An Approach to Traffic Scenario Analysis, Generation and Evaluation

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Abstract—start taking a few most applied scenarios from a traffic control centre, analysing each component and structure of the whole, and evaluating the impact of each component and some typical combinations, based on available monitoring systems. Carrying on such initial research on best practices, we build a dynamic simulation model, including these typical scenarios and evaluate the impact on traffic for each component and their whole. Evaluation criteria consist of finding an influencing area, and sensible Key Performance Indicators (travel time, delay and environment carbon footprint). This leads to an initial and quantitative expression of the impact of a component. The finding is then applied to other un-tested sets of scenarios and evaluated in the dynamic model. Evaluation is done with both model-based approach and field monitoring. The modelling and monitoring lead to some improved understanding of scenario performance and its generalization towards the implementation in a dynamic model, which hopefully accelerates the real-time automation of scenario selection towards complex or unforeseen traffic situation.

Index Terms—traffic management scenario, simulation, evaluation, performance index. *(key words)*

I. Introduction

Traffic management scenarios are the combination of traffic states and appropriate traffic management strategies. The traffic states are characterized by the flows, queues and traffic control. The traffic management strategies are suitable traffic control measures on intersection level, ramp metering control, and information provision to drivers on Variable Message Signs (VMS), radio and on-board devices like smart phones and navigation systems. The methodology that can be developed is very general, applicable in any urban road network. The details are specific for the particular network where it is applied and the technical and organizational possibilities.

However, it is still a complicated task for a traffic control centre operator and traffic management practitioners to interpret monitoring data and to pose the diagnosis to an observed problem, due to the complex interactions between measurements, and a lack of insight into network dynamics, in particular when facing non-recurrent situations. It is beneficial for traffic management to provide a decision support tool to these personnel in order for them to be able to select an effective set of measures to a given problem.

Various approaches have been tried and tested, which include rule-based and case-based reasoning, using either artificial intelligence (AI) or expert-based system (Ritchie, 1990). It is still not possible to handle large and complex networks in an urban area. A major difficulty resides in the fact that a specific and real problem at a given location in a large network is hardly easy to be represented and prompted to a readily available solution.

This paper suggests a self-learning approach, which recognises that a solution may not be available to a specific problem but a most likely one may be recommended when experienced successful cases are registered into a relational database. The more the successful cases have been collected, the more efficient the system performs. But it is the restriction also that a case should remain sufficiently robust, so that both generic characteristics of cases and efficient operation of the system can be achieved in balance.

The paper will address further issues in problem recognition, solution matching as well as knowledge database expansion. Note that the paper addresses mainly the technical solutions to support traffic management tasks, and does not deal with the potentially important institutional and usability issues such as the authority and responsibility of the operator and the measure to which this system supports the task execution. One has to expect that the availability of a decision support system changes the tasks of the traffic managers and that, as a consequence, a decision support system has to be adapted in the future to new task performance (van Zuylen 1990).

On-going development in a large metropolitan city, Changsha, China, will be presented. The other case in Beijing will also be reviewed. (Chen et al., 2005).

II. Methodology

The main aim is to be able to propose a best suitable solution to a given (either recurrent or non-recurrent) traffic problem, and to apply it to real-life traffic management. This problem-driving approach requires a fast diagnosis of problems and a quick generation/retrieval of corresponding solutions.

Decision support systems for traffic management can be distinguished in:

[1] Rule based systems, where knowledge stored in structured databases, decision rules (if … then …) and

procedures, is augmented with real-time monitoring data. The system can reason about the meaning and consequences of the monitoring data and draw conclusions about the cause of a traffic problem (diagnosis) and the best measures (remedy). These rule-based systems may be made probabilistic (conclusions are drawn with a certain probability) or fuzzy (a diagnosis or remedy are given as membership to certain sharply defined states).

