# COORDINATING URBAN INCIDENT MANAGEMENT & RECONSTRUCTION USING SOCIAL WEB

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## ABSTRACT

The enormous widespread and relative maturity of collaborative and social applications in Web 2.0 has encouraged metropolitans worldwide to incorporate them into their emergency management systems (Allen, 2010). This paper describes **SWIMS** (Semantic Web Based Incident Management System), a system that integrates Web 2.0 collaborative/social applications with software agent technologies in an aim to enhance emergency management practices in urban settings. The aim is to integrate information and work flows between responding agencies including contractors who will handle any collapsed structure or embedded access, medical staff, fire fighters and police. Interoperability between these diversified stakeholders is achieved through an ontology. Communication between these parties is achieved through web-based GIS system with social web features (annotation, tagging, etc.)
The system utilizes software agents as an interface between various Web 2.0 collaboration systems and SWIMS. This also helps to overcome any syntax and/or schematic heterogeneity between SWIMS and collaborative applications data structures. The roles of software agents in response resources allocation and management as well as coordination of relief efforts and decision updates are also discussed. The experiences in developing and implementing this project are thoroughly discussed and analyzed in this paper.

**Keywords:** multi-agent system, GIS, incident management, social web

## 1. INTRODUCTION

The construction industry has a major role in the management or urban incidents/crises, which is often unnoticed by researchers. Urban incidents include, for example, recovery from natural disasters (flood, earthquake), where the industry can help in emergency work to shore existing structures, release and channel flood water, build temporary roads. Urban crises can also include fire, where the industry can provide equipment for managing incidents and/or temporary shoring for structures. Other incidents include structural collapse, normally due to decay, but sometimes due to major traffic incidents. Finally, the management of some chemical and biohazard emergencies (such as the recent events related to a propane factory explosion in Toronto) require extensive input from the construction industry to shore structures, open access or provide new ones for evacuation.

Crisis management in urban setting is essentially a challenge in dynamic coordination. Events take place (mostly) unexpectedly, the boundaries and scope of the problem is typically unclear, there is a milieu of agencies and concerns involved, and data flows are complicated and dynamic. Surprisingly, the domain of urban crisis management has not evolved at the same level as the current challenges. Take for example traffic/incidents--information is typically relayed using technologies of limited efficiency and outreach, limited workflow analysis and integration is utilized, limited optimization and analysis of resource usage and logistics, and no semantic communication systems for human communication.

The solution, advocated by this research work, benchmarks some of the subtle lessons learned in construction informatics. It is argued that one of the major lessons learned in construction informatics is the need to integrate these three dimensions: data flows, process structures and human-to-human communication. To illustrate, One can notice that, initially construction informatics focused on data interoperability (mainly in CAD through IFC). However, it was found out that integrating process structure and people input is more important. This is why IFC had to evolve into BIM (building information model) and this why the social and semantic webs are receiving much attention in construction informatics nowadays.

Moreover, with the current almost ubiquitous communication technologies/devices and wide spread of *Web 2.0* applications; public role as information producers as well as consumers is providing more access to real-time data from incident scenes (Zhang, 2009). Authorized tracking of motorists' smart phones can provide valuable information regarding network traffic speeds and/or flow volumes. Motorists/passengers can report incidents or traffic performance information using tools such as twitter, flicker, emails, sms …etc. More importantly they can support reported information with visual aids such as photo shots or videos taken using smart devices built-in cameras.

This paper summarizes a proposed platform to enhance the collaborative management of urban incidents with focus on three fundamental issues:

1. Collaborative integrated analysis of the roles and duties of participating agencies: this includes sharing work flows, analyzing possible collaboration scenarios, identifying actors and their roles (who provide what information to who). For example, how can we share images of a collapsed structure (due to a traffic accident) with engineers and contractors to assess the best course of actions and dispatch the right equipment and talent to handle the situation?
2. Dynamic resource allocation and utilization. How can we integrate human and physical resources to handle one or more incidents? Which resources should be dispatched to which location? Why? How can we use intelligent transportation systems to route physical recourse to the emergency construction site faster?
3. Connecting decision makers to negotiate and manage situations. Developing a portal for situation management and communication between users (residents and media) and decision makers. The aim of the platform is not to optimize decision. Rather, provide quick and streamlined access to information and allow decision makers to negotiate a solution.

