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USE OF MODELING AND SIMULATION IN EMERGENCY PREPAREDNESS AND RESPONSE: STANDARD UNIFIED MODELING, MAPPING, INTEGRATION TOOLKIT

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ABSTRACT

The Standard Unified Modeling, Mapping, and Integration Toolkit (SUMMIT) is an innovative simulation platform that enables users to discover/reuse models and execute case studies to analyze emergency events. SUMMIT accelerates "what-if" analysis of disaster scenarios and improves the planning and execution of exercises. The key features of SUMMIT are in reuse of models that have been integrated into the model library, an interface that helps non-programmers to compose scenarios, ability to rapidly test and compare disaster scenarios from one location to another. SUMMIT contains a number of case files that constitute synthetic data for analysis of response and recovery operations, trends, impacts, and risks. SUMMIT supports the National Preparedness System as described in the Presidential Policy Directive 8 (PPD-8) and has been transitioned into an operational environment for use in training, exercise, threat/hazard risk assessment, resilience, and other preparedness activities.

1 INTRODUCTION

Preparing for disasters requires effective training, understanding of what to expect, managing the associated risks, and ability to react quickly to save lives and property. Response and recovery operations are resource intensive, take time, and come with significant costs. As jurisdictions continue to improve their level of preparedness and enhance their ability to respond to emergencies, there is an increasing reliance on drills, exercises and training to maintain and improve response planning and readiness (HSEEP 2007), especially as funds continue to be less available. Additionally, before, during, and after any recovery operations, a significant amount of data is generated that is ideal to support post event risk analysis (THIRA 2012). This analysis is increasingly becoming important for Lessons learned, identification of disaster cause and effect, decision making process, and finally the impact on both operations and infrastructure.

The use of modeling and simulation (M&S) technologies has also become a valuable asset in providing scientific data in the conduct of training and exercises. Further, many models, information management tools, and devices are being used both in exercise environments, and to support response and recovery operations (e.g., by improving situational awareness).

The Department of Homeland Security, Science and Technology Directorate (DHS S&T), in partnership with the Federal Emergency Management Agency (FEMA) sponsored the development of the Standard Unified Modeling, Mapping, and Integration Toolkit (SUMMIT) as a geo-agile platform that enables users to discover and reuse models, integrate them quickly and economically, and apply them in analyses to conduct "what-if" analysis of disaster scenarios, improve the planning and execution of large and small exercises, planning efforts, and support response operations (Mapar 2010). SUMMIT supports the National Preparedness System (DHS 2011), Presidential Policy Directive 8 (Obama 2011), and a critical objective of the Pot Katrina Emergency Reform Act (PKEMRA 2006) to remedy gaps in response.

The SUMMIT platform is innovative and has been used to support large scale national and regional exercises. The key features of SUMMIT are in reuse of models that have been integrated into the model library, a graphical interface that helps non-programmers to compose scenarios, ability to rapidly test and compare disaster scenarios from one location to another, and the vast case files that constitute synthetic data for analysis of causes, trends, impacts, and risks. SUMMIT also supports the National Preparedness System as described in the Presidential Policy Directive 8 (PPD-8) and has been transitioned into an operational environment for use in training, exercise, threat/hazard risk assessment, resilience, and other preparedness activities.

2 MODELING FRAMEWORK AND ARCHITECTURE COMPONENTS

The SUMMIT framework is platform-neutral; users will be able to access models from most web browsers, and models can execute on a number of platforms (Plantenga and Friedman-Hill, 2010). Results can be delivered easily to a collaborating set of users to inform the scenario, and serve as exercise injects or data for decision-makers during exercise play. The framework centers around the "integrate one, use many times" philosophy. This approach has enabled users to access models from most common operating systems and web browsers and execute them on a number of platforms. For example, the exercise community can incorporate modeling assets into their exercise design based on scenario information and parameters, run models based on their exercise-specific inputs, and deliver results to a collaborating set of users to inform the scenario, serve as exercise injects, and serve as data for decision-makers during exercise play.

SUMMIT is essentially an integrated visualization and modeling and simulation software environment that allows users—including emergency planners, responders, and decision makers—to seamlessly access and visualize integrated suites of modeling tools and data sources for planning, exercise and eventually operational response. Specifically, as shown in Figure 1, the SUMMIT service oriented architecture can be used to easily and rapidly discover, integrate, configure, execute, view and reuse the results of the nation's modeling and simulation resources and related data. These capabilities can greatly enhance the quality, cost and efficiency of exercises and planning.

