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Resilience of Incident Management in Smart Cities

Leon Rothkrantz

***Abstract*— The grow of urban environments caused many problems in traffic networks. On the roads in and around an urban environment many traffic incidents happen all the time, especially during rush hours or bad weather conditions. To minimize the negative impacts, an incident scene has to be cleared as soon as possible. Additional delay has been caused by bad communication and missing information. In this paper we present a new IT system based on the framework JADE (Java Agent DEvelopment). The system offers a blackboard like functionality for communication of first responders at the incident scene and control rooms. The system has been implemented and tested in laboratory settings and shows a significant reduction of incident process time. As a consequence, the resilience of traffic network in urban areas has been improved by better incident management and communication.**

***Index Terms*—Crisis App, JADE, Resilience Triangle, Traffic Incident Management.**

I. Introduction

THIS paper presents a study of resilience of traffic network in urban areas. By resilience we mean the ability of a system to quickly return to normal operating conditions after some disturbance. Incident management and communication play an important role in the assessment of resilience after a traffic incident. Observation and reports of incidents and communication around incidents may be incomplete, erroneous and redundant. Agent technology, agents' systems and distributed blackboard systems will be used to realize an efficient, effective communication and information around incidents.

In case an incident happens on a road in or around a city, observers dial the general emergence number 112 to inform the control room of the emergence services in the Netherlands. The three main emergence services are fire brigade, police and ambulance. The operator in the emergency control room will ask for location of the incident and description of the incident, if there are victims, danger for by standers or environment. Reports of eyewitnesses are usual full of emotions, incomplete or contain not relevant or even wrong information. Successive callers may report similar information, so there is a lot of redundancy. Next the emergency call is routed to the crisis coordination center of the three emergency services. Usual one or more surveillance police cars are sent to the place of incident to report details of the incident and start to safe the area and provide first help to the victims. In case fire and ambulance are alarmed. To decrease the ambiguity of reports of first responders, to complete the observation, a Crisis App has been developed for first responders. First responders have access to the description of crisis events, may complete the information and are alarmed in case new information is available.

Usual more than one first responders are involved and it is agreed that the fire brigade commander has the lead. But unfortunately, responders are triggered by events such as helping victims and don't take care of all the procedures, responsibilities and priority rules. As a consequence, many actions take place in an uncoordinated way, resulting in loss of time and clearance of the traffic incident. In the new system responders report their observation, plans and actions in an agent-based network around an incident.

At this moment first responders are equipped with cameras and microphones. First responders are supposed to report about their observations, plans and actions. They take appropriate pictures and spoken messages and send them to the communication network. There is no time to process these data by responders at the incident location. A network of communication agents has been designed, recording messages and process the information by fusing or deleting or launching special actions. These activities will take place in a network of distributed Blackboards.

One of the biggest problems is that first responders prefer to use their mobile phone in their communication with their colleagues. This verbal communication is fast and easy but automated processing of this data is complicated. Communication by public networks is not secure at all and will be overloaded if communication takes place via social networks. For that reason, Emergence Services in the Netherlands developed their own communication system, C2000. This special network guarantees security and available bandwidth. The only problem is that the interface is not as user-friendly. For that reason, we developed the special user-friendly Crisis App for reporting and communication.

Many operators at crisis center have a long year experience. In case of a traffic incident, they will be triggered by the first reported features. They construct a hypothesis about what is possible going on and stick to that hypothesis until new contradicting information appears. The positive aspect is that

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operators are able to reason with incomplete, ambiguous information, the negative aspect is that they may suffer from "tunnel-vision". On our distributed Blackboard system, we used a knowledge-based system to process recorded data. Bayesian expert-systems have been used to reason with ambiguous, incomplete observations data. Maybe the designed system scores less than experienced first responders. But such systems make the reasoning process transparent and reasons with complete distributed data and recorded knowledge from the past.

To summarize, the goal of our research is:

-Designing and developing a prototype of a distributed agent-based system to handle traffic incidents in urban areas.

-Improving communication and data storage around traffic incidents in urban areas.

-Implementing knowledge and experience of first responders of traffic incidents in procedures and knowledge-based systems.

-Testing the model developed in [1] to measure resilience of traffic networks in urban areas.

