A hierarchical system for optimising a dynamic system of traffic crossroads control using an expert system

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Abstract. Nowadays in the field of the automotive industry and urban public transport, there are a lot of challenges and problems to solve. Every day there are closures, roadworks, and other aspects of public transport, which cause traffic jams. This paper deals with a hierarchical system for optimising a dynamic system of traffic crossroads control using an expert system. The hierarchical system uses an expert system constructed in a few layers which evaluate the length of the green signal for each phase of the crossroad. The main goal of the proposed system is traffic optimisation at crossroads and reduction of traffic jams. The proposed system was verified on a real crossroad in the city of Ostrava.

1. Introduction

Nowadays in the field of the automotive industry and urban public transport, there are a lot of challenges and problems to solve. Every day there are closures, roadworks, and other aspects of public transport, which cause traffic jams. People spend many hours a year in these jams. That is why every urban transport department tries to optimise traffic junctions, crossroads, and overall traffic to make the jams as small as possible. There is a number of approaches that attempt scientifically different ways of optimising and managing traffic flows [1-4].

Currently, the crossroads control is usually set dynamically [5-7]. This means that we have created a signalling plan for each phase of a given junction and it switches to the basis of the evaluation of the traffic flow of vehicles, which approach the junction in each direction. Accordingly, the signal marking of traffic lights is switched.

In the event of a failure in the dynamic system, the traffic light control is switched over to the standby static signalling plan, in which the switching of green light is fixed for each phase [8].

The last option for traffic control is the traffic policeman at the crossroads, managing the situation according to the subjective point of view and representing the role of an expert.

However, traffic jams are still the main problem of the transport control. Thus, it will be suitable to supplement these systems with artificial intelligence to replace the expert’s position and dynamically manage the transport. This paper focuses on dynamic management of crossroads through a hierarchical system (using an expert system) traffic optimisation at crossroads and reduction of traffic jams.

2. Methodology
The structure of the proposed hierarchical system is visually shown in Figure 1. The hierarchical system uses a set of expert systems for evaluating the importance of specific phases in the crossroad.

![Diagram of the hierarchical system](image)

**Figure 1.** The structure of the proposed hierarchical system

Main steps of the proposed system are more described in the subsequent subsections.

2.1. *Detecting phases based on the structure of the crossroad*

In the first step, the traffic streams and their directions at the crossroad will be detected. Based on detected directions, the phases are inputs to the hierarchical expert system. An example of a crossroad is shown in Figure 2.

![Example of a crossroad](image)

**Figure 2.** Example of a crossroad
There are following directions detected at the crossroad. From P1 we can turn to H5 or go straight to C5, from P2 we can go straight to C4, from P3 we can turn to M6, from P4 we can turn to M5. PT1 is a tram and a tram can turn to HT2 or go straight to CT2, from M1, we can turn to P6, from M2 we can turn to P5, from M3 we can go straight to H5, from M4 we can go straight to H4, from C1 we can turn to M6 or go straight to P6, from C2 we can go straight to P5, from C3 we can turn to H4. CT1 is a tram and a tram can go straight to PT2 or turn to HT2, from H1 we can go straight to M6, from H2 we can turn to P6, from H3 we can turn to P5. HT1 is a tram and a tram can only go to PT2.

In Figure 3, there is a satellite map of the sample crossroad schematically shown in Figure 2 and shows the various driving possibilities.

![Satellite map of the sample crossroad](image)

**Figure 3.** Satellite map of the sample crossroad

### 2.2. Creating a hierarchical expert system

In this step, the phases detected in the previous steps will be used as input variables to the hierarchical expert system. Based on the number of detected phases, the specific layers of the hierarchical expert system will be created. For the first layer, the input variables are all detected phases. For other layers, the input variables are all the remaining phases after evaluating the previous layer.

For each phase, the workload of the phase will be recognised. The workload of the phase will be captured by traffic sensors that are along the roadway in each direction. In each direction, the sensors are in two waves to provide correction data. For our purposes, we have set the workload as "high", "medium" and "low".

The input data for each variable will be the number of cars at that phase. The individual phase is the start of single traffic lights for selected lanes.

