6 7 8 9

Width of median in meters? 8.5
```


```
                                                    X:116 Y:338
```

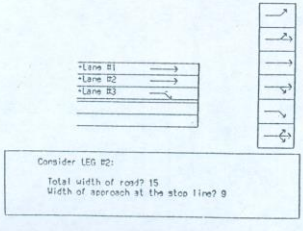


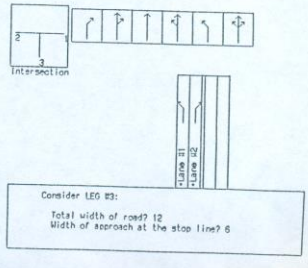

```
LEG # 1:
For Lane # 1: Using mouse, identify its designation
              and click right button.
```




```
Consider LEG #1:

   Total width of road? 15
   Width of approach at the stop line? 6
```

Similarly, the same information for Approaches 2 & 3 are asked and these are summarized in the succeeding figures.





Congested Approaches: 2

For approach #2:
Do right turn block through/left in approach #2? (y/n) y

RECOMMENDATIONS:

Provide right turn exclusive phase for Approach #2.

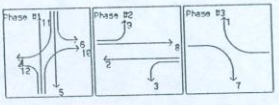
Press Any Key...

Problem 2: Requiring Green Split Modification

Problem Definition:

- 'Cross' intersection

- Number of phases: 3; Phase pattern as shown;



Green = (70sec.) (30sec.) (35sec.)

- Cycle time is 150 sec. Total lost time = 12 sec.
- Long queuing of through traffic from Approach 2 and right turn from 3 is experienced. Blockage of traffic by turning movements is not present in any approach.

Solution:

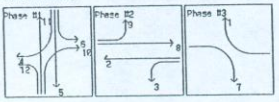
Similarly, the user inputs the initial data by following the steps discussed in the previous section.

Summary of initial data:

Intersection Type: 41
Number of phases: 3
Phase Pattern : as shown above
Congested Movements: 5, 7.

[Phases with corresponding movements, and right turn information]

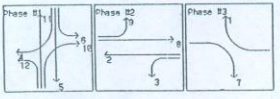
Current Phasing:




```
Right turns:  1  4  7 10

Movement 1 has exclusive phase
Movement 4 has no exclusive phase
Movement 7 has exclusive phase
Movement 10 has no exclusive phase

Please hit any key...
```

The session continues as the system poses questions and the user responds with the answers:

```
...Please input the cycle time now in use: 150

...Is there any right turn or left turn movement
   blocking through traffic (y/n)? n

...In any approach, is there long queuing
   of left turns due to pedestrians? (y/n)n
```



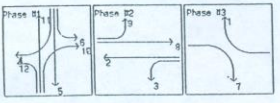

```
...What is the length of green time of Phase #2
   in sec? 30

...Is there pedestrian signal facility for
   phase #2?(y/n) y

...Width of roadway to be crossed by pedestrians
   in meters during phase #2? 18.5
```

```
RECOMMENDATIONS:

Modify split.
 Try reducing the split of any of the following phases: 2
 Give more green time to the congested movements.


 Press Any Key...
```

Problem 3: Requiring Geometry Improvements

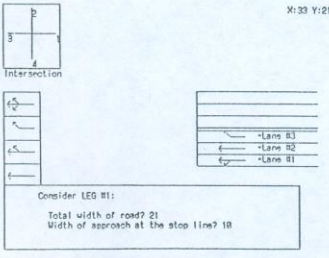
If modification of green split as suggested in the previous example does not solve the problem and the user further consults the system:

```
---Please input the cycle time now in use: 150

---Is there any right turn or left turn movement
   blocking through traffic (y/n)? n

---In any approach, is there long queuing
   of left turns due to pedestrians? (y/n)n
```

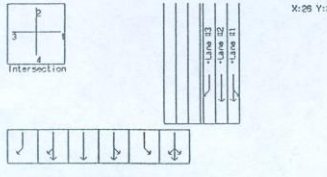



```
---What is the length of green time of Phase #2
   in sec? 16
```

The green time of Phase #2(the uncongested phase) can no longer be reduced as the minimum green time requirement for a major phase is about 15 sec. The system seeks for other solutions. Information on the geometry of the intersection are asked and these are summarized as follows:



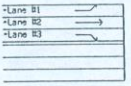

```
Consider LEG #1:

   Total width of road? 21
   Width of approach at the stop line? 10
```

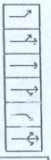



```
Consider LEG #2:

   Total width of road? 18.5
   Width of approach at the stop line? 9
```

X:445 Y:219

Intersection

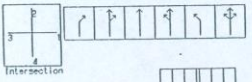




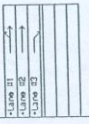
Consider LEG R3:

Total width of road? 21
Width of approach at the stop line? 18

X:131 Y:41



Intersection



Consider LEG R4:

Total width of road? 18.5
Width of approach at the stop line? 9

Congested approaches: 2 3

Checking for extra lane in the approach

Intersection

***For Approach R2:
Extra width= 0.90
No extra lane possible for through

***For Approach R3:
Extra width= 1.90
No extra lane possible for right turn

Please hit any key...

Checking for extra lane within the roadway.

Intersection

***For Approach R2:
Extra width= 1.50
No extra lane possible for through

***For Approach R3:
Extra width= 4.00
Extra right turn lane is possible
Use minimum of 2.5m. for right and 2.8m.for through/left.
Use minimum of 0.5m. for median.

Reassignment within Approach

Considering Approach R2:
Does this congestion pattern in Approach 2
occur even during other periods of the day? (y/n) y

RECOMMENDATIONS:

Intersection

Extra RT lane is possible for Approach R3.
An extra lane is possible within the roadway by
adjusting the widths of individual lanes. Use a
minimum of 2.5m. for right turn lanes; 2.8m. for
through/left lanes; and 0.5m. for median.

Reassignment for Approach R2 is possible.
Deduct 1 lane from the other side of the road to be utilized
by the congested movement; This requires the removal
of the median if it exists and repainting of the lane
designation. Adjust green time when necessary.

Press Any Key...

VIII. Conclusion and Future Works

The **Intersection Advisor**, a KBES for the design and control of signalized intersections, has been developed primarily for the purpose of maximizing the available space and optimizing the timing of existing fixed-time controllers. It has been designed considering minimum data requirements from the users.It has been shown to follow the line of thinking of an expert in solving traffic problems.

The existing system is still considered experimental. Some further works are needed for it to become a useful product. It is absolutely necessary for an expert system to be tested in order to be trusted by users. Continuous testing, therefore, on all possible cases can enhance its capabilities. Letting young traffic engineers, planners, and traffic enforcers use the system would provide the necessary feedback on its effectiveness.

Explanation facility is not yet included in the system. It will be a helpful guide for the user at any stage of the consultation.

The system deals with isolated intersections only and it may also be worth considering the potential application of expert system in solving problems usually occurring along arterial roads.

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