[2] Case-based systems, where an a-priori database is made of situations with traffic conditions and control measures (scenarios). These scenarios are evaluated with respect to certain objective functions. After the occurrence of a traffic situation, the system makes a diagnosis. A match is made between the real situation and the cases in the database. The case that has the best match with the real situation and gives the best performance with respect to a chosen objective is selected and the measures of the scenario are recommended (Hegyi et al. 2000, 2001, Hoogendoorn and De Schutter 2003).

[3] Real-time simulation, where a simulation runs parallel to the real traffic. Monitoring data are used to adapt the simulation to the real situation. The simulation program can run faster than real time and the operator can investigate what will happen in the future if he takes a measure (Mahmassani 2004). A real time simulation requires still a diagnosis and possible traffic measures, where the traffic manager can investigate the effectiveness of the measures before implementing them.

In this paper a mixture of these approaches is followed. Three major steps are being followed in the proposed DSS:

- a matching rule enables to recognize a problem and to propose a robust solution – i.e. an approach like the rule-based DSS;
- further search continues to identify a most likely scenario that has been successfully executed before – the case based approach; and
- successful scenarios for traffic situations that have not been analysed before, can be prepared offline and stored to a relational database after being tested.

The problem of the first approach is that it is very difficult to acquire a sufficiently complete set of rules to be able to react on most traffic situations. Expertise on network management is needed and in practice only knowledge about the most generic situations can be specified in a rule-based system. The second approach has the limitation that only a limited number of scenarios can be prepared and stored in a database. In a real network, even one of a moderate size, trillions of possible scenarios can be relevant and defining and assessing them all is unfeasible. The third approach that starts from an offline existing scenario is necessary to collect the most relevant scenarios and derive rules from them. This makes the system (self) learning.

These three steps are closely linked to each other and are complementary in its function. In the case that no suitable scenarios are found, a further analysis is needed. The monitoring data are stored for further off-line search for a suitable new control scenario.

Establishing a learning-based mechanism

The afore-mentioned combination would be able to combine both existing experts' knowledge of best practices, simulation-based scenarios and new knowledge.

A Case-based reasoning for most likely scenarios

A rule-based approach is similar to the current approach in a traffic control centre, where an operator follows a manual and selects procedures/measures to implement. On irregular or unstructured roads where control devices are not configured structurally, a rule-based approach may not be suitable to deliver the best control. But a rule-based approach can suggest a robust solution that is based on combination of various effective measures on known situations. As presented previously, a rule-based approach stores a typical measure to a typical situation, which allows coming up with a probable combination of measures. The robust solution needs to become a concrete measure to implement and to be operational.

There would not be a specific measure to a given problem that could happen at anywhere in the network at any moment. There is however a most likely one, based on the following:

- Knowledge-based expert system database (KBEST);
- Most likely pattern matching based on likelihood maximization.

The KBEST is filled in by historical and simulated cases, which will be the topic for the next paragraph.

The pattern matching is based on the likelihood that a case from the case base is identical with the observed situation. A short description is given in (Hegyi et al. 2000, 2001). The likelihood concept is represented by fuzzy sets, where the likelihood is converted into the membership of a situation to the class of a particular case.

A simulation approach for assessing the performance of a scenario

Computation effort may become excluded to find a best measure to a problem when a large network with many control measures is present, in the case-based reasoning as discussed above. To bypass this difficulty, a dynamic simulation approach is used. The principle is as follows:

- code a traffic network, suitable for dynamic modelling,
- obtain a dynamic (time-sliced) OD matrix,
- load the OD into the network, with DTA (Dynamic Traffic Assignment) technique,
- introduce also traffic control and measures into the DTA loading process.

This would allow experts to choose only possible combination of measures to be evaluated in simulation, reducing potentially a large number of combinations with the case-based reasoning. Of course, it may happen that some relevant combinations are skipped or missed.