Each input variable will have a range for a single cycle. The minimum value will be set to 0 cars, but maximum values are set to 10 - 20 - 40 cars per cycle. Thus, the mean value will be between 5 and 10-20 cars, see Figure 4.

For creating a knowledge base of the expert system, the LFLC tool can be used. This tool is able to define input and output linguistic variables and IF-THEN rules. LFLC tool also has inference mechanisms and implemented defuzzification procedures, so we can create a complete expert system with this tool. The LFLC tool is more described in [9].
2.3. Evaluating the priority phase for each layer of the system

Depending on the use of the individual phases, we will define the strategy to determine the priority phase that will have the majority part of the overall crossroads cycle. Then, based on the number of phases the strategies are defined. Here are strategies for four phases:

- Strategy S0 - in this case, the cycle will remain in the standard way
- Strategy S1 - the majority part will be set at Phase 1
- Strategy S2 - the majority part will be set at Phase 2
- Strategy S3 - the majority part will be set in Phase 3
- Strategy S4 - the majority part will be set at Phase 4

Examples of IF-THEN rules for the first layer are:
- IF (PHASE 1 IS HIGH) AND (PHASE 2 IS HIGH) AND (PHASE 3 IS HIGH) AND (PHASE 4 IS HIGH) THEN STRATEGY IS S0
- IF (PHASE 1 IS HIGH) AND (PHASE 2 IS HIGH) AND (PHASE 3 IS LOW) AND (PHASE 4 IS LOW) THEN STRATEGY IS S1
- IF (PHASE 1 IS LOW) AND (PHASE 2 IS HIGH) AND (PHASE 3 IS HIGH) AND (PHASE 2 IS LOW) THEN STRATEGY IS S3
- IF (PHASE 1 IS LOW) AND (PHASE 2 IS LOW) AND (PHASE 3 IS HIGH) AND (PHASE 4 IS HIGH) THEN STRATEGY IS S4

2.4. Hierarchical evaluating by the expert system

Evaluation by the expert system is provided hierarchically. For each layer, the output variable is the strategy which defines the priority phase (with a major part of the overall crossroads cycle). For the second and next layer, the input variables are all remaining phases, and the output variable is again strategy.

For instance, if there are four phases at the crossroad, the evaluating will be done as follows:
1. There are four phases: Phase 1, Phase 2, Phase 3, Phase 4 and three layers
2. For the first layer there are four input variables, and after evaluation, the priority phase is set by the evaluated strategy (for example, strategy S4 represents Phase 4)
3. For the second layer, there are three input variables representing all phases except the priority phase of the previous layer evaluation (Phase 1, Phase 2, Phase 3) and after evaluation, the priority phase is set by the evaluated strategy (for example, strategy S3 represents Phase 3)
4. For the third layer, there are two input variables represent all phases except the priority phase of the previous layer evaluation (Phase 1, Phase 2) and after evaluation, the priority phase is set by the evaluated strategy (for example, strategy S2 represents Phase 2)

The process of evaluation is more described below.
In the first layer of our system, the expert system will evaluate the traffic situation, which is the most difficult. In the next step, the expert system selects the stage of the signalling plan which is to be activated to ease the traffic situation. After selecting the phase called “priority phase”, we set the largest time period of the entire cycle of a specific crossroad, namely 60% of the real cycle. The length of the real cycle, in which the signal is green in each direction, is determined by the saturation flow method. The second layer will again perform the same procedure as in the first layer but without the first selected phase. After selecting the second priority phase, we set the length of the signal so that it gets again 60% of the time, but now from the remaining time after the first layer. Then the system switches to the third layer. In this layer, we only select from two phases that will be a priority. This phase then reaches 60% of the remaining time after the second layer and the remaining time gets the phase only the least busy. We have to ensure that each phase in a single cycle is done and there is no situation that in some direction the red signal will be still on. Therefore, we will observe that each phase must be at least 5% of the total cycle time. The output of the expert system will be a single time setting for the individual signal markings of the test crossroad.

2.5. Setting the green signal for each phase
After evaluation of all layers of the hierarchical expert system, the length of the green signal for each phase will be defined.