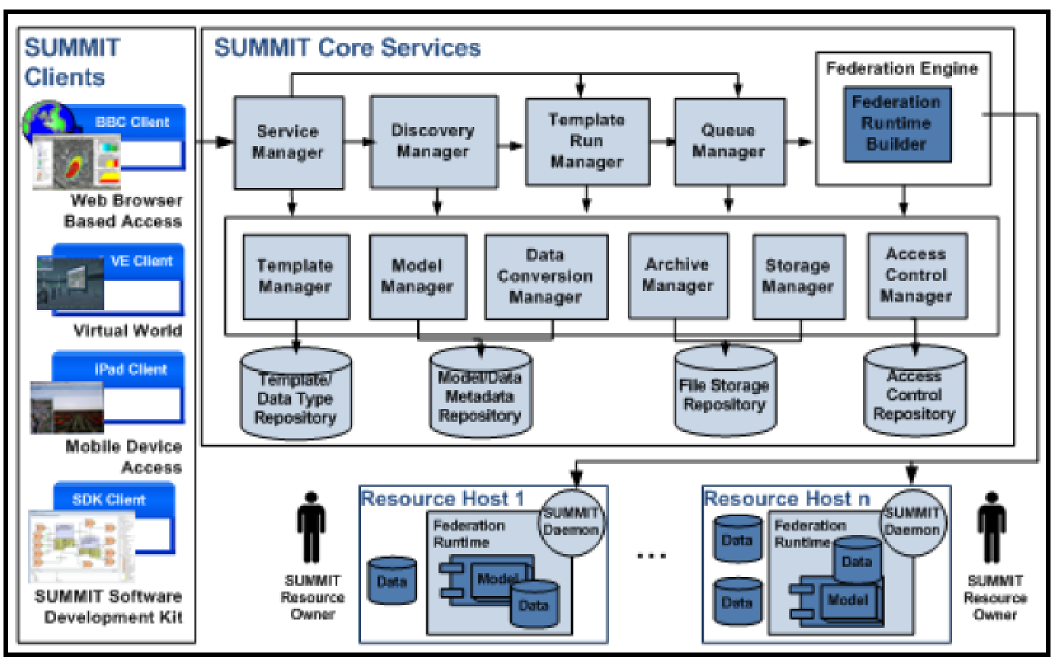
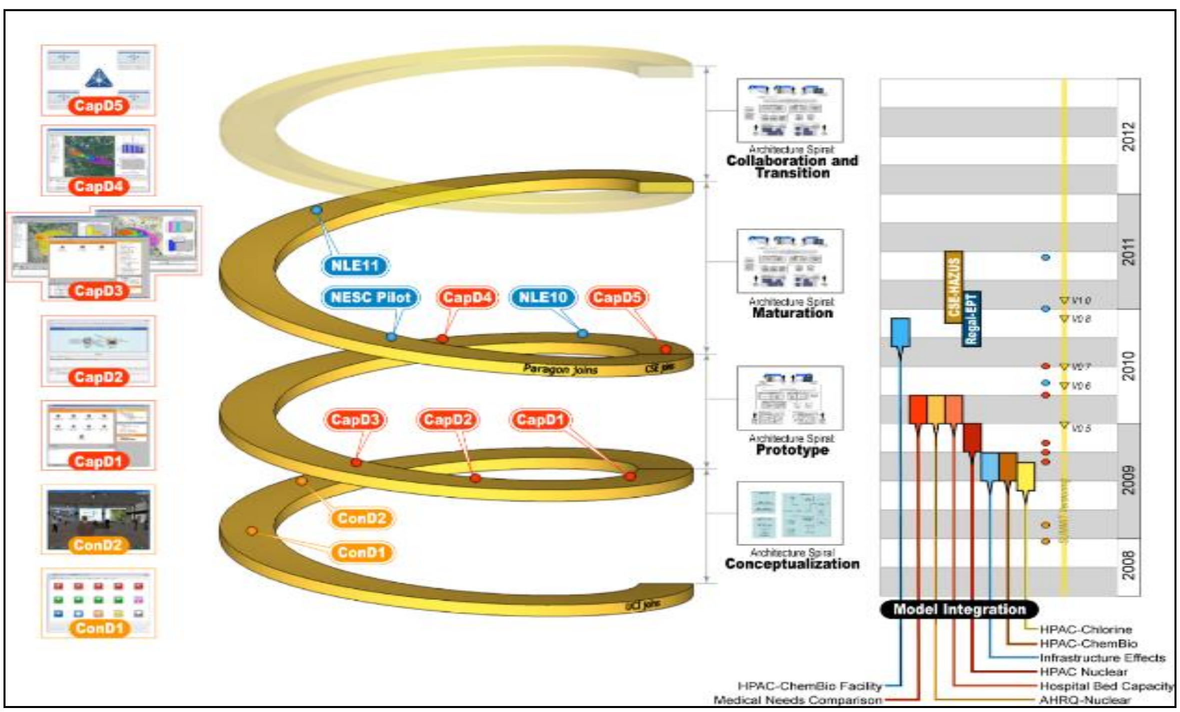


Figure 1: SUMMIT Architecture.