II. RELATED WORK

Researchers of Delft University of Technology and TNO are for many years involved in research on road traffic resilience. In [1] they developed an indicator to detect poorly resilient road sections. The indicator called Link Performance Index for Resilience (LPIR) has been tested to analyze recovery and prevention of traffic congestions on road segments. The authors discuss the following related concepts: reliability, vulnerability, robustness and resilience. Resilience was defined as "the ability of a system to cope with disturbances and recover its original function after a loss function". The performance of traffic flow on road segments or network using the developed system was tested in some experiments on roads around the city of Delft, Rotterdam and The Hague. Our research fits in the framework TRAIL, the research school in the Netherlands on traffic and transport.

TRAIL is the Netherlands Research School on TRAnsport, Infrastructure and Logistics. It is a cooperation between 6 Dutch Universities, including Delft University of Technology. The Independent Research Organization TNO is also a member of TRAIL Artificial Intelligence and related research topics are dominant over the years in TRAIL. In the TRAIL-work of Vink [2] the AI concept Blackboard has been used to design a system for Traffic Incident Management, called Incident Management Information and Communication System. Pronk [3] puts a focus on agents and computed resilience along Dutch roads using simulation tools and an agent-based traffic model. Both AI-topics play an important role in our research. Our developed System Resilience Traffic (ResilTraf) [4] is a continuation of previous work of Vink (Incident Management Information and Communication Systems, IMICS) and Pronk.

The research project [5] is based on a multi-agent approach. The authors research the literature on traffic management in Australia and New Zealand. They developed a new framework for Traffic Management, integrating common practice and technology. The project was inspiring because the authors used real agencies to model their agent-based approach. In our research we used a similar approach.

The authors study in [6] the traffic accident profile in the city of Legazpi on the Philippines. The system architecture was based on activity diagrams. An emergency response system was proposed to improve the communication and coordination process. There was a special focus on improvement of the community awareness process. Users may send a report of incidents and location to a nearby response unit. A similar approach was used in our research project. The proposed system architecture was evaluated using the Architecture Tradeoff Analysis Method.

Reference [7] reports the work of the Rockefeller Foundation and its strategy partner ARUP a company involved in eco-research, supporting 100 cities to develop as Resilient Cities. They developed the city resilience wheel. According to the Rockefeller Foundation, urban governance needs to be: Flexible, Redundant, Robust, Resourceful, Reflective, Inclusive and Integrated. ARUP developed a "city resilience framework". Key terms in this framework are "reliable mobility and communication". Both topics are researched in our paper.

In [8], the authors studied the impact of malignant traffic accidents on the operation of a city in some simulation studies. They used SUMO, Simulation Software of Urban Mobility and show the whole process of traffic accident starting from an initial stable period, disruption period, stable period after disruption, recovery period and stable period after recovery. The underlying theoretical model is based on the relation of the "6R" concepts redundancy, reduction, robustness, recovery, reinforcement and rapidity and the main concept resilience. This model is an extension of the classical 4R resilience theory as discussed in the paper of [1]. They also analyze the ideal resilience curve and the results are discussed in our paper.

In paper [9] five measures of urban highway network resilience are discussed consistent with the concept of resilience triangle. The involved features are queue length, link speed, link travel time, frontage road delay and detour route delay.

The authors of [10] discuss resilience in the framework of shocks in urban systems. They state that resilience focused on urban mobility has increasing interest of researchers. But applications of simple mobility indicators are still missing. The authors propose a resilience evaluation method to define a resilience indicator based on available origin-destination datasets. The research has been performed in some urban areas in Brazil.

III. COMMUNICATION AND INFORMATION

The process of communication and information plays an important role in incident management. In the Introduction we reported that this process has some shortcomings. The main goal of our research was to design a new system to improve the process of communication and information. The new system is composed of the following modules:

-Crisis App. To report information around traffic incidents and corresponding actions, first responders are supposed to use a special Crisis App.

-Distributed Blackboards. The information from the Crisis

App will be stored on Blackboards. This information will be processed and distributed via a network of cooperative agents.

-Knowledge Based Systems. The storage and distribution of information on the Blackboards will be performed by agents. These agents operate according to specific procedures and rules.

A. Crisis App

In case of an incident first responders are requested to report their observations and request for help via a special App on their mobile. The goal of the App is to get a complete description of an incident in a standard way. In the past first responders use their own individual way of reporting events. It proved that this information was incomplete, ambiguous, wrong or not relevant. In case of a new report of an incident or an update, connected first responders in the environment get an alarming message. On the interface of the Crisis App a specific button starts flashing. The distribution of this messages is according to strict rules. Selected responders are requested to perform some actions.

