

## **Combining Sensors and Simulation for Real Time Decision Support**

**John A. Sokolowski, Ph.D.**  
Virginia Modeling, Analysis and Simulation Center  
Suffolk, VA  
jsokolow@odu.edu

**Daniel R. Snyder**  
Booz Allen Hamilton  
Suffolk, VA  
Snyder\_Daniel@bah.com

### **ABSTRACT**

Many groups use sensors to monitor complex processes and systems. For example, highway departments monitor road networks with cameras and vehicle counters embedded in the roadway. These sensors alert traffic centers of problems on the road and allow center managers to provide early interventions to minimize traffic flow interruptions. However, they have no way of knowing if their interventions are optimum for the circumstances. Having a system that could provide insight into the outcome of various decisions in a rapid manner would help them choose the best course of action. This paper proposes investigating how real time sensors could be coupled with a road network simulation to provide a real time decision support capability for traffic managers. It reports the results of a prototype system to test the usefulness of such a system.

### **ABOUT THE AUTHORS**

**John Sokolowski** is a senior research scientist and Acting Director of Research at Old Dominion University's Virginia Modeling, Analysis & Simulation Center (VMASC). He holds a Bachelor of Science degree in Computer Science from Purdue University, a Master of Engineering Management from Old Dominion University (ODU), and a PhD in Engineering with a concentration in the Modeling and Simulation from ODU. Prior to coming to VMASC, he spent 27 years in the Navy as a submarine officer with his final assignment as Head, Modeling and Simulation Division, Joint Warfighting Center, U.S. Joint Forces Command. His research interests include human behavior modeling, multi-agent system simulation, and simulation architectures supporting homeland security. He has extensive experience employing artificial intelligence techniques to develop simulations supporting command and control. He has also researched and managed the integration of multiple simulation systems in a distributed environment.

**Daniel R. Snyder** is a modeling and simulation (M&S) architect in support of the USJFCOM J9 Experimentation Engineering Department of the Joint Futures Lab, and Booz Allen Hamilton employee. He has worked with M&S since July 1994. He earned a B.S. from the United States Military Academy, and a M.S. in Information Management from Bowie State University, Maryland. He is currently a Ph.D. student at the Virginia Modeling and Simulation Analysis Center, Old Dominion University.

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### **INTRODUCTION**

Within the United States, many local municipalities use sensors to monitor complex processes and systems. For example, highway departments monitor road networks with cameras and with vehicle counters embedded in the roadway. These sensors alert traffic centers to problems on the road and allow center managers to provide early interventions to minimize traffic flow interruptions. However, they have no way of knowing if their interventions are optimum for the circumstances. Having a system that could provide insight into the outcome of various decisions in a rapid manner would help them choose the best course of action (COA). Further, finding means to better share information could also assist in command and control (C2) to make the execution of the selected COA more effective and efficient.

Lessons learned from military studies involving the modeling of natural and man-made disasters may be adapted to meet the needs of local municipalities to assist in optimizing COA selection. For example, the United States Joint Forces Command (USJFCOM) Experimentation Directorate (J9) conducts studies that investigate an effects-based approach to operations that takes into account the behavioral differences among the varying echelons of a nation's government should a response to a disaster be required. Some of these studies use modeling and simulation (M&S). One can use M&S techniques to rapidly replicate the impact a disaster may have on a region's infrastructure and its corresponding populace. M&S creates a virtual sandbox to investigate the range of possible responses to counter the adverse effects associated with these modeled disasters. In turn, synthetic environments provide more than just a graphical depiction of a phenomenon. They can aid the way local and state governments communicate and make decisions.

This paper proposes investigating how real time sensors could be coupled with a road network simulation to provide a real time decision support capability for traffic managers. It reports the results of a prototype system to test the usefulness of such a system, and how this prototype could assist in

mitigating loss of life and property due to manmade and natural disasters. The intended use of this system is to allow decision makers to direct first responders using a systematic means to identify meaningfully different alternative courses of action, and indicators that provide insights in that those alternatives so that they may become more or less likely over time in the area of monitoring complex processes and systems. Further, this prototype may also assist in extending the effects-based approach to operations for applications in the commercial sector of our culture.