For example, utilization of science-based models helps ensure a realistic grounding for exercises and other emergency management activities. Reuse of models and data (e.g., reusing a model that previously has been vetted in a different locale or another exercise) can greatly reduce the cost and time required for the exercise and planning cycles. In addition, the ability to rerun models enables "what-if" trade-off analyses that are crucial for effective response during an actual event. The SUMMIT service oriented architecture has three main components: the SUMMIT web-based clients, the SUMMIT server, and SUMMIT-accessible data and models.

SUMMIT web-based clients allow users to connect to, configure, execute, and access the results of modeling and simulation runs on the SUMMIT system. The SUMMIT server maintains a repository of simulation templates and model results. A template (Freidman et al. 2010) is an abstract representation of an incident to be simulated. It provides a pattern or workflow for linking together and rendering interoperable models and data to address that incident. The SUMMIT-accessible data and models are resources provided by model contributors that users can access through SUMMIT. The data and model components are the property of the model contributors and typically run on hosts that are remote to the SUMMIT server.

Additional customized clients can be created that make use of SUMMIT to provide exercise support, emergency response, and visualization capabilities to users. For example, mobile applications have been developed that access the SUMMIT server for scenario ground truth to support exercise play. The SUMMIT architecture development strategy, as shown in figure 2, utilized a spiral development process to draw upon emerging research and information in order to continually refine the summit framework. thus, summit was used to support exercises while the architecture continued to mature. a goal of summit is to provide a flexible service-oriented architecture by providing access to the proper set of utility services, figure 1, that enable users to discover modeling and simulation resources, configure and execute template runs, visualize and review results, and create what-if scenarios. A key design benefit of the SUMMIT architecture that enhances reusability is its ability to provide for separation of concerns Security Operation Center (SoC) in



ConD1: Concept Demonstration 1 **CapD1: Capability Demonstration 1** **CapD3: Capability Demonstration 3**
ConD2: Concept Demonstration 2 **CapD2: Capability Demonstration 2** **CapD4: Capability Demonstration 4**

Figure 2: SUMMIT Spiral Development Process.

the model development process. Traditionally when creating a computer simulation, the model designers need to develop for all parts of the process, spanning data type design, model development, model execution provisioning, and data visualization. SUMMIT breaks up this process into individual pieces, allowing developers to make use of existing capabilities or examples and interfaces when available, and provides a means to improve upon or replace existing implementations when they can be done better. This allows users to avoid being locked into a specific implementation. When a new capability is added to SUMMIT, it is often applicable and can be made use of by many resources that are already in the SUMMIT ecosystem.

The client-server nature of SUMMIT and the adoption of common, open web standards allows light-weight clients, for example, clients that execute within a web browser or on a mobile device, to make use of heavy-weight services and compute-intensive models making these models broadly accessible across a wide variety of platforms. This also cuts down on installation and sustainment costs.

When a user executes a simulation, template run the SUMMIT server will contact SUMMIT Daemons to execute the models or retrieve data. The server integrates and organizes the results and makes them available to authorized users. The SUMMIT Software Development Kit (WebSDK) allows user to add content to the SUMMIT system such as new data types, templates, and information on available models that make federated simulation possible.

The application of SUMMIT's framework also includes a prediction model used to solve real-world preparedness problems. The SUMMIT framework is designed to enable the tools needed to generate, view, and execute models that give emergency planners the information needed to respond effectively. With its support for custom inputs and ability to model and execute custom simulations, SUMMIT provides a complete analysis of the "what-if" scenarios that are critical to successful response during an event. As there is an inherent difficulty in rapidly unifying disparate models, SUMMIT provides a singular location for the exercise and first responder communities to identify models, integrate them quickly and economically, and apply them in analysis to improve exercise, planning, and response efforts. SUMMIT provides an API-based, integrated modeling approach linking together disparate models, visualization and collaboration tools, and integrating users and datasets from internal and external entities.