## 2. SCOPE

The veracity and accuracy of information about incident location, as well as the information on the characterization of such incidents, has always been on the agenda of discussion of various parties involved in traffic incident management. Traditionally, this information is provided by either law enforcement or traffic agencies and therefore tend to be highly centralized and slow to disseminate. Response agencies (such as contractors, medical staff, fire fighters) may not receive accurate or timely information about the incident, its evolution, and its management status (who has been dispatched, who has arrived at site, which resources have been deployed, which additional resources exist or are available, etc.). It allows users to access and register incident related information at different locations on a map interface supported with underlying GIS-based tools and application. GIS provide spatial database infrastructure for storing traffic network real time performance data/information, locate closest response facilities, and estimate incident impacted routes travel time. On the other side, GIS stores reported information, so that analysts can collect this data and analyze incidents occurrence patterns.

The main advantages/features of the proposed system are: (i) increase detection rate and decrease detection time through fostering public participation in traffic incidents reporting, (ii) enhanced initial assessment of incident severity through videos and photos provided through smart personal digital assistance devices (PDA), e.g. iphone, ipad, blackberry …etc, (iii) efficient incident information dissemination through increasing public interaction using *Web 2.0* social media, and (iv) alleviate the burden of handling massive information flow from human operators through using intelligent software agents.

The realization of these goals requires the interaction of multiple heterogeneous **IT** systems/applications and is subject to the provision of communication interoperability between them. The construction engineering domain provides several lessons to be learned specifically in this area. In the construction engineering literature there are established research trends in data exchange standards (e.g. IFC and BIM) and ontologies integration in order to achieve interoperability between heterogeneous **IT** systems (Succar, 2009). Ontologies support interoperability through knowledge rather than information sharing, providing capabilities for high level domain reasoning that can be used by interacting intelligent software agents.

## 3. SYSTEM ARCHITECTURE

The proposed system is called Social Web-Based Incident Management System (SWIMS). It adopts an open and ad-hoc architecture, where various stakeholders are free to join or leave the system. ***SWIMS*** uses multi-agent system (MAS) architecture that allows multiple human and artificial software agents to interoperate in pursue of individual and/or common goals. In such framework, any agents can join/leave the system subject to certain rules and constrains. ad-hoc open MAS should incorporate the following characteristics:

- A knowledge model capturing the domain of interest, defining the attributes and relationships of the domain component entities. Built on this knowledge model a set of axioms (rules) constraining and defining the agents' behavior norms in the vicinity of the developed system, i.e. domain ontology.
- Well defined agents' roles based on the design of MAS workflow/s and/or interactions with external systems. The system should have a set of unique roles; however each role can be fulfilled by one or more actor (agent).
- Adoption of a standard set of interaction protocols, covering possible interactions scenarios in the MAS. Thus agents' actions/reactions follow defined patterns, simplifying the coding and implementation of their business logic.
- Agents interact through asynchronous message exchange, direct invocations among agents is strictly prohibited. Message exchange is the core of any MAS. Upon a message receive, it is up to the receiver agent to reject or respond to the message based on the coded business logic and/or inferred system rules. In addition, relying on message exchange will make the MAS platform and coding language independent, i.e. agents from external heterogeneous systems can interact with the MAS.

Agents need to be able to communicate with users, system resources, and each other to coordinate their decisions/actions. The *Foundation of Intelligent Physical Agents* (**FIPA)** supports a set of standards for message communication between interacting agents, expressed using special communication languages, *Agent Communication Languages* (**ACL**), the most common of which is the **FIPA ACL** (Bellifemine and Poggi, 2004). **FIPA** was founded in 2003 to provide a set of universally accepted standards that defines agent interaction protocols, supporting interoperability between different systems (Bellifemine, 2007). The content of **FIPA ACL** is formed standard speech acts and interaction protocols, Figure-1. In order to efficiently communicate agents must also share an ontology of their domain; formed of the terminology that they use to describe this domain. In an open environment, agents are designed around various ontologies, either implicit or explicit, although explicit ontologies, together with a standard mechanism for accessing and referring to them, are necessary in order to allow communication (Bellifemine, 2007).

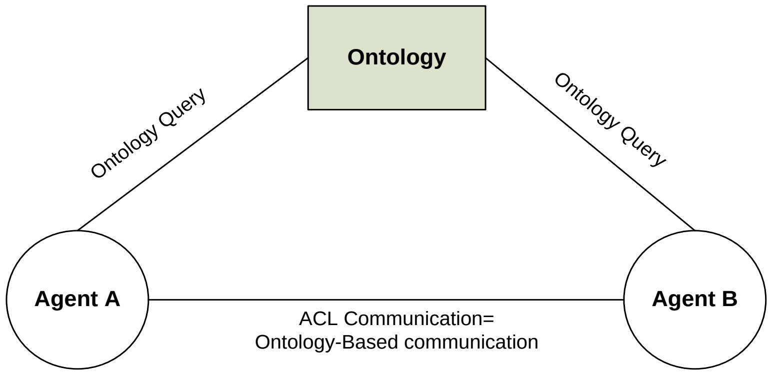

Figure-1, Agent Ontology-based Communication Model

## 4. SWIMS COMPONENTS

***SWIMS*** is designed as an open collaborative system that is able to seamlessly integrate public participants (i.e. travelers), involved agencies and legacy systems in ad-hoc framework formed upon an occurrence of traffic incident. Accordingly, ***SWIMS*** can be defined as the Set formed of the following main components:

$$\textbf{\textit{SWIMS}}= \{A_s, A_R, A_O, A_E, A_{RE}, LS, O, IP, N\}$$

$\mathbf{A_s}$ are the system core agents responsible for monitoring, lifecycle management, publish and search for other agents services. Two types of agents are defined under this category: the **DF** and **AMS** agents. Based on **FIPA** Agent Management Specifications, every **FIPA**-compliant platform should at least host a default **DF**, and **AMS** agent. The **DF** (*Directory Facilitator*) agent provides ‘yellow pages’ service that allows other agents to publish description of one or more service they provide in order to be easily discovered by other agents in the system based on description/s match. ***SWIMS*** support the deployment of several **DF** agents- if required- to provide a **single** distributed yellow page catalogue, supporting system fault tolerance.

The **AMS** (*Agent Management System*) agent is responsible for managing the system agents’ lifecycle. Each agent must register with the **AMS** agent to obtain a unique id, which is used by **AMS** to monitor the agent status (e.g. active, suspended, waiting …etc.). **AMS** is the only agent with the ability to enforce termination on any agent with undesired behavior or service. Several copies of the **AMS** can exist in the platform, however only one copy is allowed to be active. It has also the ability to request any agent to perform specific management function/s, based on coded logic.

$\mathbf{A_R}$ represents set of agents representing each response agency involved in the incident management process. It can be EMS Agent (Emergency Medical Services), structural designer, contractor, equipment supplier, Fire-Rescue, Law-Enforcement …etc. these agents mimic the major players, their resources, capabilities and roles. Each Responder Agent has unique geographic coordinates, representing its spatial location within the network (e.g. a hospital location for EMS Agent).

Organizational agents ($\mathbf{A_O}$) are defined according to the organizational role of the agent in the incident command organizational hierarchy. Four types of agents defined under this category: the Communication, Commander, Safety, Media agents. The Communication agent is the first to receive incident alert. For example, Law-Enforcement agency can be the first to know about an incident. In other situation (especially with traffic incidents) traffic management centre can be the first to know. Based on the reliability of the alert source the agent decides whether to initiate a verification process or not. **SWIMS** is designed to receive incidents alerts from variety of resources, including Automatic Incident Detection software, public notification to emergency call centers or traffic report hotline, on scene police or traffic patrols, through the internet using hand held PDA's or smart phones…etc. Each of those sources initiates an *Incident-Alert* message that is sent to the *Communication-Agent* containing the incident data collected so far.

The *Communication-Agent* classifies alerts as either trusted or untrusted. Trusted alerts for example are alerts from on scene officers that require immediate responders dispatch. Untrusted alerts are verified through CCTV within the incident location proximity otherwise police patrols are dispatched to the incident scene to verify. *Commander-Agent* receives the updated incident alert report from *Communication-Agent*, and generates a response plan, which may or may not require the approval of *Safety- Agent* representing domain expert, assigned this agent role based on reported incident attributes. It may be an experienced structural engineer in case of bridge collapse or environment protection expert in case of HAZMAT spillage. The *Commander-Agent* takes as well the role of coordinating the notification and dispatching other responders to the incident scene. *Media-Agent* is responsible for posting incident related information to roadside variable message signs, traffic radio channels, dedicated websites and other registered media sources.

*External-Agents* ($\mathbf{A_E}$), are probably the most emphasized component in ***SWIMS***. They are not originally registered in the system but their participation is favored (mainly through *Web 2.0* apps) during the incident relief effort. This type of agents can be freeway travelers sending incident alerts with their smart phone through the internet or agent/s disseminating traffic data to motorists. It was a design choice either to establish a new infrastructure to interact with these external agents (i.e. web apps developed from scratch) or relying on existing Web 2.0 apps and the favor went to the latter. This was rationalized based on the following three reasons: (i) using already popular resources of collaborative systems (micro-blogging in ***SWIMS*** case) such as '*twitter*' will build upon the existing popularity of this *Web 2.0* apps and save the need to publicize it to the traffic network users, (ii) It will save development and maintenance costs by relying on the already existing freeware open source capability with no need to worry about running costs such as maintenance, and finally (iii) a generic interface will be used between these collaborative systems and ***SWIMS*** which can be used by other developers to integrate their applications similar to twitter to the system. Thus the system can have unlimited outreach and growth to include other social web applications in the future, e.g. Flickrs or electronic mailing list.