The real time generation of measures and its assessment by simulation looks as an interesting option, but has a limitation in the case of large cities like Beijing or Changsha. The standard procedure for traffic management measures is in some cities that they should be approved before implementation. This means that the operator can develop a control strategy and assess it by simulation, but he should get approval before implementation. Therefore, a simulation approach needs to be followed by a (slow) process of verification and approval, after which it can be inserted in the case base. This shows that a new decision support tool has to be combined with a task analysis and task reconstruction in order to be effective and usable (van Zuylen and Gerritsen, 1990).

A learning mechanism

At a traffic control centre, an experienced operator should know the performance of a specific measure or scenario (combination of various measures). This can also be established with a dynamic simulation where measures can be evaluated.

Performance of a measure or a scenario can be stored together in a relational database. A best performing one would replace or update the existing one in the database, or saved in the database if none is available yet. With this possibility, any scenario/measure, whether existing or new, can be simulated and evaluated. A best solution can emerge in practice.

Building a relational database of scenarios

The rule-based approach provides a robust and overall first level suggestion. This is based mainly on operators and practitioner's experiences. It stores effective scenarios as well as individual measure to problem, together with performing indicators, into a relational database (KBEST), where historical and simulation-based evaluation need to be performed to fill in the data. A dynamic traffic measure (Chen et al., 2004) is an action that produces signals to control traffic behaviour by informing, recommending, warning, facilitating, or enforcing. The case-based approach provides more specific measures and needs most efforts to prepare. Again similar info such as the rule-based cases is stored into the database.

The database contains these info: (1) event description (type, location and time, etc.), (2) traffic response (area, devices and time, etc.), and (3) measure of effectiveness (area, indicator, etc.). It is meant for both storage and retrieval. Further the measure will have also a location and time indication, so that implementation can take place. Together with performance indicators provided by a dynamic

simulation, this information will be stored into the KBEST for further retrieval.

The traffic management options can be distinguished in three categories:

- Local measures on single intersections,
- Coordination measures for adjacent intersections,
- Rerouting and access metering measures on a network wide scale.

Queues are unavoidable in time periods of large traffic demand. It is not a serious problem when drivers have to wait in a queue because they have to pass a capacity bottle neck in the network. The problem becomes serious when queues spill back to upstream intersections and block there the movement of vehicles that will not pass the bottleneck or when the queue spills back to the start of a turning lane and prevents turning traffic to enter these lanes. If this happens the network performance is reduced, which can be observed as a reduction of traffic flows.

The local measures are especially the adaptation of the traffic control, for instance to restore the balance between traffic demand and green phases and adapt the signal cycle to the actual traffic flows. Since the traffic controllers often work on a fixed cycle when there is congestion - since vehicle actuated signals will have green phases that extend to the maximum green length - a balance between demand and flows can lead to a different cycle time and green splits. Especially if spill back occurs, the traffic control on the downstream can be modified to increase the outflow of the link with spill back.

Coordination measures are taken to reduce the inflow to a link with spill back. We call this 'metering'. The consequence might be that the queue on that link disappears, but the queue on this metering intersections increase and may cause new spill back and grid lock (Le et al. 2013, Gazis and Potts 1962).

Rerouting is the measure to stimulate or force drivers to take a route that reduces the congestion in some area. It is obvious that such measures may just shift queues, unless the alternative route has sufficient capacity. Therefore, such rerouting measures should be well analysed before they are implemented.

The methodology described in this paper has been developed in Beijing at the first instance, and now for the city of Changsha, the capital of Hunan province in China. In Changsha the intersections are controlled by a SCATS system. This system monitors the traffic streams by loop detectors on nearly all lanes of the signalized intersections. Furthermore, all 6000 taxis in the city have a GPS on board that gives the position, driving direction and speed every 30 seconds. Both data sets have been used in this study.

