1.9   Disaster Response Modeling through Discrete-Event Simulation

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Abstract. Organizations today are required to plan against a rapidly changing, high-cost environment. This is especially true for first responders to disasters and other incidents, where critical decisions must be made in a timely manner to save lives and resources. Discrete-event simulations enable organizations to make better decisions by visualizing complex processes and the impact of proposed changes before they are implemented. A discrete-event simulation using Simio® software has been developed to effectively analyze and quantify the imagery capabilities of domestic aviation resources conducting relief missions. This approach has helped synthesize large amounts of data to better visualize process flows, manage resources, and pinpoint capability gaps and shortfalls in disaster response scenarios. Simulation outputs and results have supported decision makers in the understanding of high risk locations, key resource placement, and the effectiveness of proposed improvements.

1.0 Introduction

1.1 Motivation

Disaster response organizations are faced with the challenges in planning against a rapidly changing, high-cost environment. Incidents can strike with or without warning, and critical decisions must be made in a timely manner to save lives and resources. Essential to making such key decisions is the timeliness of information gathered during the first few hours of a disaster. To minimize decision time and maximize response effectiveness, organizations should understand their overall mission capability and identify key performance gaps and shortfalls that must be addressed.

Government organizations conduct Incident Awareness and Assessment (IAA) missions to provide timely information to first responders. These missions involve the tasking, collection, processing, exploitation, and dissemination of aerial imagery. Images of key disaster zones provide invaluable information to decision makers during a disaster response operation [1].

However, current IAA missions are conducted in an unplanned, ad-hoc manner [2]. In addition, performance requirements have not be adequately quantified and tracked. The current government performance standards have been deemed ineffective and inconsistent across various platforms [3].

Having the ability to consistently measure and track mission performance through time will provide organizations with a comprehensive understanding of current mission capability and identify areas for improvement. The challenge that faces these organizations is devising a flexible and repeatable methodology to quantify performance.

1.2 Approach

We present an analytical approach to quantify IAA disaster response performance and simulate the progression of IAA operations during a disaster response though the use of dynamic modeling.

The disaster response quantification framework and discrete-event simulation presented here is not limited to IAA operations. We see further application towards our approach in search and rescue missions, transportation logistics, and other time-based operational systems that involve a number of moving parts.

2.0 Methodology

The disaster response quantification framework involves researching the disasters in focus, identifying inputs and key relationships, developing performance metrics, designing and running simulations, and analyzing results.
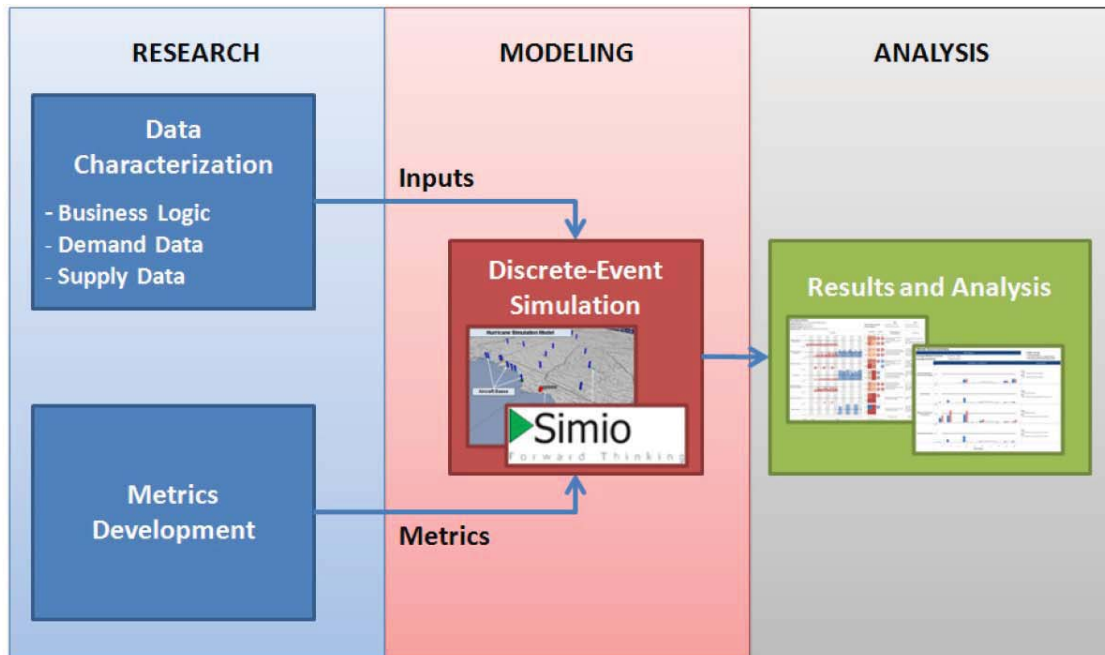
Figure 1. Disaster Response Quantification Framework