The *Reputation-Agent* ($\mathbf{A_{RE}}$) is responsible for keeping an updated database of the credibility of various agents/users interacting with the system. The credibility is calculated based on the agent/user interactions and acceptance of ***SWIMS*** norms defined in ***N***. *Reputation-Agent* deals primarily with *External-Agents* and users sending incident alerts to the system, classifying them into one of the following categories: *certified*, *invited* and *untrusted*. Entities tagged as '*certified'* are sources that has provided true incident alerts and the past and had gained ***SWIMS*** credibility. '*Invited*' sources are entities that do not have strong record in the system and their alerts must be verified, while '*untrusted'* refers to entities with track of false alerts.

**LS** refer to the set of *legacy software* applications, e.g. GIS, traffic simulation, route guidance, vehicle tracking …etc. **O** is ***SWIMS*** agents' communication ontology, and **N** is set of norms (rules) used for agents reasoning and behavior definition. An *interaction protocols* (**IP**) are set of message exchange sequence following a predefined communication pattern (Miyazaki, 1998). They are generic communication patterns that can be applied in several situations irrespective of the application domain (O'Brien and Nicol, 1998). The main interaction protocols used in ***SWIMS*** are **FIPA-Contract-Net** for dispatching *Responder-Agents*, **FIPA-Subscribe** for notifications of traffic status updates, **Inform-Confirm** protocol for incidents alerts, and **FIPA-Request** for carrying out tasks such as routing emergency vehicles, finding closes facility...etc.

## 5. AGENTS ACQUAINTANCES DIAGRAM

Agent acquaintances identify interactions between agents, human operator and external resources and legacy system. **SWIMS** agents diagram depicted in Figure-2, includes four types of elements: agents, human operators, external resources, and acquaintances between agents. **SWIMS** interact either directly with external/legacy software application if these applications performs atomic functionalities (simple single functionality), or through a transducer agents for application requiring complex interactions.