### **PERTINENT CONCEPTS AND DEFINITIONS**

**Operational Net Assessment.** An Operational Net Assessment (ONA) is one method to develop an understanding of today's complex, interconnected operational environment from a systems' perspective (Pace, 2006). This view of our environment is not inherently military, and in fact has many applications in the civilian and private sectors. This is because an ONA is an integration of a process that helps to build common situational awareness, including a tool that supports planning; a product based on a systems understanding in the form of a common shared, relevant database; and a network of people who collaboratively develop this knowledge base (Pace, 2006). Items of interest within this database can be called nodes or elements, and the interdependences of these elements is the database product referenced above. Additionally, the historical data captured in the supporting ONA database allows analysts to discern patterns and/or emerging trends that help to place the significance of the real time updates in context, and provides a means to achieve a level of predictive analysis (Snyder and Tolk, 2006). Traditionally, a team of analysts would create and maintain this database with an emphasis on identifying and managing the linkages or interdependencies among these elements in some retrievable manner. It is the collaborative building of this type of common and relevant database of a transportation system of systems (SOS) and how it may interact with systems that are the focus of this paper.

**Effects-Based Approach.** An Effects-Based Approach (EBA) to operations is a planning process that emphasizes the clear linkages of desired objectives to the effects that must be created to achieve these objectives (Pace, 2006). An EBA uses an ONA to gain situational awareness and understanding of an environment. With relevant and timely updates to this ONA, this could provide a means to determine insights into how and when resources may be best applied in response to a crisis. Relevant information feeds back through the supporting networks and turns from just real time information into actionable knowledge. Local emergency operations centers (EOC) may use this actionable real time knowledge together with historical patterns and emerging trends, captured in an ONA, to model the optimum application of their resources. Under specified conditions, an ONA coupled with real time data updates may assist EOCs in how to best achieve desirable effects. Thus using an ONA under the auspices of the EBA becomes a powerful COA selection decision support tool.

**Measures of Merit (MoM).** No single measure or methodology exists to satisfactorily assess the impact of C2 systems, as the benefits of C2 should be evaluated through its impact on the fulfillment of objectives and in terms of specific qualities that are relevant to these objectives (DoD, 2004). Thus Measures of Merit (MoM) is a generic term to include the different classes of measures that relate to performance and effectiveness. Adapting this concept to the needs of local municipalities, MoM becomes the indicators that their presence or lack of presence provides insights into COA optimization. With the proposed traffic model and relevant synthetic environment described below, the rationale for MoM selection is critical as these indicators must not only be measurable, but they must also be agile to support the dynamic linkage to objectives that are situationally dependent.

**Network Centric Warfare (NCW).** One of the fundamental principles of network-centric transformation is the tenet of Network Centric Warfare (NCW), which is a two-step process; first, achieving shared awareness, and second, leveraging shared awareness to achieve a greater degree of self-synchronization, leading to increases in agility and effectiveness (Alberts and Hayes, 2006). The Net-Centric Enterprise Services (NCES) is one program to assist in moving the nation towards this vision of a greater degree of self-synchronization all the way from the federal government to every state and out to the most rural of our local governments. Hence, one of the greatest benefits of NCES will be to enable

information sharing by connecting people and systems that have information with people and systems that need information. Further, a tenet of NCES is a greater reliance on machine-to-machine messaging (M2M). Adapting an ONA to a more M2M has direct application and will result in better information sharing to assist in more effective and efficient C2 in the execution of the selected COAs.

**Service Oriented Architecture (SOA).** The Department of Defense (DoD) is committed to an Information Age transformation focused on achieving shared awareness and leveraging this shared awareness to achieve a greater degree of self-synchronization, leading to dramatic increases in agility and effectiveness (Walker, 2006). While it enables application collaboration within a Service Oriented Architecture (SOA), it also promotes the decoupling of information producers and consumers. Gaining situational awareness and understanding of a given event requires that an observer gather data and process it. A SOA is a loosely coupled architecture where traditional applications and their supporting data resources are treated as services. The concept behind a SOA is to better orchestrate data sharing to better facilitate data gathering and processing. Additionally, the components that comprise these services make their data immediately available to users using publish and subscribe services as depicted in Figure 1 below. Here, systems A and B represent two sensors that dynamically update their respective data resources with real time updates. These systems represent the producers of information, which when queried using appropriate discovery techniques; can create actionable knowledge for system X.

**Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM).** JC3IEDM is an evolving data specification to enable information exchanges among many multinational command and control systems. This model represents years of data modeling efforts under the administrative management of the Multilateral Interoperability Program (MIP), and supports specifications that can represent many aspects of the effects-based approach (Snyder and Tolk, 2006). Extending the JC3IEDM to capture real time information such as for the proposed traffic model could expand the multinational data modeling effort into the Homeland Security (HLS) and Homeland Defense (HLD) realms as well as providing predictive analysis for natural disasters. Then by extending the JC3IEDM to support domestic information exchange requirements (IERS), such as those required to capture the MoM of key traffic

indicators, it may also influence advances in EOC command and control systems to support these IERs.

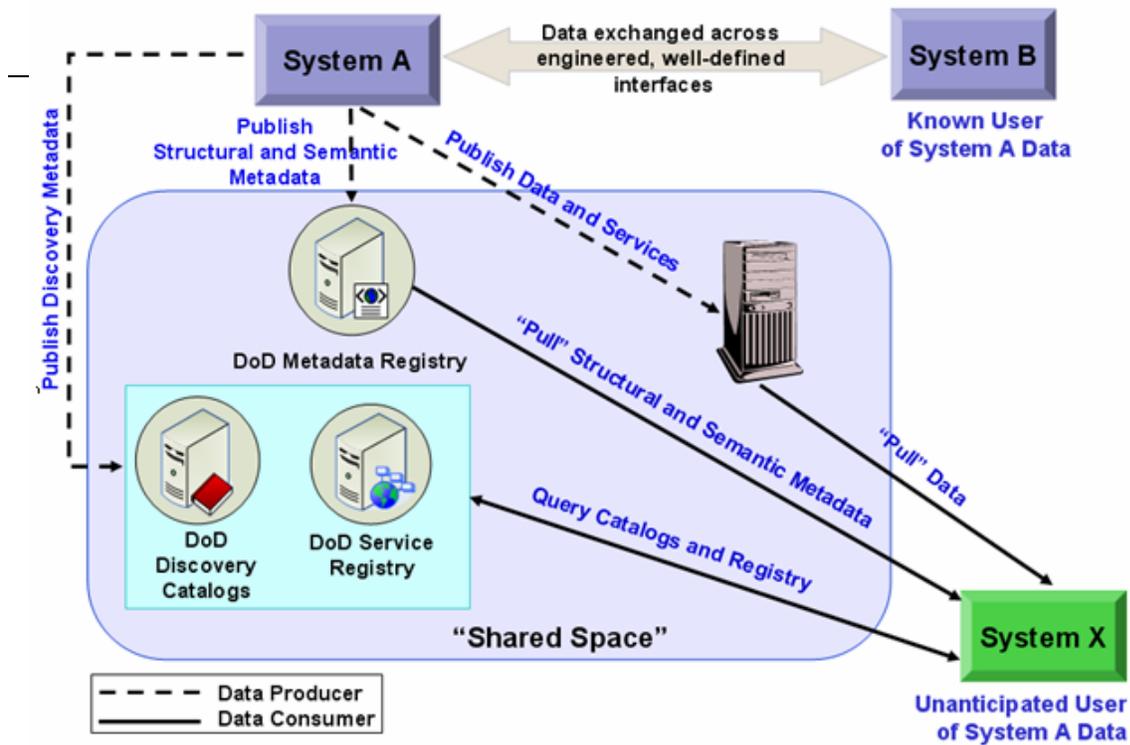


Figure 1 Concept of an SOA approach that support HLS needs (Tolk, 2006)

## SYSTEM DESCRIPTION

The military uses M&S to enhance many aspects of warfighter training. Simulations are available on demand and are used to train service members on skills that are either too dangerous or too costly to be done on real systems. The military has also employed M&S as an analysis tool to solve problems or provide insight into solutions that are unattainable by other analytical techniques. The concepts in this paper extend M&S to a third area, decision support. Here, we propose combining simulation with real systems (sensors) to provide a decision support capability otherwise not available with the real systems alone. While sensors provide instantaneous information about a system they do not allow a decision maker to manipulate the system and see the effects of that manipulation over time. M&S adds this capability by replicating the real world system and populating it with information from live sensors so that the simulated system acts just like the real system. Then when one wants to explore possible decision scenarios he or she can manipulate parameters in the simulation and observe the outcome. They can repeat

this process multiple times to look for the best result before ever having to change the real system.