2.1 Data Characterization

In order to accurately model and track the performance of current IAA operations, business logic and input data was researched to provide the blueprint for modeling.

The data involved in an IAA Disaster response situation can be separated into two categories, supply and demand. Demand data consists of the overall need for IAA missions to be conducted (i.e. - what the first responders require in order to be successful). Supply data consists of the overall resources that can be drawn upon to satisfy the demand for IAA in a disaster (i.e. - what equipment/platforms can be used to provide IAA).

2.1.1 Business Logic

The disasters in focus were determined to be the following six major types:

- Earthquake
- Hurricane
- Severe Storm/Flooding
- Tornado
- Wildfire
- Winter Storm

To accurately understand the business processes that occur in an IAA disaster response, interviews with various stakeholders and subject matter experts were conducted. These stakeholders and subject matter experts consist of government response forces and first responders that provide IAA support during a disaster incident.

Data collected include:
- Anecdotal data of typical IAA missions
- Major tasks required in a disaster
- Timing during the incident for each required task.

2.1.2 Demand characterization

The demand characterization stage involved researching historical disaster statistics to accurately gauge the magnitude and geographical behaviors of disasters.

Utilizing historical FEMA data, the basic statistics gathered for each disaster incident are as follows:
- Disaster Magnitude

- Counties Affected
- Total Population Affected
- Population Density
- Seasonality

From these elements, the requirements for IAA were determined for each disaster incident across all six disaster types.

2.1.3 Supply characterization

The supply characterization work stream involved research into current IAA aircraft and sensors that perform each IAA task identified in the demand characterization phase.

An extensive database of IAA aircraft and sensor packages was compiled, data included:
- Technical specifications
- Location
- Inventory

In addition, each platform's availability was determined based on their respective agencies, location, and quantity deployed. Availability determines how fast a specific platform could be deployed when a disaster strikes.

2.2 Performance Metrics

Performance metrics were developed to more accurately gauge the effectiveness of the IAA response. These metrics compare how well the platforms and sensors perform when deployed in a disaster scenario.

2.2.1 Penetration

Penetration is the geographic measure of sensor coverage. Penetration is derived from the coverage capability of an individual sensor flying on a specific airframe. When analyzed across a single incident or single disaster, penetration is the weighted average level of coverage for missions given that an aircraft is tasked and deployed.

2.2.2 Persistence

Persistence is the temporal measure of sensor coverage. This metric is two-fold – it

first determines the frequency in which the enterprise is able to provide resources in an incident, if at all. This value allows easy identification of gaps in which aircraft are not available at all. The second step examines, among events where resources are available, the percent of time these assets were devoted to conducting missions rather than flying in-transit, refueling, or awaiting crew rest restrictions. In mathematical terms, persistence is the number of hours resources were conducting missions over the total number of hours of incident response.