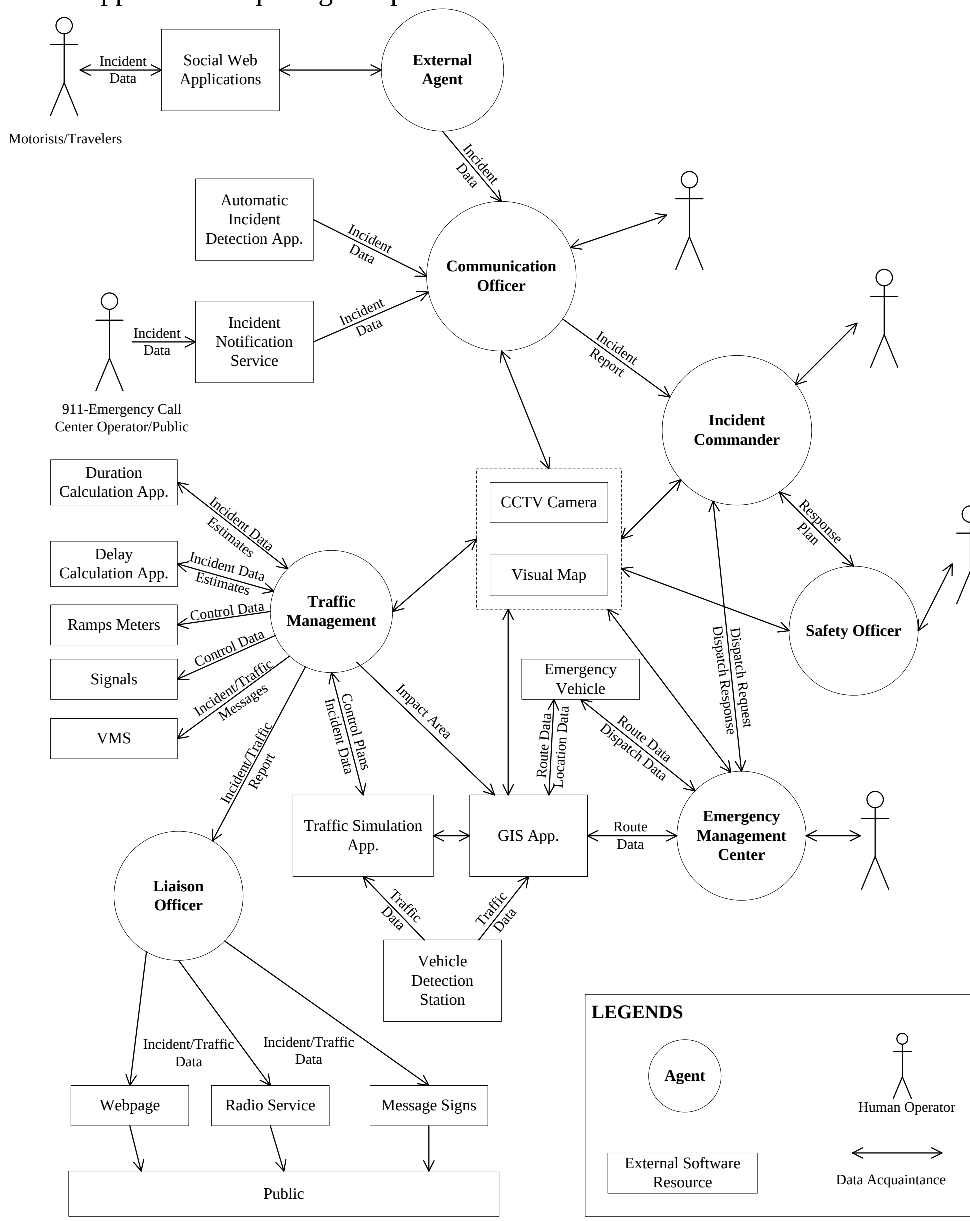


Figure-2 **SWIMS** Agent Acquaintance Diagram

## 6. GENERAL WORKFLOW

***SWIMS*** provides span of channels to detect and report incidents this includes automatic incident detection algorithms, phone calls, smart phones short or *Web 2.0* messages …etc. The incident alert is sent to the *Communication-Officer Agent* and pop-up on map interface for the human operator. The operator then verifies the incident occurrence using closest camera to the incident location. The closest camera algorithm is provided by GIS functionalities underlying ***SWIMS***. Figure-3 depicts the system architecture, while Figure-4 illustrates the interface of the communication officer agent portal.