## Simulation Component

To explore combining sensors and simulation we employed a commercial traffic simulation package called VISSIM by PTV (PTV, 2006). VISSIM is a microscopic, time step and behavior-based traffic simulation package capable of detailed urban traffic and public transportation simulation. It affords one the opportunity, through its COM interface, to couple its simulation capability with external inputs to provide a real time update to parameters within the simulation. However, since no live sensors were available for testing this concept, simulated sensors were used as input to the model.

## Traffic Model

To illustrate this decision support capability, we have chosen to model a traffic network representative of a set of roads and interchanges in the city of Norfolk, Virginia. We will show how real time input in the form of sensor data can be combined with a

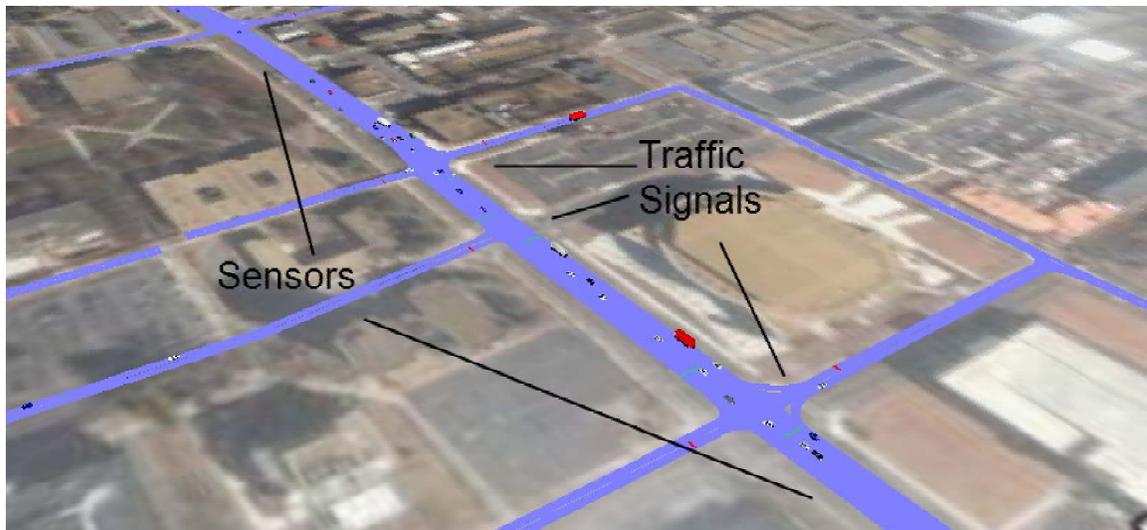
simulation of the area being sensed to facilitate decision-making.

Several systems compose the traffic network including the road structure, traffic signals, and sensors embedded in the roadway to monitor traffic flow. ONA allows us to characterize the structure of these interconnected systems in a model. NCES allows the simulation to subscribe to the real time sensor data and automatically adjust traffic flow in the simulation to match that of the real road network.

We may also need to combine statistical information about certain parameters in the system with the real time information provided by the sensors. In some cases, real time data necessary to properly characterize the system may not be available. For example, the percentage of trucks vs. cars on the road network affects the overall flow of traffic. Identifying vehicles as trucks and cars may not be practical given the available sensors. Rather, one may need to collect data on the distribution of cars vs. trucks and then

sample from this distribution to provide the percentage for the simulation. Thus combining statistical parameters with real time data helps provide for a valid representation of the physical system when real time information is not available.