2.2.3 Precision

Precision is the qualitative measure of sensor output. Precision is based on whether the coverage satisfied two conditions, optimality and resolution. The first condition identifies whether the sensor is optimally suited to conduct the task based on the operational considerations identified for each task. The second condition is whether the coverage satisfies the minimum National Imagery Interpretability Rating Scale (NIIRS) rating for the required task.

The combination of all three metrics (persistence, penetration, and precision) form Optimal Coverage Level, which is the amount of area to be covered using the optimal sensor at the desired resolution.

3.0 Disaster Response Model – Discrete-Event Simulation

The disaster response modeling framework utilizes discrete-event simulation as its analytical backbone. Discrete-event simulation synthesizes all data elements researched and provides the execution of the business processes involved in an IAA disaster response. The simulations are based on models built using Simio® [4] [5] software developed by Simio LLC.

3.1 Process Model

The disaster response model takes in the supply and demand inputs, simulates the disaster response, and computes the

performance metrics for each historical disaster scenario.

The process model first considers the location, magnitude, and type of disaster and generates the raw mission demand required over the entire disaster period. The demand is parsed out by mission type and represents the total land area that is required to be imaged by the aircraft over the disaster incident.

The model then considers the number of aircraft available, the sensor packages attached, equipment specs, and the geographical location to calculate the overall supply resource pool to draw from. Depending on platform restrictions (range, availability), certain platforms are excluded. Each platform is assigned a number of tasks in which it can conduct and the model calculates the land area coverage rate it can image.

In addition, the model calculates the closest aircraft base for platforms to refuel and redeploy. A buffer is considered such that the closest service station is not within the disaster radius.

3.1.1 Business Logic
Once the variables are calculated, the model follows the following business logic to simulate the disaster response.
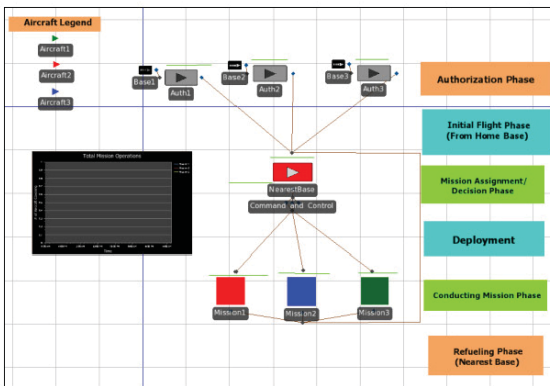

Figure 2. Disaster Response Process Model

Table 1. Model Business Logic

1	Depending on availability, aircraft are released from base and travel to the nearest base
2	Aircraft refuel, and the model assigns a specific task for the aircraft to conduct
3	Aircraft travel to disaster site to conduct mission, collecting various IAA imagery depending on type of task
4	Aircraft runs out of fuel, returns to base
5	Based on current performance metrics and demand, aircraft redeployed to a new task

During the simulation, the model continuously tracks the performance levels of each task required in the disaster. The tasks required may change depending on the current time (as certain missions are needed later in a response). The model will adjust the aircraft deployment logic based on these changes dynamically.

3.2 Graphical View
The Simio modeling software has a 3-D rendering capability, allowing the disaster response model to be displayed in a three dimensional format. In addition, objects in the process model can be animated to visually represent more closely to the real-world counterparts. In the graphic below, the model represents a disaster scenario that is occurring in Florida.

The graphical view provides a method for troubleshooting as well as for presentation purposes to provide a better understanding of the overall simulation logic.
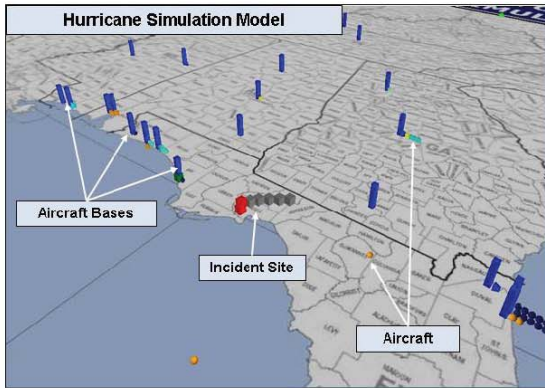
Figure 3. Disaster Response Graphical Model