III. Scenario analysis, generation and evaluation

To store effective scenarios (measures to problem) into KBEST and make them offline and online available, two sources are used: historical and simulated cases. Key aspects to support such process include: (a) a problem identification

based on a fuzzy matching procedure; and (b) a measure evaluation that can be performed according to performance indictors evaluated by a mesoscopic large-scale network dynamic simulation.
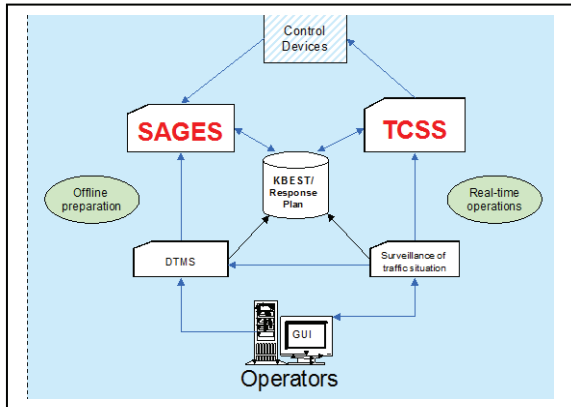

Figure 1: DSS Operations

A mesoscopic dynamic traffic simulation model is used to incorporate major traffic elements together and simulates their interactions. These elements include the traffic network, traffic demand (vehicles), traffic control, and network-wide traffic control strategy. The flows in the dynamic simulation are based on Dynamic Traffic Assignment (DTA) method.

The simulation program evaluates a measure to a given problem with respect to certain objectives and determines whether it is the good scenario in a given circumstance. This can be performed specifically for all recommended measures to all identified problems. More interesting is that it can be done offline to prepare the KBEST and using the expert experiences for matching measure to problem.

A successful evaluation gives us a good case to store effective scenarios into KBEST. They can be called later on by real-case operations. The case-based reasoning is applied in the following way:

- Check further whether there are cases available in KBEST; this includes checking the availability of a specific measure in the given area;
- If available, select or update the case, based on the maximum likelihood of cases. This is where KBEST is filled in and updated.

The selection and retrieval of scenarios is done by assessing the membership of scenarios. The match is based on traffic patterns parameterized by flow, speed, and travel time at given locations/areas or between defined OD pairs. How quick a scenario can be recommended to an online operation depends largely on the size of the case base KBEST and how fast the matching procedure runs.

The Scenario Analysis, Generation and Evaluation System (SAGES) allows users to customize with the DSS system and to learn how to identify major traffic problems and what impact a traffic management measure or control scheme has on the network traffic. Effective scenarios are then sent to real

operations (TCSS – Traffic Control and Surveillance System) for the traffic operators to execute the actions. See Figure 1.

Network-wide mesoscopic simulation

To access the impact of a given measure to a problem, two possibilities exist. One is to use a dynamic simulation to access the scenario offline, and the other is to evaluate it on-site by real operations observation. See Figure 1. Both methods are adopted, by testing first offline with a dynamic simulation and then implement and test online. At this moment with on-going development, only the simulation method is presented in this paper.

Network and data model

Our first application case was the whole Beijing network that includes the major arterials and the 5th ring road (circular distance of 66 km) and the inside area. The city centre is within the 2nd ring, and the Olympic area between 3rd and 4th ring of the north part of the city. The network contains more than 610 zones, with 24 matrices sliced at 10 minutes each (a typical day from 7:00 to 11:00).

Each link is coded with a type, number of lanes (or turn-bay), as well as a traffic flow model to apply. Variable message signs (VMS), incident, work zone and ramp metering are also added to each link. Each node (junction) has a type, controlled or not, with turning movements.

Calibration of a simulation model

Dynasmart-P (Mahmassani 2004) has been chosen for such an application. It uses a modified Greenshields model for the traffic propagation, which takes into account relationship between speed and density. On major sections, Greenshields traffic flow models are estimated, using time-sliced traffic counts. This has been done in a few chosen areas and for different types of roads, ring roads, arterials, etc. An overall flow display per 2 minutes, combining counts, CCTV (camera) monitoring, road work and congestion report are also used to calibrate the running Dynasmart model.

IV. Application case

The initial case in Beijing is reported in previous sections and in (Chen, 2005). This section reports the case that is being implemented for a large urban area in Changsha.