The early stages of research and development for SUMMIT focused on challenges in streamlining the integration of models, combining models on-the-fly, and composing scenarios dynamically and rapidly. This early work was influenced by the users in the emergency management communities. These interactions helped to shape the final architecture that has resulted in a platform that supports both technical and non-expert users. As depicted in Figure 2, SUMMIT was developed and implemented in four phases—Conceptualization, Prototyping, Maturation, Transition.

SUMMIT templates, hosted on the SUMMIT server and accessible by SUMMIT web-based clients, provide an abstract representation of a hazard or incident to be simulated and may be customized with data types and models to reflect the exercise scenario. Emergency responders may input scenario information and parameters into a template and run models based on their exercise-specific inputs, ultimately delivering results to a collaborating set of users to inform the scenario, serve as exercise injects, and serve as data for decision-makers during exercise play. The SUMMIT Template, as shown in Figure 3, shows a simulation template whose purpose is to quantify medical risks to a population subjected to an aerosolized chemical agent release. It consists of 4 slots (rectangles), data flow connections between slots (thin arrows), template-level inputs (thick arrows pointing in), and template-level outputs (thick arrows pointing out).

Simulation templates provide an abstract representation of a hazard or incident defined by a scenario designer. A template also defines the components and parameters needed to form an executable simulation. The abstraction allows users to discover a template based on the scenario it addresses. The user can then instantiate a template run instance from that template and populate the slots with particular models, simulations, and data sets. A fully populated and configured simulation template run contains enough information for the SUMMIT server to automatically create and execute a simulation. Hence, a simulation template includes interoperability and connection information for executing models, though much of this detail is hidden from the user.

Beyond executing a single template run, SUMMIT supports linking together models via connecting one models output as input to another. Executing end-to-end modeling scenarios can be achieved via this linking procedure and requires that the user configure each template level input port for the template run. Once the template run is submitted to the SUMMIT server for execution, the SUMMIT server will contact the appropriate SUMMIT Daemons hosting models and data and will feed them the configured inputs. These models may then produce intermediate outputs that are then fed to other models until all template run outputs are set. Users of the template run can access the template level outputs directly or run data conversions on them to produce output in a format that is suitable for visualization.

The SUMMIT model execution system was designed to be a distributed architecture and as such it performs well on even low-end hardware and a given server instance will support multiple simultaneous users without performance degradation. This is unlike many traditional modeling tools which modeling and simulation on a single backend. The server component can be run on a lightweight machine, and the thin client can be run on virtually any machine. SUMMIT incorporates a simple service-based architecture in Java and is optimized for speed and efficiency. SUMMIT system supports scaling components to effectively solve the problem through web server, application server, network, and/or database.

The loosely coupled, flexible architecture utilized by SUMMIT can be easily scaled at all levels if necessary. The web server, application server and database are all open source components that can be scaled with no addition cost other than hardware. Additionally, if better performing versions of the chosen hardware configurations are released, they can be swapped out in favor of the better options with minimal effort. There is also the option of simply increasing the number of SUMMIT server instances on the network to alleviate any performance problems resulting from a large number of simultaneous users or

