SYSTEM ARCHITECTURE OF THE DECISION SUPPORT SYSTEM EMPLOYING MICROSCOPIC SIMULATION AND EXPERT SYSTEM IN PARALLEL FOR THE POST INCIDENT TRAFFIC MANAGEMENT

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Keywords: Traffic management center, Micro simulation, Expert system.

Abstract: This paper presents system architecture of the *post-incident decision support system* (PIDSS), which incorporates the predicted incident impacts from an offline microscopic simulation platform into an expert system. The system yields an immediate operational strategy for the freeway managers that can further be fine-tuned with the online simulation results. The novel idea presented in this paper is the replacement of the domain expert and knowledge engineer with the output of the microscopic simulation that would make post incident congestion mitigation on the road network more efficient and cost effective.

1 INTRODUCTION

Non-recurring congestion is the result of traffic accidents, bad weather, road works or unplanned special event that disrupts traffic flows and causes unexpected delays. It abruptly reduces the available capacity and reliability of the entire transportation system and thus needs to be intelligently tackled. .The orthodox approach of tackling the non-recurring congestion relies heavily on the individual expertise and experience of the traffic managers who tend to nominate certain heuristics (or *guesswork*) about the impacts of an incident. This approach may cause time loss and induces inconsistency in the entire incident management operation resulting in an inefficient use of resources and uncoordinated mitigation strategy.

In a post-incident scenario, the problems faced by the traffic managers at the Traffic Management Center (TMC) have also been acknowledged by Nagel and Schreckenberg (1992) and there have been a significant number of other attempts in this area by researchers as well as practitioners (Hayashi, Morisugi, 2000; Yoon, et al., 2008). However initial algorithms for the incident related congestion mitigation were mainly based on the analytical models, knowledge-based expert system and geographic information system (GIS). (Xaichen and Daniel, 1995) used cellular automata (CA) model for the prediction of flows using real-time inductance loop data for freeway traffic that demonstrates the viability to integrate inductance loop data, cellular automata and car-following models to simulate the traffic dynamics for the prediction of the post incident traffic flows.

This article imparts the system architecture of a hybrid solution that is named as *post-incident decision support system* (PIDSS) that employs micro-simulation in conjunction with intelligent system for the analysis based traffic management. The cornerstone of the approach is an appreciation of the real incident scenario that demands an expeditious decision and the participation of the local network managers for the optimal effectiveness and coherence through automation of the whole post incident decision-making process. The feasibility aspects and specification of requirements of PIDSS are discussed along with its ability to work in post-incident scenario for the efficient functioning of the freeways as well as the urban road networks.

Akhtar Ali Shah S. and Kim H..
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DOI: 10.5220/0003385301130117
In *Proceedings of the 13th International Conference on Enterprise Information Systems* (ICEIS-2011), pages 113-117
ISBN: 978-989-8425-54-6

2 THE CONCEPTUAL FRAMEWORK OF PIDSS

The conceptual framework of PIDSS is based on associating the output of the *freeway incident analysis system* (FIAS), in the whole process of traffic management and modifying the mitigatory measures as per online simulated results (Figure1). The FIAS, which was developed earlier by the authors and has been, discussed elsewhere in detail (Kim et al., 2004 and Shah et al. 2008) employs historical data supplemented with the real-time data from the toll collection system (TCS) and the vehicle detection system (VDS) as well as the spatial data on micro-simulation platform.

The perception of an incident and its impact forecasting is the kernel in the whole process of non-recurrent congestion management and needs to be consistently measured with a significant degree of reliability. In this context, findings of the micro simulator (FIAS) are found useful and can be injected as a replacement to the traditional heuristics that are neither consistent nor tangible. As online simulation needs certain time before displaying the impacts of an incident and the scenario requires immediate mitigatory measure, therefore, offline simulation results are used to devise an immediate mitigatory plan that shall be refined and updated once real-time incident impact data is available (Figure 1).