Identifying network-wide traffic problems

The network for which we applied the queue management methods is a part of the CBD of Changsha, the capital of Hunan, P.R. China. The city centre experiences frequent congestion. Notwithstanding investments in traffic control, installation of Variable Message Signs (VMS) and adaptation in the road geometry, congestion occurs daily during the peak hours. In several cases congestion spills back to upstream intersections causing a reduction of their performance.

The map of the area is given in Figure 2. As shown in Figure 3, spillback (marked in red line in Figure 2) occurs on the Laodong Road between the intersection with the Shaoshan

North Road (North-South road crossing the red circle) and the Furong Middle Road (parallel road at the left junction to the red circle). The critical road section is the one between these two parallel roads. According to Figure 3, the critical time is between 8:00 and 8:30, while the queue spillback occurs around 8:15.

In Figure 3, the GPS positions of stopped and slowly driving taxis are visualize between 8:00 and 10:00 (time is on the horizontal axis). Their position in meters along the road is along the vertical axis. The intersections are 1870 m and 2910 m resp.
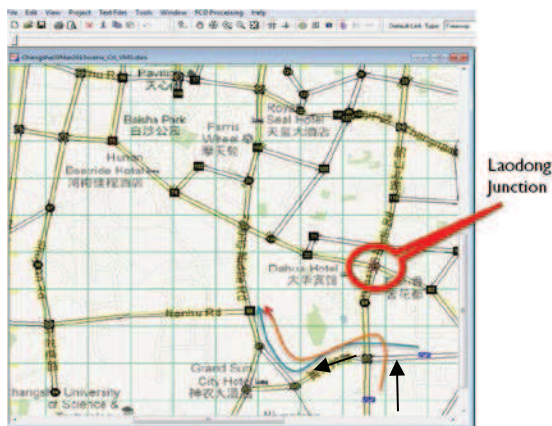
Figure 2: Map of the application area with the queue spillback on the Laodong road
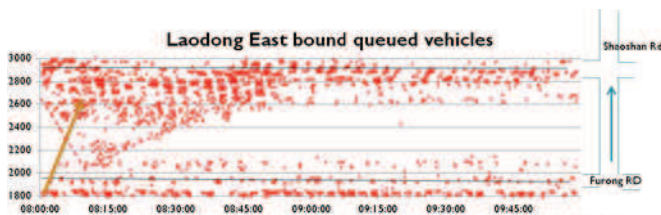

Figure 3: Positions of taxis at low or zero speed along a road (Laodong Road in Changsha) and emerging queue spillback). Horizontal axis gives the time of the day, the vertical the position of taxis along the road.

One can observe that a queue builds up between 8:00 and 8:15 and that this queue spills back to the Furong Middle Road intersection. Observing the threatening spill back is not too complicated using the GPS data, the flow data and the traffic control (van Zuylen, 2010). This is a mesoscopic monitoring approach based on average microscopic traffic data.

Selection and Application of a scenario and control strategy

Possible strategy to alleviate the congestion could be the following options:
- allocate the queues on links that can act as buffer space with sufficient room to avoid spill back to critical intersections, or
- reroute traffic over intersections that have still sufficient capacity.

Buffer space has a limited storage capacity and will have a temporal character. If we assume that traffic will continue to follow the same routes, buffering is simply done by metering the inflow of the critical link or by giving the flow on the critical link more green time at the cost of other direction on the critical intersection (Chaudry, 2013, Le et al. 2013). The consequence of both solutions is that queues develop at other links than the critical on. This is, of course, a temporal solution (Li, 2012).