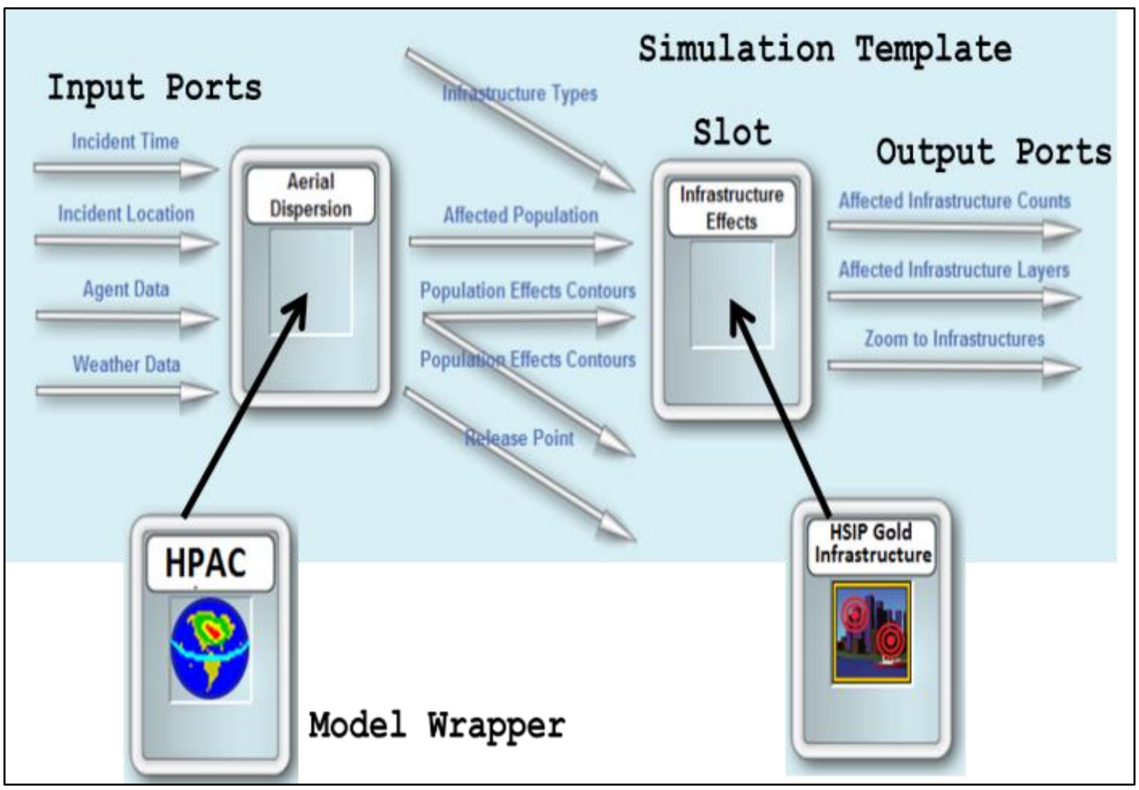


Figure 3: SUMMIT Simulation Template.

high network traffic. As an example, SUMMIT Server instances have been efficiently scaled on Amazon EC2. SUMMIT's modular and distributed architecture enables optimized performance in comparison tools that process data on a single backend.

The SUMMIT web-based component has been designed to provide an intuitive modeling and simulation experience in a consolidated interface, so that personnel can easily and rapidly discover, integrate, configure, execute, and view the results of M&S resources and related data. The SUMMIT interface has been designed to enable a dynamic view of fast-moving events that allows for analysis of the "what if" trade-offs that are crucial to effective response during an emergency event. The SUMMIT model parameterization, template discovery features, and output APIs are part of a three-step workflow. The first stage of the workflow is a discovery process, where users can discover M&S capabilities. The second stage of the workflow allows users to configure an M&S template with specific models and inputs. The third stage of the workflow executes a model or series of models and produces results. In the final stage of the workflow, the results are returned to the user and can be viewed. Figure 4 shows the SUMMIT system operational process/workflow.

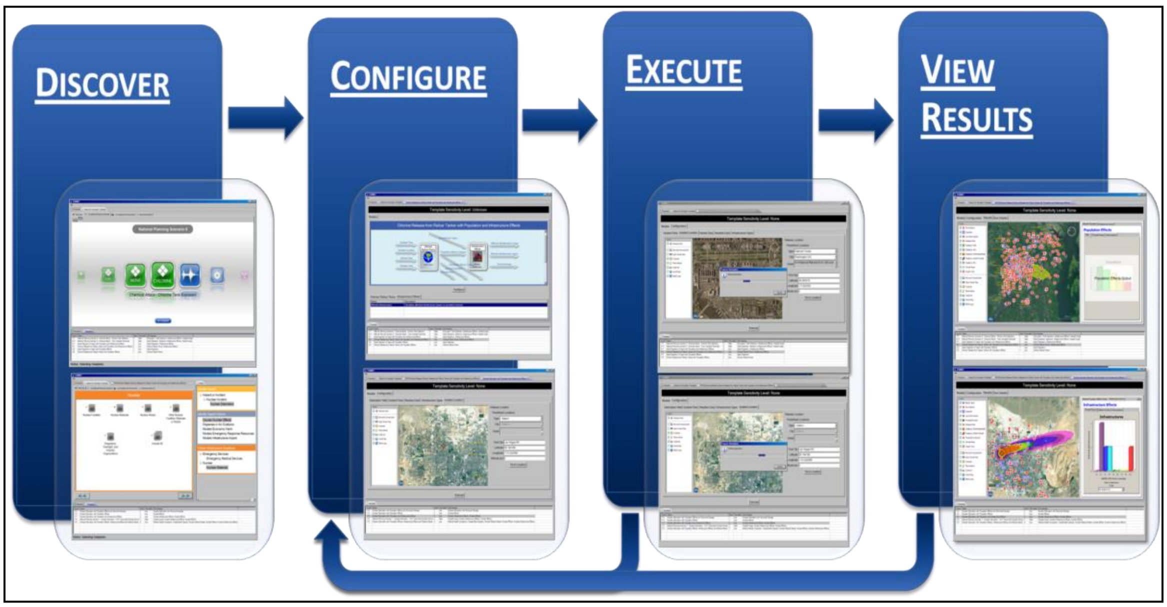


Figure 4: SUMMIT System Operational Process/Workflow.