3.3 Experiments

The IAA disaster response model can rapidly generate a large number scenario runs simultaneously using Simio's experiment feature. This allows the model to run all the historical disaster scenarios researched. Over the past 12 years, there have been over 500 documented federal disaster declarations. The IAA disaster response model simulated all of the scenarios and calculated the performance metrics for each. The metrics are aggregated by geographic region and seasonality to provide an enterprise level analysis of the current IAA response capability.
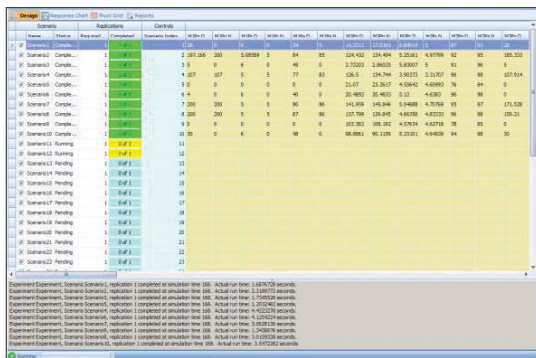

Figure 4. Disaster Response Experiments View

The disaster response model generates .xls outputs of the scenario performance metrics. The persistence, penetration, and precision values are displayed in dashboard format using MS Excel.

4.1 Single Incident Outputs

Performance metrics for each disaster scenario are displayed using a combination of sand charts, donut graphs, and matrices to highlight missions where there are excess or shortfall in capability.

A shortfall in penetration suggests a lack of available assets to adequately cover the mission demand.

A shortfall in persistence suggests an absence of required assets, and that new equipment or platforms are nonexistent or unavailable in the disaster region.

A shortfall in precision suggests a lack of optimal equipment, and that suboptimal sensors and platforms were deployed due to a lack of appropriate resources.
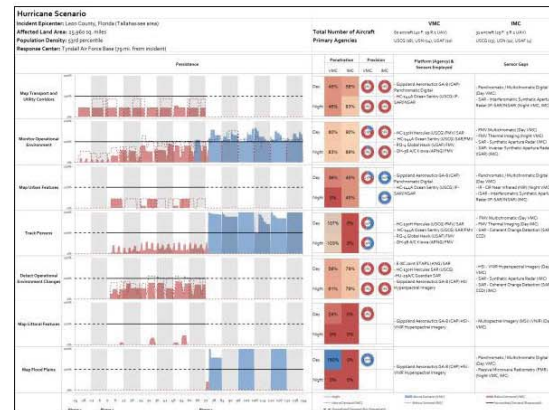

Figure 5. Single-Incident Simulation Dashboard

4.2 Enterprise Level Outputs

In addition to outputting performance metrics for individual scenarios, the disaster response model also generates enterprise-level scenario data by disaster type.

Data from each of the six incident types is aggregated geographically by FEMA region into an enterprise dashboard. Persistence metrics for each incident task are measured

across each region to identify under equipped regions. The metrics are also compared to the frequency of incidents within each region to provide the severity of a capability gap. Smaller gaps bear more weight in a region frequently affected by an incident than a larger gap occurring in a region less affected.

4.0 Conclusion

Dynamic modeling with discrete-event simulations provided a consistent, robust, and repeatable framework for the analysis of IAA disaster response operations. The application assisted the study in understanding the current gaps and shortfalls in current resourcing. Data generated from simulations helped pinpoint geographically the problem areas within the overall enterprise that need additional attention. In addition, dynamic modeling allowed the study to better visualize their current business processes, and also provided a talking point for discussion.

In the future we plan to expand the disaster response models to further applications. Such applications include forest fire resourcing operations, cost analysis, and also disaster imagery Processing, Exploitation, and Dissemination (PED) architecture analysis.

5.0 References

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6.0 Acknowledgments