3 KNOWLEDGE-BASED EXPERT SYSTEM

In a post-incident scenario, a knowledge-based expert system (KBES) has been conventionally

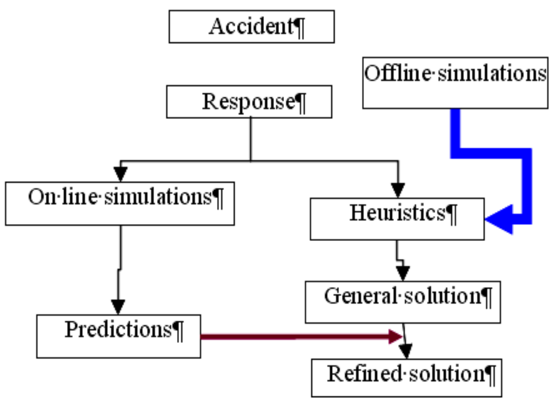

Figure 1: A conceptual framework of PIDSS.

recommended because of its potentials to streamline and automat certain low level procedural tasks and emulate the experienced traffic manager (Zhang and Ritchie 1994; Ritchie, 1990; Flippo and Ritchie, 2002). The essence of these systems is the application of expert's knowledge in a narrow and well-defined problem arena. A KBES can employ symbolic reasoning and heuristics in problem solving that enhances its suitability for the complex scenario analysis with deficient algorithmic solution (Mitrovich, et al., 2006).

Santa Monica Freeway Smart Corridor (Flippo and Ritchie, 2002) project was one of the very first attempt in which a full-fledged real-time knowledge-based expert system was employed for the traffic surveillance and control purposes. In this work, a conceptual framework of a multiple real-time knowledge-based expert system was suggested. Zhang and Ritchie (2004) propose a knowledge-based expert system and name it as *freeway real-time expert system demonstration* (FRED). Their proposed methodology is to follow experienced TMC operators' and traffic engineers' approach using an expert system. It incorporates symbolic reasoning and heuristics for solving the problem. This system is capable of network level operations, multiple incident handling, better user interface and incident recovery monitoring. Nonetheless, FRED does not predict the post-incident traffic delays and the significance of the historic data are also not realized in the analysis.

In another attempt (op cit.) a knowledge-based system is employed focusing on the cooperative inter-jurisdictional traffic management. The system adopts a multi-decision maker approach that reflects the spatial and administrative organization of traffic management agencies in US cities. It provides a cooperative solution that exploits the willingness of agencies to cooperate and unify their problem solving capabilities without compromising their individual authority and the inherent distribution of data and expertise.

4 SYSTEM ARCHITECTURE

The indispensable part of modelling is to establish a logical information exchange between the user and the system besides *in vitro* processing and simulation methods that takes place within the system. System architecture constitutes interactions amongst various components of the system for achieving predefined user objective. The two elements of system architecture of PIDSS are described in greater depth below.

4.1 Logical Architecture

The logical architecture of PIDSS (Figure 2) primarily considered as a 'specification of requirement' upon which the working model of deployment guide exists. The main activity flow diagram is flanked with two fundamental units of the architecture: FIAS and the Simulation Based Expert System (SBES). Incident detection (using prevailing algorithms like speed map) and verification is followed with the insertion of incident parameters like type, severity, cross sectional location, time, number of vehicle involved in the expert system. The domain of the expert system extends from incident categorization based on input parameters; through impact assessment for encapsulating each individual category of incident; to the application of different mitigatory measures. These tools are mostly ITS applications that are primarily operation and information oriented at local level but may cause significant travel and traffic impacts at a regional levels.

Autonomously, managers also instigate FIAS for the cross reference and any subsequent tuning in the impact assessment is based on online simulation in the later stages of operation. SBES also contains a significantly large data bank of offline coordinated relative weight of individual measures and its linear combination for the optimal mitigatory impacts. The relative weights are derived from the significance of each measure and its overall performance and impacts on the operational functioning of the whole network.