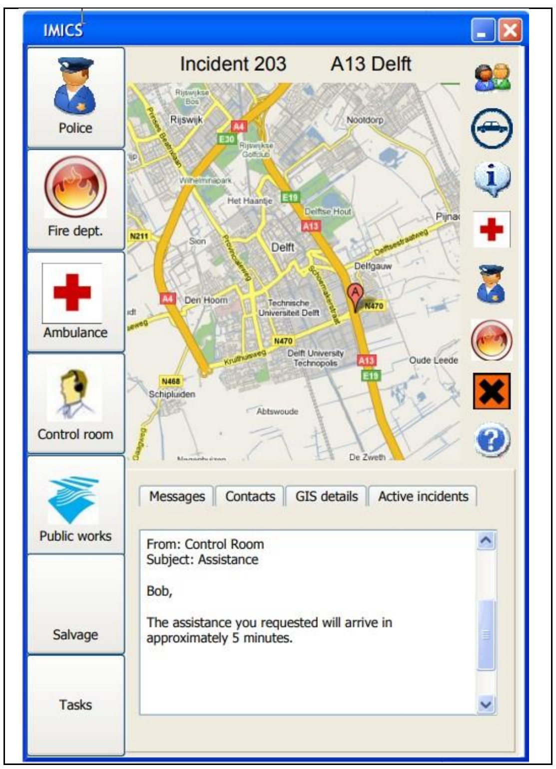

Fig. 1. Crisis App used by first responders to report traffic incidents.

During a crisis/traffic incident many people use their mobile to report their situation and request for help. It may happen that the network will be overloaded and even rescue workers are not able to communicate. For that reason a special network C2000 has been developed in the Netherlands. The system is composed of freestanding transmitters and antenna installations at roof locations. Much effort has been investigated to design a secure system under own control and to be independent of commercial systems. The C2000 network enables fast and safe communication between emergency services (police, fire brigade, ambulance services and parts of the Ministry of Defence such as the Royal Netherlands Marechaussee). Employees of the emergency services are able to communicate with the control room via their walkie-talkie and mobile radio. The preferred modality is speech. But in noisy environments, and overcrowded network with multiple partners, speech communication may be complicated. For that reason, we developed a special interface for "text"-communication (see Fig. 1). A rescue worker is able to generate a text message via the Chat box. By pressing one or more buttons at the left side of the interface, the message can be sent to corresponding emergence services. And from the other side if one of the buttons start flashing there is an incoming message, which can be visualized in the text-box.

We designed an emergency network for every city. The nodes of the network are composed of the fire brigade stations, police offices, hospital/medical services, ambulance services, municipality house. As an example, we display a map of the city of Delft, with possibility to visualize nodes and links of the communication network. The nodes are fire brigade station, police stations and medical centers. The city is crossed by a highway, connected by a city ring. At regular time traffic incidents happen at the slipstreams of the highway, but also on roads near schools. A telephone call of an observer alerts the whole emergency network as described in the next section.

B. Distributed Blackboards

First responders send a description of traffic incidents and related actions to the central Emergency room using the Crisis App. It cannot be expected that they will inform all stakeholders and distribute updated versions of the crisis event. One of the problems in the past was that first responders didn't share their findings and informed stakeholders according to the defined protocols. For that reason, we developed a system of distributed Blackboards. The main container has been installed on the server of the Control room and sub containers on a distributed system of Blackboards ending at the mobiles of the first responders (see Fig. 4).

To implement the system, we used the Java Agent Development framework (JADE) as an open-source implementation of the FIPA standard. Figure 3 shows how mobile phones, handhelds, servers and desktops can be integrated, using LEAP, containers that provide a homogeneous API on all platforms. This makes it possible for agents on a handheld to communicate with agents on a server and vice versa, over fixed Internet connections and wireless connections. Each client node has a local Blackboard facilitating storage and functionality. The server has a central Blackboard with which all client blackboards exchange data. The central Blackboard is responsible for receiving updates and distributing the new data to the client Blackboards. The central Blackboard is also responsible for data exchange with external systems (e.g. license registration database). If a client node loses its connection to the system, it cannot receive updates. To keep users as up-to-date as possible, the server will send the missed updates to the client as soon as the connection has been re-established.