Therefore, the criterion for additional control action is the position of the back of the queue with respect to the length of the link. In Changsha the queue length can be estimated from the positions of the taxis that are standing still or are moving with low speed.
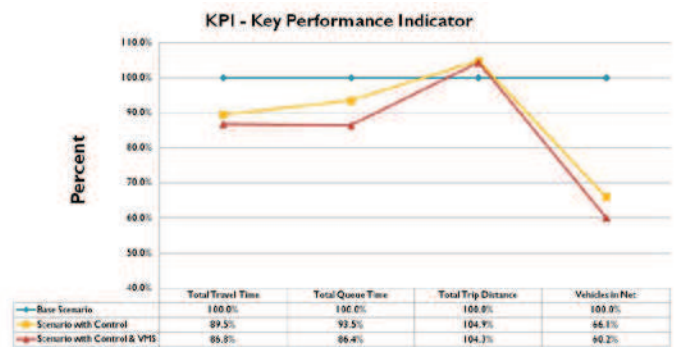

Figure 4: KPI of a scenario

A check on the available queuing space in that time period showed that some buffer space was still available on the Laodong Road West of the intersection with the Furong Middle Road. The intersection between Shaoshan Middle Road and Chengnan East Road had a rather high load. On the South side of the critical area, the Huangtuling Road still had space and intersection capacity.

The metering and rerouting strategy becomes, therefore, to restrict the inflow to the Laodong Road (red circle in Figure 2) from the intersection at the Furong Middle Road during the period 8:00 to 8:15, and to give traffic coming over the Shaoshan North Road from the South (of red circled junction) the advice to use the Huangtuling Road (indicated by orange line) to turn Westwards instead of turning left on the critical intersection, as depicted in black arrowed lines and blue and orange lines.

This rerouting strategy is depicted in Figure 2, where both VMS and junction control are adapted. For the control setting

(red circle junction), the left turn from south to west at the critical junction is separated and reduced to a minimum level. This is tested in the simulation model. Simulation results show that this rerouting plus the traffic control optimization at the critical junction improves the junction flow and reduces largely the spillback. Effective scenario could be found for a given bottleneck as shown with KPI in Figure 4. We can see that the total travel time and total queue time are reduced by an average of 10%, and the number of vehicles remaining in the simulation period is reduced by 30%. We can see also that the introduction of VMS does increase the total trip distance, by about 4%.

A scenario based decision support system for the traffic managers

The combination of a traffic state and suitable traffic measures is called a scenario. Several of such scenarios can be prepared in advance. If the traffic conditions of some scenario occur, the traffic measures that can deal with this situation can be recommended to the traffic managers. The structure of such a decision support system is that traffic data is collected in real time and stored in a database after initial processing. The stored historical data are used to develop scenarios. The scenarios are also stored in the database. If some specific situation occurs, a scenario can be presented to the traffic managers who can chose to implement the measures. That can be done using the traffic signals, by giving information on VMS, by manual control by policemen on the spot and by giving information to road users. The total system iTides (Chen et al, 2013) is being developed now for the city of Changsha and will be implemented this year. See Figure 5.
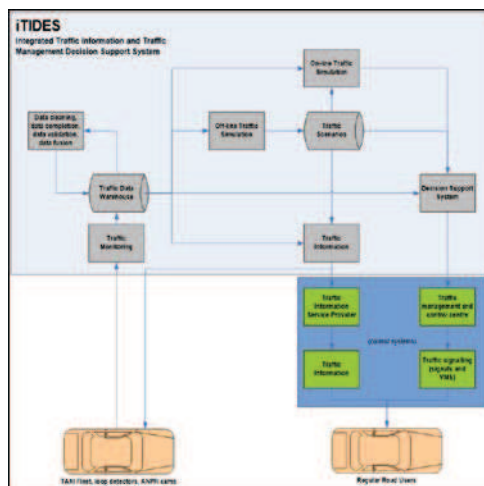

Figure 5: iTides Framework

V. Concluding remarks

In Changsha now for a large urban network with huge amount of mixed traffic, a self-learning mechanism is being implemented in the three level decision support process, which is based on best practice and case-based reasoning. Key is to select and prepare effective scenarios by historical and simulated cases, and then to store and retrieve these scenarios into KBEST for further use. Dynamic simulation has been used for offline assessment and the evaluation of relevant scenarios and the KBEST provides background for case-based selection. Further development and the test of systems are on-going in Changsha.

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