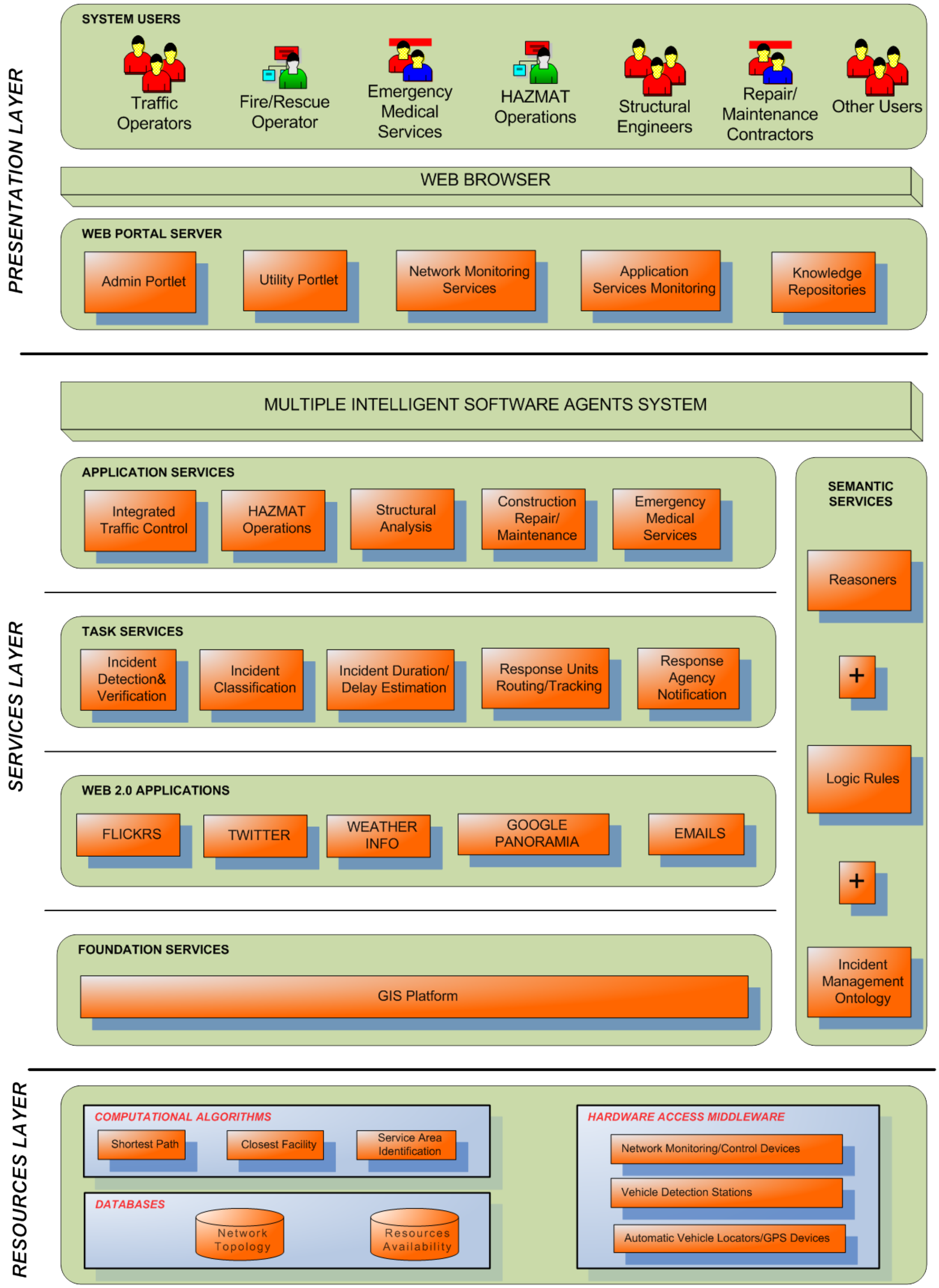


Figure-3 System Layered Architecture

Once the incident occurrence is verified, an incident report is generated from the *Communication-Agent* and forwarded to other agents in the system. The *Commander-Agent* analyzes the reported incident attributes, identify required response resources, and allocate these resources using closest facility algorithms provided by the underlying GIS infrastructure. Dispatch requests are then triggered between the Commander-Agent and other emergency response units to confirm availability and route these units to the incident scene. Simultaneously, a traffic controls agent overtakes the management and relief of incident related congestion. Figure-5 depicts ***SWIMS*** underlying process models, expressed using *business process modeling notation*.