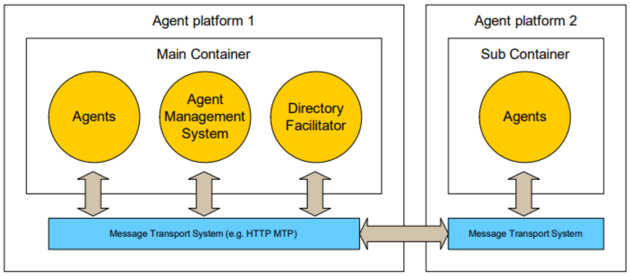

Fig. 2. System of Distributed Blackboards.

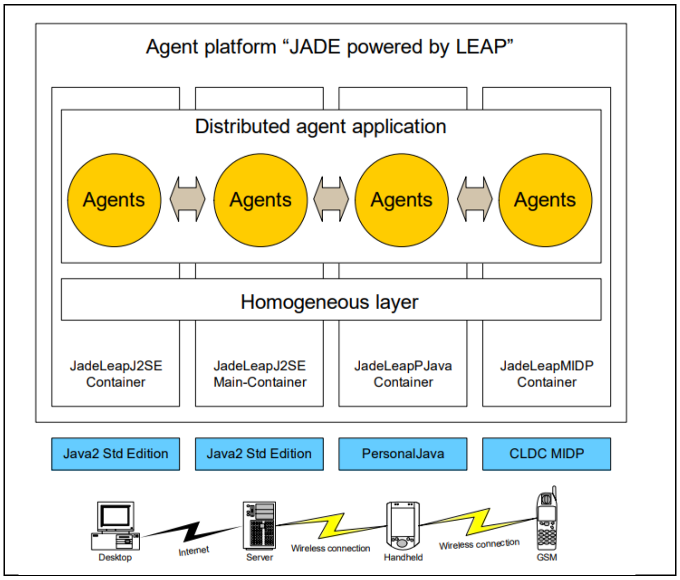

Fig. 3. System of Distributed Agents including mobile phones, handhelds, servers and desktop.

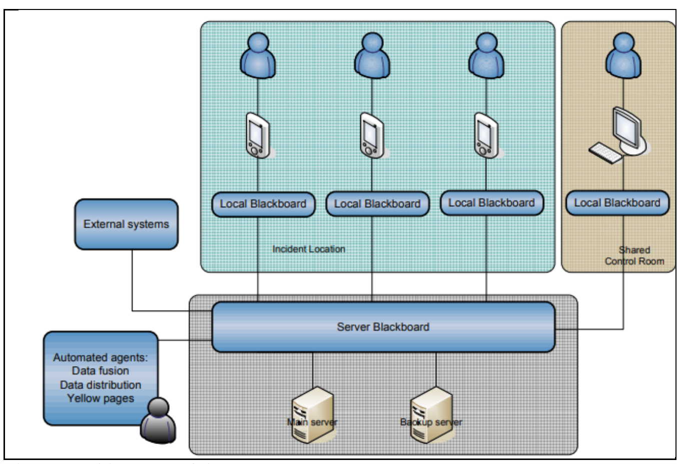

Fig. 4. Architecture of the system.

The architecture of our system is composed of distributed Blackboards as displayed in Figure 4. If a new traffic incident happens on the roads in around Delft, this is usually observed by citizens who report this via their smartphone to the control room. All these messages are placed on the server Blackboard of the Control Room. Observations by citizens maybe incomplete, ambiguous or even wrong. Special agents are activated to process observation messages reported via a special template. Traffic incidents should be reported using a special standard protocol. Citizens send a message composed of a string of keywords, which are converted to the template. If information is missing or ambiguous and not reported by other observers, a request is sent to the observer to complete their message. As soon as the report is more or less correct and complete, the message is forwarded to the local blackboards and can be visualized by first responders.

There is a special protocol how incidents are reported. First the command of the local fire brigade is alerted to take the lead. Police officers from the local police are alerted to move to the place of traffic incidents and report their observations. In case there are one or more victims an alert message is launched to the medical service. It is up to the local commander if the incidents will be upscaled. This will be the case if many cars and victims are reported, or related incidents on nearby places. We observe that one or more emergency services is activated to go to the place of incident and perform some actions. A crucial aspect of our system is that all events are reported and shared between the emergence services.