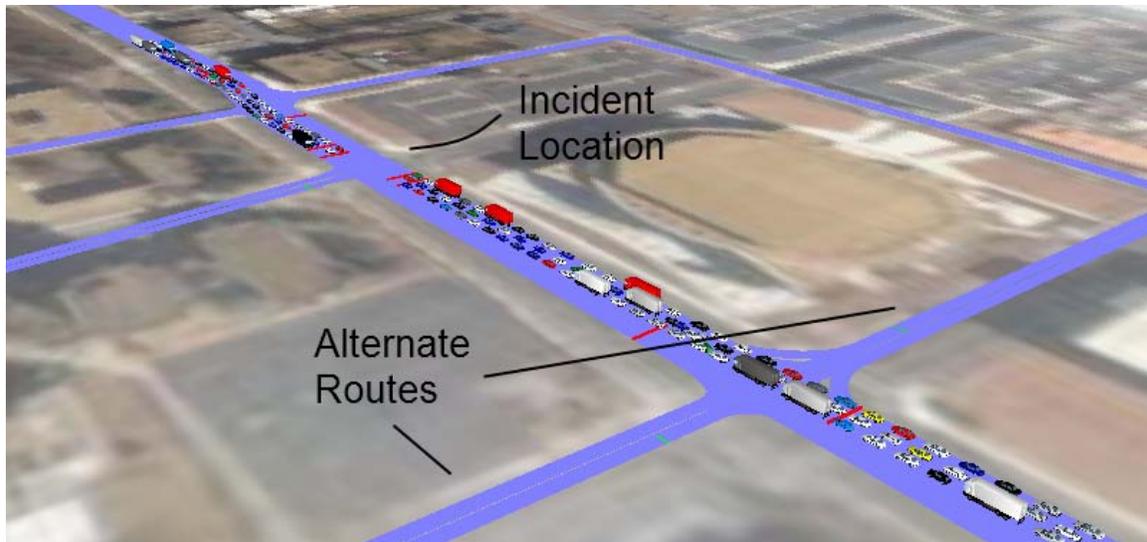
Figure 2 provides an overhead view of the modeled area showing the road network and adjacent terrain. Overlaid on this view is the simulated road network depicted by the solid roadway lines. Traffic sensors that provide the rate of vehicles per hour passing each sensor are also marked on the figure, as are traffic signal locations. This rate is fed into the simulation in real time to represent the actual arrival rate of vehicles into the road network. Signal timing is set per the parameters used in the real network. Sensor locations also contain data collection points that gather the simulation information such as vehicle delay time, vehicle stopped time, and travel time. This data represents the MoMs that the decision maker is interested in optimizing given a certain disruption in traffic.



**Figure 2 Traffic Network**

To illustrate the employment of the system from a decision support standpoint, consider the following scenario. At the point marked in Figure 3 an event occurs that blocks all lanes of traffic. This event could be overturned tanker truck carrying liquid chlorine or the detonation of an improvised explosive device. As you become aware of the incident and the subsequent disruption in traffic flow you go to the simulation and block the traffic to observe the result. After observing the result, you are concerned about rerouting traffic to