The SUMMIT web-based component allows the client, the user (most likely an analyst, exercise planner or controller) to input parameters to discover, configure and execute exercise templates; search the results archive; and request data visualization. These actions are detailed below.

- **Template discovery:** The system guides the users through a number of questions related to exercise or analysis objectives and scenario preferences, and users can locate templates, based on exercise objectives, Emergency Support Functions, Target Capabilities and National Planning Scenarios.
- **Configuration and execution of templates:** A template is not specific to any models or inputs. A user composes and populates templates with models in the system . Metadata will allow users to distinguish among models, if more than one fit a particular slot. After configuring the models with input data (e.g., specify the scenario location, date/time, threat characteristics, etc.), the system automatically links the models and seamlessly executes them.

- **Results archive:** Once a template has been executed, the results are archived. Configuration parameters and results are archived in the system results archive, and the template can be easily accessed and rerun. A user can search and find results in the archive.
- **Advanced data visualization**: Results are viewed by users via a number of advanced data visualization techniques to provide a heightened sense of situational awareness to exercises. SUMMIT exports results into formats that other tools, e.g. desktop tools and/or visualization tools, can consume. Output from multiple models can be overlaid within GIS systems to provide a geospatial visualization of results.

Once a model (or template run) has been executed, the SUMMIT web-based client provides several outputs. Configuration parameters and results are archived in the system results archive, and the template can be easily accessed and rerun. A user can search and find results in the archive. In addition to searching, cloning and rerunning templates through the results archive, SUMMIT supports advanced visualization of results on a GIS map as well as tables and charts. Modeling and simulation results can be viewed by users, using a number of advanced data visualization techniques to provide a heightened sense of situational awareness to exercises. SUMMIT exports results into formats that other tools, e.g. desktop tools and/or visualization tools, can consume. Output from multiple models can be overlaid within GIS systems to provide a geospatial visualization of results. SUMMIT can also deliver these outputs to clients connected via web services. Users can access all SUMMIT outputs from the Web Based Client.

In addition, users can utilize the SUMMIT SDK, depicted in Figure 5, to add new models to the SUMMIT environment. Specifically, model and simulation developers can “Wrap” their model with an interface that allows the SUMMIT server to communicate with the model. This standardization of models and data has many advantages for the M&S development community. First, making a model SUMMIT-compliant enforces conformance with a community-driven data standardization, which allows for easy data exchange with other SUMMIT-compliant models and software toolkits. As a result, models that are SUMMIT-compliant will have greater exposure and usage within the EPM community, through SUMMIT’s M&S discovery process. This process leverages a tagging system that is populated as part of the SUMMIT-compliance process, allowing users to discover all models and data sets applicable to their scenario.