C. *Knowledge Based Systems*

Every day many traffic incidents occur on the roads in and around cities. Incidents are reported by citizens using their smart phones. Such messages maybe incomplete, ambiguous, contain errors or even fake. The crisis messages in 2020 around the city of Delft were collected in a database. Incidents maybe a crash of a car, other vehicles or pedestrians may be involved. There may be only car damage but also victims.

A model of incidents has been developed. The data is ordered in 5 subsets location, traffic, vehicles, persons and risk factors. An example of template "incident" is displayed in Fig. 5. To record the observations in a structured way, a Crisis App has been developed as displayed in Fig. 1. This App was modelled on the bases of recorded messages of traffic incidents in 2020.

The Crisis App is composed of many open slots and has to be filled with data such as location of incident, traffic, vehicles, persons, risk factors. The messages of civilians send to the Control Room are usually composed of a "one liner" and some keywords. Manual processing of the observation data takes too much time and effort. An automated procedure has been designed. A list of keywords, alias, synonyms, abbreviations, stemming has been extracted from the database of recorded messages. Templates of possible types of incidents has been designed. And the recorded list of keywords is ordered on the slots of templates.

In case of a new incident citizens send their observation to the emergency room using their smart phone. Such a message maybe incomplete, ambiguous, contain errors or even fake. To process incoming messages, they are first placed on the Blackboard of the Control room. Different types of agents process the messages on the Blackboard. Keywords are detected and relevant information is placed in the Crisis App. Next an appropriate template of incident will be selected. If more keywords are detected the choice of incident will be adapted in case of ambiguity or wrong information slots can be filled with double info. After verification by additional messages, slot filling with low frequency will be deleted. In case some slots are still open a request is send to observers for additional info. A request is sent to the police station to direct a first responder for verification. Finally, the info form of the Crisis App and corresponding templates are placed on the Blackboard.

If victims are reported an ambulance is send to the place of incident. If smoke, fire, toxic or other dangerous substances are reported a fire brigade car is send to the place of incident. All first responders use the Crisis app to update, ambiguate or complete the reported incident. The communication process is ruled by agents but still under supervision of human agents. Standard rules and procedures are executed by agents but more complex cases are still a task of human agents for the time being.

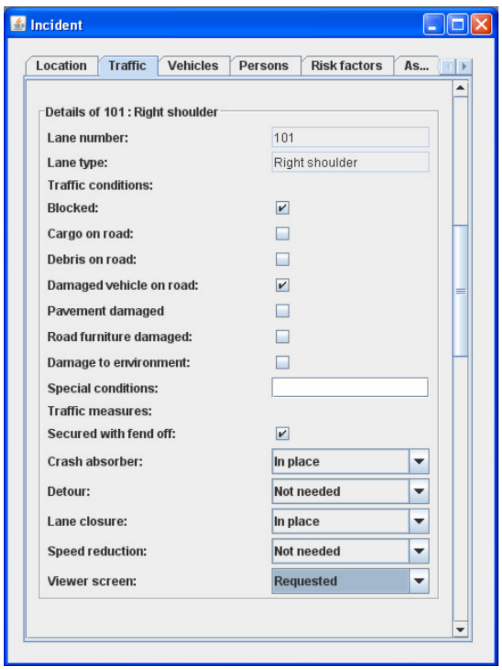

Fig. 5. Screenshot of the traffic tab.

IV. RESILIENCE

Resilience may be defined in different ways. Let us consider the graph of average speed on a special location during the whole day (see fig. 6). These graphs give the time versus the average speed. The data is averaged over 5 minutes to remove some of the random fluctuation and noise. On highways there was a speed limit of 120 km/h for private cars and 100 for lorries/h. We observe that the average speed is varying between these two limits. At some moments we observe a reduction of speed. This may be caused by different reasons. In case of traffic congestions, we observe a successive reduction and increase of speed after some time. This typical waveform is caused by braking car drivers followed by speeding up (shock waves). In case of an incident the graph shows a sharp reduction in speed, a dip for some time, followed by speeding up. The graphs of traffic incidents have our interest.

The area of the dip is a good measure of traffic delay. The dip can be modelled by two crossing lines as a first linear approach. Tayler [14] provides a visual representation of resilience and robustness in the form of a "resilience triangle" (see fig 7). The crossing lines of the triangle may be computed by linear or higher order interpolation using recorded data of average speed measurements. But in some cases, there are two incidents shortly after each other (see fig 8). The question is to model one dip or two successive dips together.