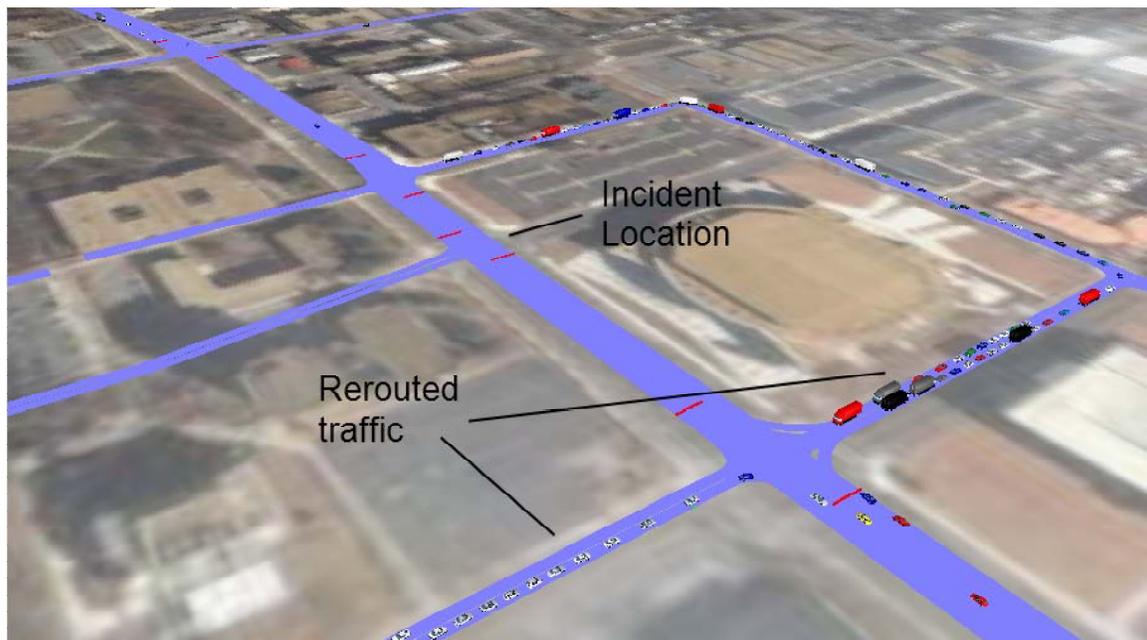
clear the area as quickly as possible. You are also concerned about getting emergency equipment in place in a timely manner. The simulation allows you to visualize the rate and magnitude of traffic backup and depicts routes that may be used to restore traffic flow and to send in emergency equipment. Figure 3 represents the situation 10 minutes after the event and clearly depicts the level of traffic backup.



**Figure 3 Depiction of Incident Location and Traffic Backup**

Based on the portrayed information you want to see the effect of rerouting traffic per the marked alternate routes. By playing the simulation in faster than real

time you quickly see the effects of your decision (Figure 4).



**Figure 4 Traffic Based on Rerouting Decision**

You can also see routes to bring in the emergency equipment in a timely manner. While not being an exact replication of reality you still have a statistically valid depiction of the situation and can make a better-informed decision than just knowing that the road is

blocked with no indication of how traffic is flowing in and around the area.

Besides observing the results of a single decision you can explore alternative courses of action. From Figure 4 you notice that traffic is backing up on the alternative routes. You may need to adjust traffic light timing or position a law enforcement officer to override the traffic signal to improve the flow.

The simulation also shows routes that are probably clear of traffic. Even though you don't have direct sensor information to provide this status, the model statistically predicts that these routes are most likely clear. With law enforcement on or near the scene, you can verify the simulation prediction to best route emergency vehicles in an expeditious manner.

### CONCLUSION AND FUTURE WORK

As one can see from the scenario above, real time sensors and a statistically valid simulation can be effectively combined to provide a decision support capability that otherwise would not be available to a decision maker. Having the ability to play out decisions before actually executing them provides a valuable tool in understanding complex situations and increasing ones chances of making a better decision.

Traffic modeling is a needed aspect to support HLS/HLD modeling in support of the pending prototype being developed at the USJFCOM J9 (Cerri and Chaturvedi, 2005). This prototype is called Sentient World Simulation and serves as the basis for evolving the Political Military Economic Societal Information and Infrastructure (PMESII) Center of Excellence (CoE) concept for the Department of Defense (DoD). The idea is to use an agent-based simulation as an environment where agents dynamically search and update the data resources with relevant real time information that could be later accessed as actionable knowledge. This environment will be continuously running as a mirror model of the real world that can be used to predict and evaluate future events and courses of action. The proposed traffic model update capability will react to actual events as they occur and incorporate newly sensed data from the real time sensors.

This PMESII CoE project will prototype how relevant culture-specific human behaviors are factored into an urban representation of our major population centers. This prototype will include investigations into how

these representations can be visualized and when, where and by whom they are needed to better enable decision makers to gain more immediate situational awareness of the developing event. The proposed web-enabled environment creates a dynamically updating environment supporting PMESII modeling and kinetic simulations sufficient to model quantifiable, observable effects based on integrated or individual actions.

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