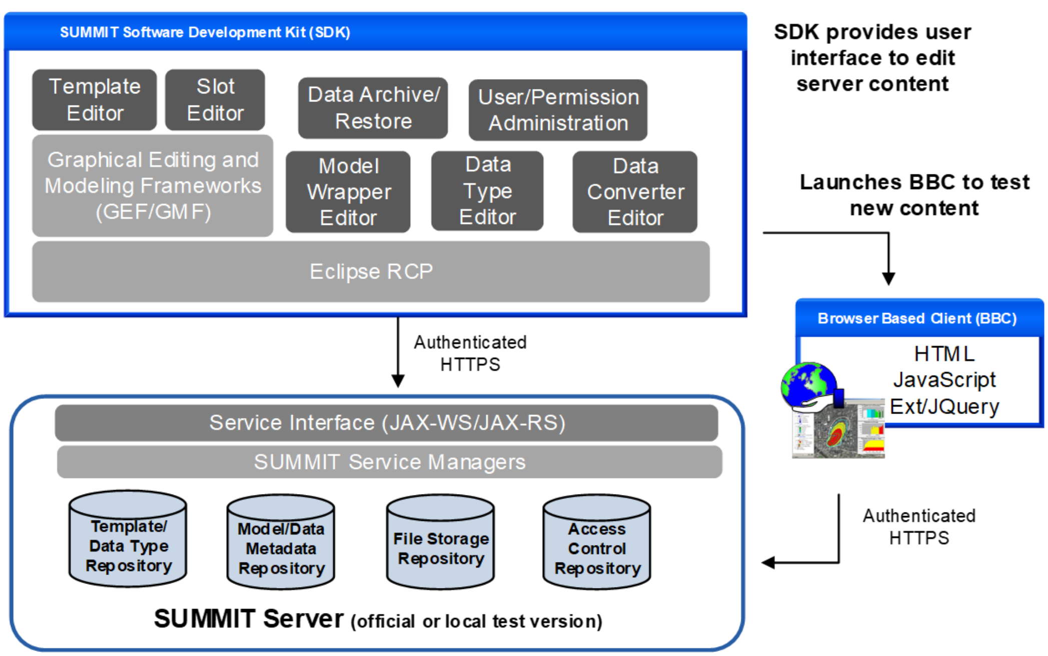


Figure 5: SUMMIT SDK Architecture.

The SUMMIT SDK is a software development kit that enables scenario designers and model owners to rapidly integrate new content into SUMMIT. The SDK can also be used to administer a SUMMIT Server or SUMMIT Daemon instance by providing functionality for setting passwords and importing content from archives. Using the SDK, users can create new Data Types, Slots, and Templates. They can submit model wrappers and data converters to the SDK and indicate what SUMMIT Daemons they can be hosted by. The SDK provides utility features for generating Java project templates to aid model owners in the development of model wrappers. The SDK comes with an instance of a SUMMIT server for local testing. Their work can be archived to a file which can be imported into another SUMMIT server instance. Figure 5 depicts the SUMMIT SDK architecture.

The SUMMIT SDK consists of several components that make it possible to rapidly to add new models and content to SUMMIT, including features that enable sharing and setting permissions on models. The SUMMIT SDK features are described in further detail below.

- **Data Type Editor**: The data type editor is a user interface that allows editing information for a new or existing data type. The data type editor incorporates the Data Type Schema editor, which allows specifying the format of the data type. SUMMIT's core mechanism for defining data types is XML Schema.
- **Slot Editor**: The slot editor provides a user interface for encapsulating input and output ports that are used as part of a template. The slot is designed to be a general and reusable component that separates interface from implementation. Slots allow for easy access and utilization of existing resources by allowing models to be plugged in and out of slots, forgoing the need to create an entirely new template for each new model.
- **Template Editor**: A template is the most basic part of a simulation. The template consists of the inputs for the scenario data and the outputs of the resulting simulation. The template editor provides three components to add/modify a template: 1) Template Properties, which allow viewing and editing properties for the template, such as name, description, input/output ports, contained slots, and connections, 2) the Template Design graphical editor that allows adding slots to a template and creating connections between slots and template level input and output ports, and 3) the Template Layout graphical editor which allows modifying the layout of a template and how it shows up in the application.
- **SUMMIT Package Editor**: SUMMIT Packages allow users to combine multiple model wrappers and data converters and dependencies into a single archive file that can be deployed to a SUMMIT Daemon. It mirrors the concept of java's WAR file. The SUMMIT package editor allows for performing CRUD operations on SUMMIT packages.
- **Model Wrapper Editor**: A model wrapper is the interface by which SUMMIT interprets models and incorporates them in to its framework. The Model Wrapper Editor provides three methods for wrapping a model: Java API, command line, and Web API. Additionally, it provides the functions to set the model wrapper type and generate model wrapper code.
- **Data Converter Editor**: Data Converters are a type of SUMMIT Process used to convert a SUMMIT resource from one format to another. One can create data converters as Java classes. Generally, this is done by adding code to a Model Wrapper project. The Data Converter Editor provides the functions to create and modify data converters for data types.
- **User and Permission Administration**: Users who are logged in as administrators can manage permissions to access templates, template runs, and models via the SUMMIT web application. The Admin Tab can be used to add and modify user permissions and to control which users are able to access particular resources (templates, models, runs, etc.) via Authorization Scripts. This interface provides functions to add and modify user accounts, which are the mechanism of identifying real people who use the system, user groups which are collections of user accounts, and define access for user groups. Access permissions are positive and cumulative and only the designated owner of a resource can create permissions for it.

- **Content Archiving/Restore**: SUMMIT provides the ability to create an archive of a SUMMIT server's state. This is useful if one would like to share templates, slots, data types, model wrappers, data converters, or SUMMIT packages between SUMMIT server instances. The administration menu can be used to archive the following types of data: repository, user data, results (single or multiple template runs), reports, and cached reports.