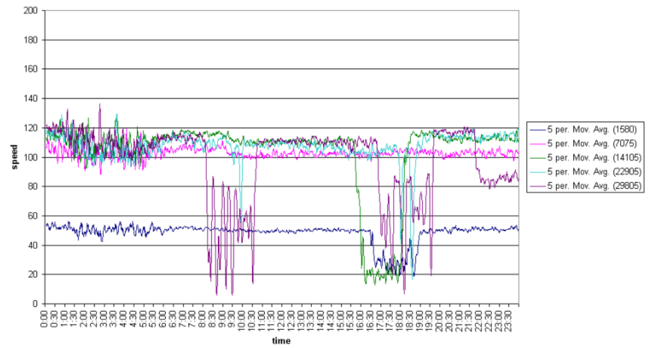

Fig. 6. Graphs of average speed along the highway a13.

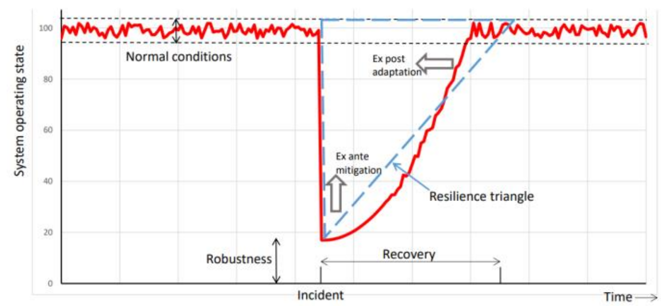

Fig. 7. Resilience triangle adapted.

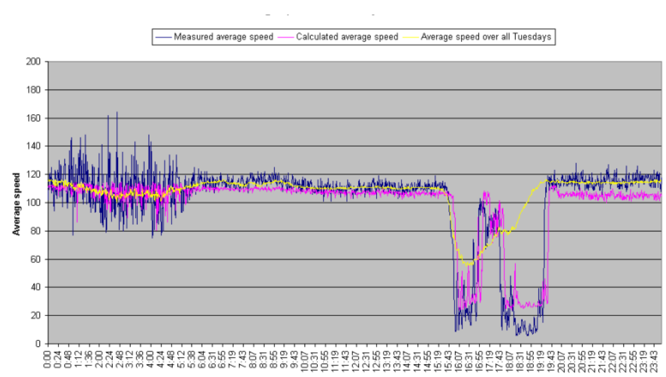

Fig.8. Graphs of average speed along the highway A13.

V. EXPERIMENT

Our developed system was tested in a simulation study. Different sets of scenarios of traffic incidents on the road A13 crossing the city of Delft were developed. At start of the experiment simulated SMS messages were send to the Control Room. The messages were labeled with Test to indicated that these messages were send in the framework of an experiment. The messages were inspired by the messages in the database recorded in 2020. These messages were processed by agents on the Blackboard of Control Room and send to the Blackboards of Emergency Center of Police, Fire brigade and Medical centra. The progress of the experiment was recorded on a special form, displayed in Fig. 9. The experiment took place on a special training day of first responders in the region Delft.

After the experiment the organizers defined the following conclusions and recommendations:

1. The developed system IMICS must be refined in cooperation with the stakeholders.

a. Discuss with stakeholders and gain support for follow-up project.

b. Refine IMICS design in cooperation with stakeholders.

2. The IMICS implementation must be extended to include additional functionality.

a. Security and advanced synchronization.

b. Search function.

c. Improvements to the client interface.

d. Server interface.

3. The IMICS system must be tested in a realistic field test.

a. Test research goals and security, scalability and robustness in practice.

As stated in section II agent-based traffic models play an important role in traffic research of TRAIL. The MSc thesis work of Pronk [3] will be continue as PhD study. The shortcomings of IMICS will be repaired. With help of Bachelor and Master students from TUDelft a realistic field test has been designed. On special day the control room, emergency room, police and medical cars will be double staffed with students. Parallel to the work of first responders, students run in parallel the IMICS system. Recorded data will be analyzed and published by the PhD student.