The coordinated initial mitigatory plan is thus injected into the system that has been locally optimized and is reviewed for any changes in consultation with the lower tier of the system network at local level to avoid any friction from other stakeholders in the system before effectuation. This pluralistic approach is essential and highly recommended to use the full potential of the physical infrastructure. The system also provides a real-time monitoring mechanism that suggests improvement in a running mitigatory plan or any of its components. This is supplemented with a post-incident evaluation that helps in the expert system database evolution.

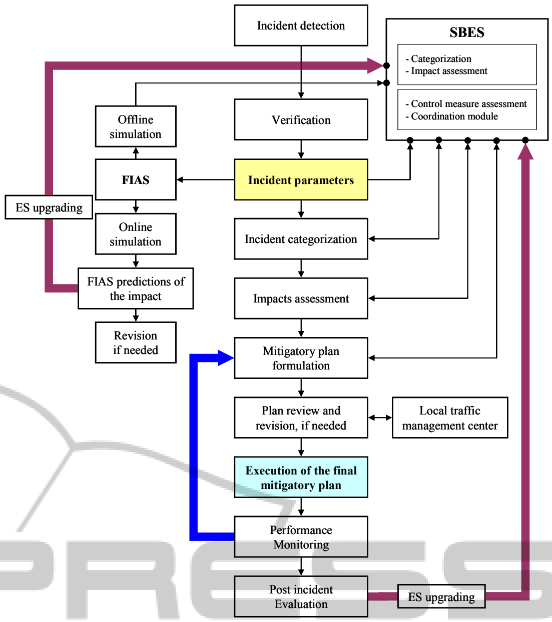

Figure 2: The logical framework of PIDSS.

4.2 Physical Architecture

The physical architecture of PIDSS (Figure 3) addresses organization of the system on the functional lines which is based on information flow mapping and logical modeling. It supports a range of evaluation conditions and effectuation strategies in terms of standardized framework of the logical architecture. The architecture generates information in a format that is more tangible and can invoke a locally optimized and globally integrated mitigatory plan at its terminal point.

Traffic managers are placed at the crux level and have interfacing with every internal subsystem and execute a control over all data flow. The essential architectural flows in the key logical units like incident categorization; impact assessment or strategy coordination with the local traffic mangers encapsulates huge data sharing and information exchange between the terminal point and the subsystem. The manger, who has access to the essential ITS infrastructure like the surveillance system; verification infrastructure; FTMS and *highway geographic information system* (HGIS) server, injects incident parameters into the Expert System

4.3 Simulation based Expert System

Collecting knowledge needed to solve problems and build the knowledge base continues to be the biggest bottleneck in building expert systems. This impedance is resolved in this hybrid system by replacing an expert domain of a conventional expert system with the microscopic simulation platform trained in knowledge acquisition and representation into a dependency network. The high level structure around the fundamental activities of the system defined in the logical architecture is realized in an orthodox transport planning paradigm with two typical modules: analysis and intervention. The analysis stage is further sub classified into main categories incident categorization and impact assessment module. The intervention stage encompasses coordination (with the local agency) module and mitigatory measure module. The key modules of the stages are discussed below.

4.3.1 Incident Categorization Module

This is an ES tool that provides a representation scheme for incident categorization expressing knowledge about parameters and categories. Parameters include location, type and severity, number of vehicles involved, critical section and capacity reduction, estimated duration, and location of the nearest rescue infrastructure. These parameters classify the incident into previously defined categories as per type and combination of parameters.

4.3.2 Impact Assessment Module

This module is one of the indispensable components of the proposed expert system. It replaces the conventional knowledge base with both off and on-line versions of FIAS impacts of all predefined categories, which are assessed and tabulated as a knowledge base. The FIAS off line simulation module is a major component in the knowledge base that encapsulates all categories of an incident for impacts prediction and subsequent indexing. On-line FIAS predictions bring dynamism in the system with the supplementation of real-time scenario.