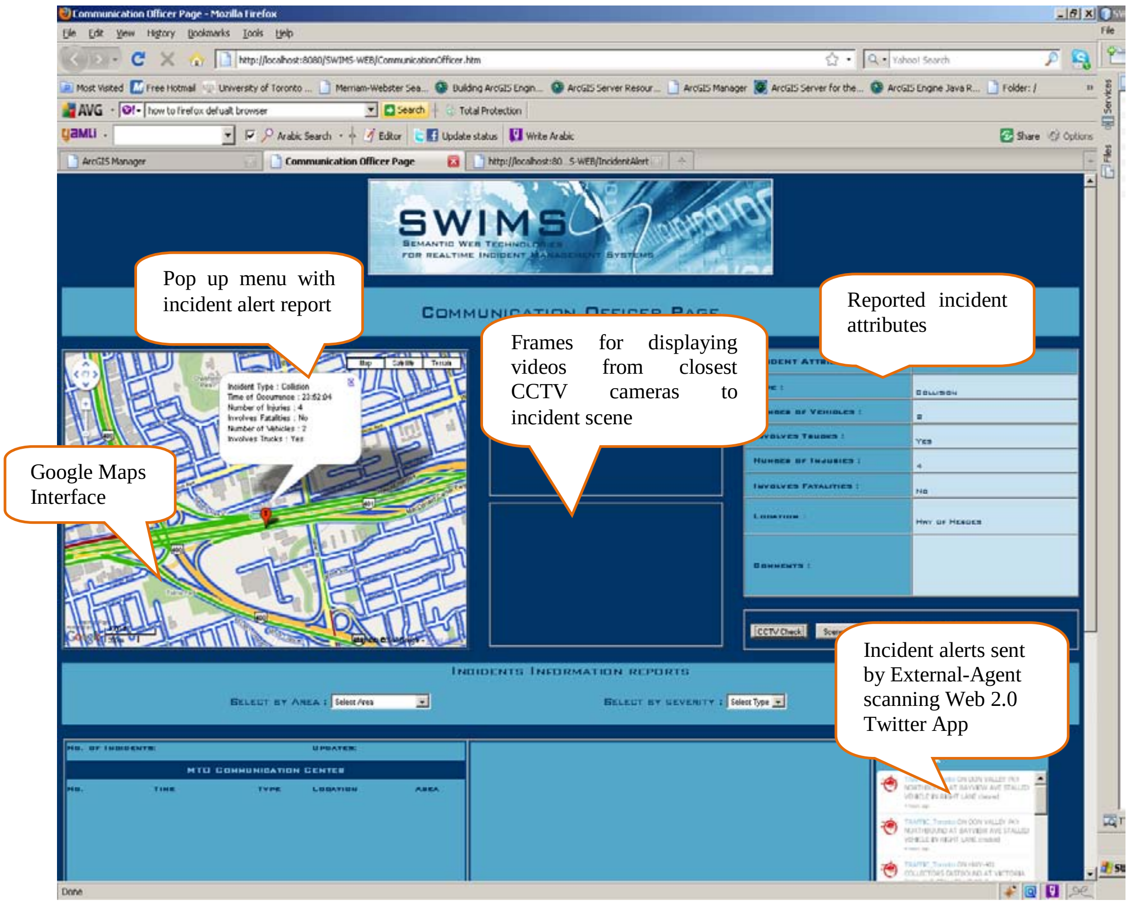


Figure-4 *Communication-Agent* PortletInterface

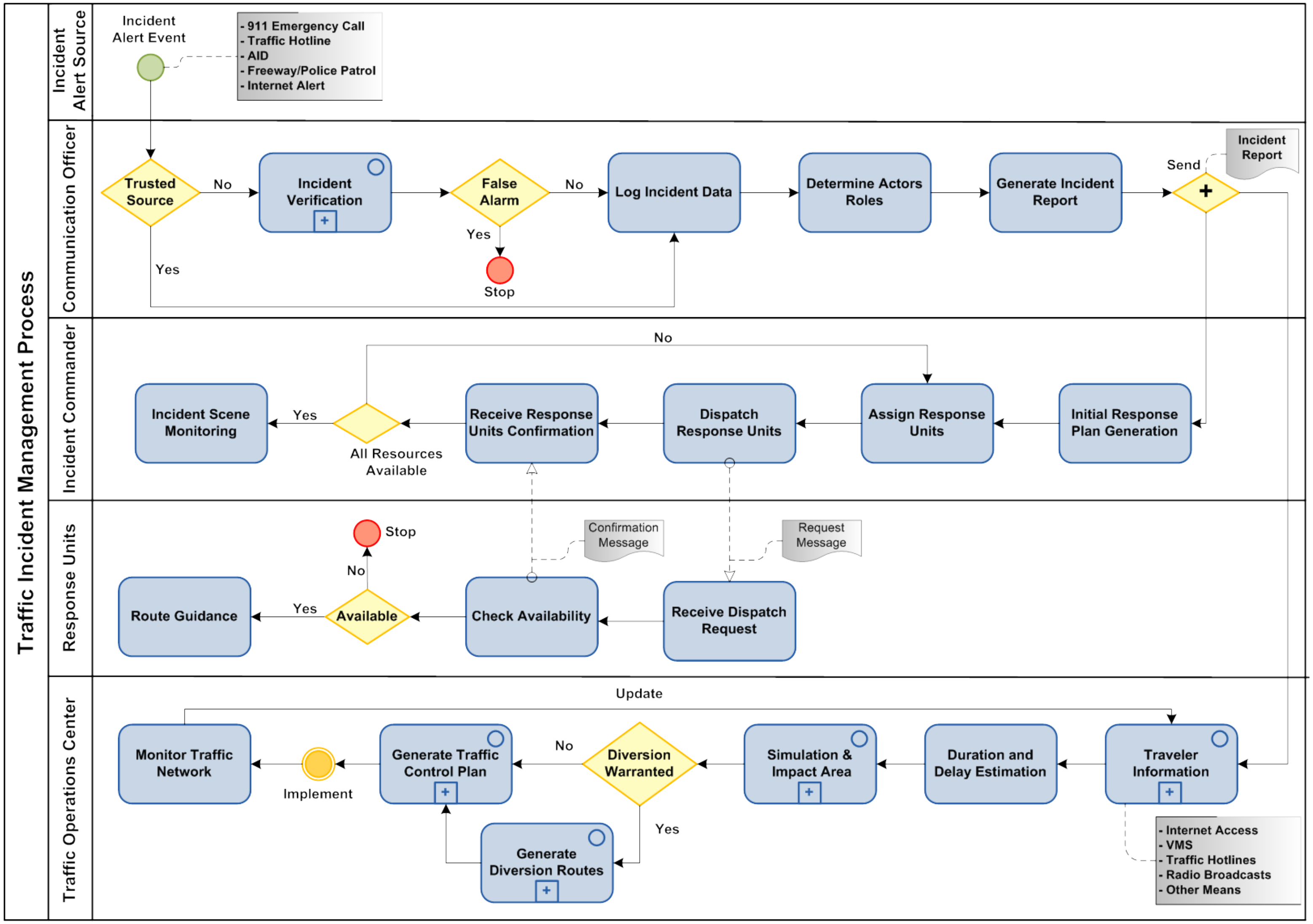


Figure-4 SWIMS Traffic Incident Management Process Model Workflow

## 7. CREDIBILITY OF USER/S REPORTED INCIDENTS

***SWIMS*** collaborative and open style dictates the need for mechanisms for rewarding/punishing *External-Agents* that delivers incidents alerts to the system. There is a trade-off between diminishing constraints imposed on agents in order to increase participation and rigid control to avoid unwanted behaviours, such as false alarms or fake incident information. ***SWIMS*** does not require the user to become a member in the system in order to report an incident. For example an incident reported through *Twitter* micro-blogging tool will only include the username and email address. However, the credibility of the information is further boosted if the message is supported by visual aids such as photos and/or videos. Furthermore the more alerts that are reported, the more trustworthy they are.