3. Verification
Verification of the expert system was carried out on data obtained from the city of Ostrava, which measured the traffic through the crossroad shown in Figure 3. The measurements took place in four cycles at the rush hour, from 15:00 to 16:00. The evaluation by the hierarchical expert system is shown in Figure 5.

Table 1 shows the numbers of cars in each phase of the given cycles.
Table 1. Number of cars in each phase

| Cycle | Phase 1 | Phase 2 | Phase 3 | Phase 4 |
|-------|---------|---------|---------|---------|
| C1    | 22.7    | 5.8     | 11.6    | 33      |
| C2    | 24.9    | 6.3     | 15.7    | 34.1    |
| C3    | 34.5    | 4.1     | 5.2     | 19.3    |

The outputs of the first expert system layer for each cycle are shown in Table 2.

Table 2. The output of the first expert system layer

| Cycle | Strategy |
|-------|----------|
| C1    | S4       |
| C2    | S0       |
| C3    | S1       |

From the table, we can conclude that for cycles C1 and C3 the strategy is chosen to divide the time for one of the phases in the majority of ways. For C2, strategy S0 is chosen, which means that the time division for each phase will be done in a standard way.

For cycles C1 and C3 and their resulting S4 and S1 strategies, this method will be used to calculate the times for the individual phases (analogously would be used for strategies S2 and S3):

- For the phase that represents the output of the first layer of the expert system, 60% of the total time determined on the total intersection cycle
- All cycles outside the cycle representing the first phase output will be used to enter the second layer
- For the phase that represents the output of the second layer of the expert system, 60% of the remaining time will be used
- The remaining cycles will be used to enter the third layer
- For the phase that represents the output of the third layer of the expert system, 60% of the remaining time will be used

The following tables show a multilayer calculation for cycle C1. After selecting the resulting strategy of the first layer shown in Table II, all phases will be input into the calculation of the second layer except for the phase representing the first phase output. The second layer input variables and the resulting strategy of the second layer of the expert system are shown in Table 3.

Table 3. The output of the second expert system layer for cycle C1

| Cycle | Phase 1 | Phase 2 | Phase 3 | Strategy |
|-------|---------|---------|---------|----------|
| C1    | 22.7    | 5.8     | 11.6    | S3       |

Thus, the table shows that for phase 3, 60% of the time remaining after reading the first layer output was used (strategy S3 was chosen).

After selecting the resulting second layer strategy, the remaining two phases - Phase 1 and Phase 2 - will enter the third layer. The third layer input variables and the resulting strategy of the third layer of the expert system are shown in Table 4.
Table 4. The output of the third expert system layer for cycle C1

| Cycle | Phase 1 | Phase 2 | Strategy |
|-------|---------|---------|----------|
| C1    | 22.7    | 5.8     | S1       |

Thus, the table shows that for phase 1, 60% of the time remaining after calculating the output of the first and second layers will be used.

Calculation for cycle C3 will also be performed. The second layer input variables and the resulting strategy of the second layer of the expert system are shown in Table 5.

Table 5. The output of the second expert system layer for cycle C3

| Cycle | Phase 1 | Phase 2 | Phase 3 | Strategy |
|-------|---------|---------|---------|----------|
| C3    | 4.1     | 5.2     | 19.3    | S3       |

Thus, the table shows that for phase 3, 60% of the time remaining after calculating the first layer output was used (strategy S3 was chosen).

After selecting the resulting strategy of the second layer, the remaining two phases - Phase 1 and Phase 2 - will enter the third layer. The third layer input variables and the resulting strategy of the third layer of the expert system are shown in Table 6.

Table 6. The output of the third expert system layer for cycle C3

| Cycle | Phase 1 | Phase 2 | Strategy |
|-------|---------|---------|----------|
| C3    | 5.2     | 4.1     | S0       |

4. Conclusion
This paper deals with the area of crossroads traffic control.

In the introduction, the current state of crossroads traffic control was outlined. Then, a hierarchical system for optimising the dynamic system of traffic crossroads control was proposed. The hierarchical system uses an expert system constructed in few layers which evaluate the length of the green signal for each phase of the crossroad. The proposed system was described and the main parts of the system were explained.

The proposed system was verified on a real crossroad in the city of Ostrava.

In future work, our attention will be drawn to the verification of the proposed system at other crossroads.

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