4.3.3 Coordination Module

Several research development and deployment projects have acknowledged the importance of multi-agent, coordinated and inter-jurisdictional approach that was reported by Flippo and Ritchie, (2002). The multi-decision making in PIDSS simplifies the scenario by executing a knowledge base for the priorities of the local authority of the abutting road network regarding different mitigatory measures and its diversity with the many other parameters like category, type and location of the incident and its impacts on the general flows in the area. These knowledge bases shall be reviewed periodically and updated by assigning the revised priority through relative weighting system approach. Besides the real-time participation of the local agencies is also insured using a fast TCP/IP based communication protocol.

4.3.4 Mitigatory Plan Formulation Module

Mitigatory plan can be classified into two groups: Preliminary and revised. The preliminary plan originates from the knowledge-based relative weighting system of individual mitigatory operation selected by the respective stakeholders from the local areas as well as the freeway agencies. However the dynamism of the system allows for any real-time incorporation of the changes in the values of the relative weighting depending upon the revised priorities for any local reason like time of the day, conditions of the network and so on. These revisions are amalgamated into the plan, which will be regarded as the revised plan and executed. The real-time coordination with the local agents allows for the optimization and globalization of a solution using the full potentials of the network as a unit.

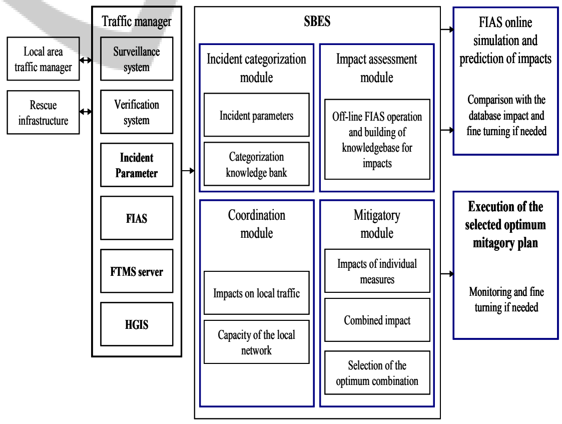

Figure 3: Physical architecture of PIDSS.

5 DISCUSSIONS AND CONCLUSIONS

This paper discusses an application of transport telematics to automate decision support for the TMC personnel in the post-incident scenario using a hybrid system of microscopic simulation and artificial intelligence. The unique feature of PIDSS is the immediate decision making in the crises state incorporating offline simulation results used to instigate a preliminary mitigatory plan. The tool facilitates local integration for a regional solution incorporating the predefined interest of all key stakeholders employing relative weighting algorithm, which is rapidly coordinated and updated using IT infrastructure. This initial plan is revised with the FIAS online simulation for incidents impacts prediction that incorporates real data with historical and spatial data in the incident analysis stage. The flexibility of the tools allows for the incorporation of the priority revision of all stakeholders with mutual understanding and collaboration.

In the development of PIDSS, unlike some of the known algorithms (Zhang and Ritchie 1994; Ritchie, 1990; Flippo and Ritchie, 2002), a different approach of the knowledge acquisition was opted. The domain expert was replaced with the microscopic simulation platform, trained in knowledge acquisition and representation. Using a data manipulation algorithm the outputs of simulation are transformed into dependency networks (an outline of the rules), which is subsequently coded and programmed into the system. Thus the simulation replaces both the expert domain (the source of knowledge) and the designers of the expert system (knowledge engineer). The most obvious advantage of this development method is its cost effectiveness to build expert systems to eliminate the need for an expert domain and the knowledge engineer for the extraction and representation of knowledge. Nonetheless the crucial advantage is the speed, coordination and time saving in a crisis scenario.

PIDSS knowledge base is rooted into a microscopic simulation based model that predicts the post-incident traffic impacts, which is imperative for the real-time incident analysis and improves the functioning of TMC. It is anticipated that the incident analysis result in this format will help the traffic managers to take significantly consistent steps based on tangible information and not the speculative approach.

ACKNOWLEDGEMENTS

Part of this paper was developed in collaboration with the Korea Highway Corporation (KHC). However its content reflects views of the authors; it neither constitutes a standard, specification or regulation nor official views or policy of the KHC.

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