***SWIMS*** uses two types of scores (ratio) to assign a *reputation index* for each user interacting with the system, these ratios were adopted from (Furtado, 2010). More precisely:

- The rate of true reporting ($N_{True}$) made the by the user divide by the total number of previous participations ($N_{Total}$), denoted as $R_{Report}$.
- The rate of addition information provided $R_{Add}$ is measured from the number of incident reported by the user in which additional material was provided ($N_{Add}$) divided by $N_{Total}$.

Finally, the *propagated reputation (PR)* is then computed from each acquired *reputation index (RI)* as a cumulative value from each number of participation. More formally, the user 'A' has the reputation function of $\rho(A)= w \times PR + (1 - w) \times RI$, where $w$ is a weight to ponder the importance of one type of reputation over the other. ***SWIMS*** reputation scores are used only in the background analysis by the *Communication-Agent* in order to account for the historical reputation for the user reporting the incident.

## 8. SUMMARY AND FUTURE WORK

In this paper we propose and outline a conceptual framework for an incident management system that adopts an open collaborative architecture supported by multi-agent system middleware. Within this system, ontologies are used to model the incident management processes and for agent communication. They integrate those processes based on their semantics and knowledge and enable the use of their encapsulated knowledge to achieve knowledge based collaborative incident management system.

This system will allow resources and knowledge sharing together with cross domains coordination leading to a cooperative decision making process among various stake holders involved in the incident management. It will provide a set of advanced services, which are seen as essential for any cross-domain successful incident management process. These services can be extended to future applications that can enhance further the system performance. The system will provide a platform framework that allows future users to develop their own applications. The sharing of resources coupled with information and communications management services, provided by the system, will help establish a flexible incident management model that can be easily copped to various municipalities, traffic authorities, and other incident management agencies under one geographically unlimited virtual incident management innovative organization.

## 9. REFERENCES


Allen, J. (2010). "Knowledge-sharing successes in web 2.0 communities." *IEEE Technol.Soc.Mag.,* 29(1), 58-64.

Bellifemine, F., and Poggi, A. (2004). "FIPA-compliant agent infrastructures." *Methodologies and Software Engineering for Agent Systems. The Agent-Oriented Software Engineering Handbook,* Kluwer Academic Publishers, Dordrecht, Netherlands, 259-72.

Bellifemine, F. L. (2007). *Developing multi-agent systems with JADE.* John Wiley, Hoboken, NJ.

El-Diraby, T. (2005). "E-infrastructure: A roadmap for semantic web-based project development for civil infrastructure systems." *IEEE Systems, Man and Cybernetics Society, Proceedings - 2005 International Conference on Systems, Man and Cybernetics, October 10, 2005 - October 12,* Institute of Electrical and Electronics Engineers Inc, Waikoloa, HI, United states, 3479-3485.

Furtado, V., Ayres, L., de Oliveira, M., Vasconcelos, E., Caminha, C., D'Orleans, J., and Belchior, M. (2010). "Collective intelligence in law enforcement - The WikiCrimes system." *Inf.Sci.,* 180(1), 4-17.

Miyazaki, Y. (1998). "Interoperability among intelligent agents-FIPA 97." *NTT R & D,* 47(2), 19-24.

O'Brien, P. D., and Nicol, R. C. (1998). "FIPA-towards a standard for software agents." *BT Technology Journal,* 16(3), 51-9.

Succar, B. (2009). "Building information modelling framework: a research and delivery foundation for industry stakeholders." *Autom.Constr.,* 18(3), 357-75.

Zhang, J., and El-Diraby, T. (2009). "SSWP: a social semantic Web portal for effective communication in construction." *Journal of Computers,* 4(4), 330-7.

Zhang, J., and El-Diraby, T. (2009). "A social web approach to managing information and knowledge in the AEC industry." *International Conference on Management and Service Science, MASS 2009, September 20, 2009 - September 22,* IEEE Computer Society, Wuhan, China, Communication University of China; Wuhan University; James Madison University; Institute of Policy and Management, Chinese Academy of Sciences; IEEE Wuhan Section.

Zhang, M., Karmouch, A., and Impey, R. (2001). "Towards a secure agent platform based on FIPA." *3rd International Workshop on Mobile Agents for Telecommunication Applications,* Springer-Verlag, Berlin, Germany, 277-89.