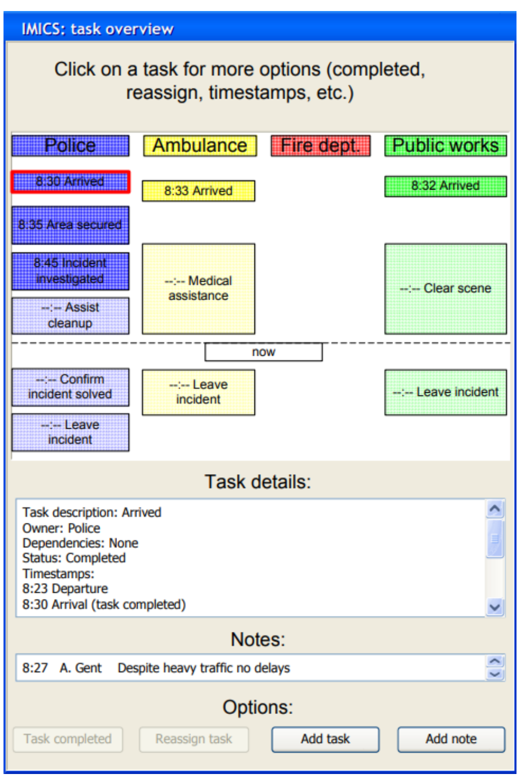

Fig.9. Form to present task overview.

SUMMARY AND CONCLUSIONS

In this paper we presented a new model of communications and information around traffic incidents in urban areas. The new system is based on the JAVA network of distributed blackboards and communicating agents. Observers of traffic incidents send their messages to the Control room via their smart phone. These messages are placed on the Blackboard and processed by automated agents. It was possible to set up a knowledge base to process messages automatically. First responders don't waste their time in processing and communicating messages, this job is taken over by agents. The goal of the new system was to improve resilience of Traffic incidents. The developed system was tested on real life data, recorded on the crossing highways around the city of Delft in the Netherlands.

REFERENCES

[1] S. Calvert, M. Snelders, "A methodology for road traffic resilience analysis and review of related concepts," *Transportmetrica A: Transport Science*, pp 1-23, August, 2017.

[2] B. Vink. "Incident Management Information and Communication System (IMICS)". MSc thesis, Faculty of Electrical Engineering, Mathematics and Computer Science Delft University of Technology, 2009.

[3] E. Pronk. "Assessing Traffic Network Resilience using Agent-Based Modeling and Simulation", MSc thesis, Faculty of Engineering and Policy Analysis, Delft University of Technology, 2020.

[4] Allan, P. & Bryant, M. (2011) 'Resilience as a framework for urbanism and recovery'. Journal of Landscape Architecture 6(2), p. 43

[5] P. Desai, S. W. Loke, A. Desai, and J. Singh. Multi-Agent Based Vehicular Congestion Management. IEEE Intelligent Vehicles Symposium, Badeb-Baden, Germany, 2011.

[6] M. Charmy A. Arispe , R. T. Bigueras2 , J. Torio, D.Maligat. Analysis and System Architecture Design for Road Traffic Incidents. International Journal of Advanced Trends in Computer Science and Engineering. Volume 9, No.1.2, 2020

[7] J. da Silva. City Resilience Index. Research Report Volume I: Desk Study Arup, April 2014.

[8] A. Karndacharuk, A. Hassan. "Traffic incident management: framework and contempory practices ", in the Autralasian Transport Research Forum 2017.

[9] M. Charmy, A. Arispe, R. Bigueras, J. Torio, D. Maligat, "Analysis and System architecture Design for Road Traffic Incidents," *International Journal of Advanced Trends in Computer Science and Engineering*, vol 9, No. 1.2, 2020.

[10] H. Leitner, E. Sheppard, S. Webber, E. Colven, "Globalizing urban resilience," *Urban Geography*, vol 39, 8, pp. 1276-1284, 2018.

[11] Yiding Lu, Zhan Zhang, Xinyi Fang, Linjie Gao and Linjun Lu, "Resilience of urban road network to malignant traffic incidents," *Journal of Advanced Transportation*, Vol 2022, pp. 1-13, May, 2022.

[12] E. Balal, G. Valdez, J. Miramontes, R. Long Cheu. "Comparative evaluation of measures for urban highway network resilience due to traffic incidents." *International Journal of Transportation Science and Technology 8,* pp. 304-317, 2019.

[13] M. Carlos da Manta Martins, A. Nelson Rodrigues da Silva, N. Pinto, "An indicator-based methodology for assessing resilience in urban mobility," *Transportation Research Part D: Transport and Environment*, Vol. 77, pp.352-363, December, 2019.

[14] M. Taylor (2017), *Vulnerability analysis for transportation networks*. Elsevier, 2017.