SUMMIT's modeling workflow, collaborative features, and advanced visualizations support the objective of a complete analysis of the "what-if" scenarios that are critical to successful response during an event. The SUMMIT workflow and the use of its intricate parameterization and dynamic scenario adjustment features are described next in the context of a real-world tornado event.

3 MODELING REAL WORLD DISASTERS

Tornadoes are a common occurrence in the United States. There have been 536 confirmed reports of tornadoes in 2018. Measuring tornado damage currently consists of estimating wind speeds, width, and distance traveled. Most tornadoes have a wind speed less than 62 mph, are about 250 ft across, and travel a few miles before dissipating. The worst tornadoes may attain wind speeds of more than 300 miles per hour, are more than two miles in diameter, and stay on the ground for dozens of miles. Tornado characteristics are measured using the Enhanced Fujita Rating (EF Scale), which rates the intensity of tornadoes in the United States and Canada based on the damage they cause. It is a proxy for actual wind speeds that correlates expert elicitation, engineering studies, radar data, and other factors with potential damage. The Fujita Rating consists of six scales, corresponding wind speed estimates with resulting damage potential.
SUMMIT's Tornado Building Damage Model, as shown in Figure 6, enables specification of real-world tornado damage parameters, such as EF-scale based on Enhanced Fujita Rating, as well as maximum

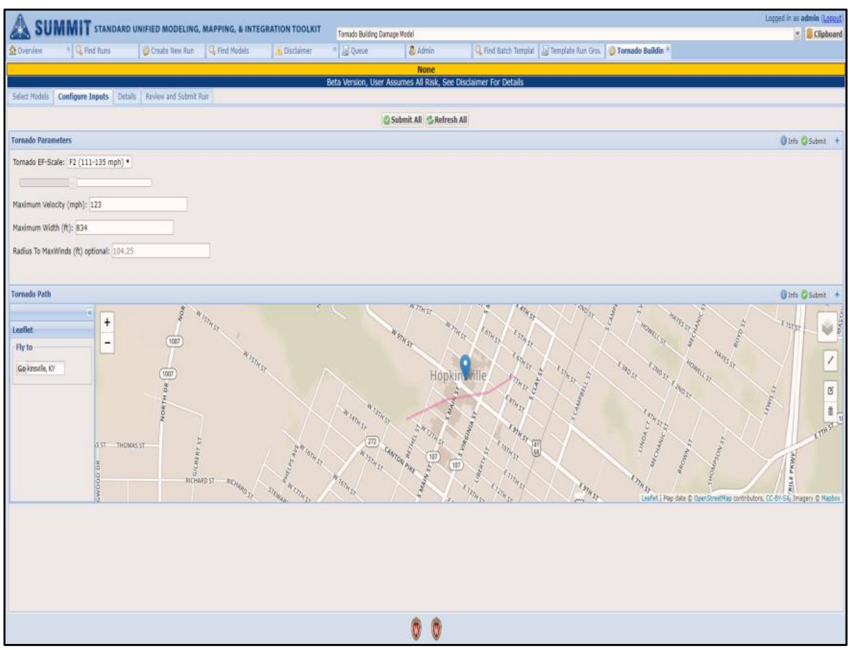


Figure 6: SUMMIT Tornado Building Damage Model Parameter Interface.

velocity and maximum width. The results of the SUMMIT model allow tracking a tornado across geographic localities with real-time adjustments, visualizing and analyzing damage predictions, such as expected wind damage, storm surge damage, property damage, and impacted emergency services. SUMMIT GIS components enable identifying critical damage areas, development of evacuation routes, identifying offsite emergency shelters, analyzing available hospital resources vs anticipated need, and local services to the damage area that provide needed supplies such as food, water, and shelters. SUMMIT analysis tools enable emergency workers to pre-position supplies and emergency workers and strategize response before the tornado touches ground.

On February 24, 2018 the Storm Prediction Center issued several tornado warnings across much of the Lower Mississippi River Valley area. While many of the resulting tornadoes were relatively brief, some were strong, resulting in major damage and fatalities. Of these, a high-end EF2 tornado stuck the southeast side of Hopkinsville, KY severely damaging multiple two-story apartment buildings and injuring nine people.

SUMMIT may have been used to model this tornado at the point of inception, predicting areas most vulnerable to damage, such as the apartments buildings, and evacuated civilians before disaster struck. SUMMIT provides a comprehensive modeling framework for tornado scenarios, including ability to map scale and the anticipated path of the tornado. For the purpose of displaying the real-world modeling capability provided by SUMMIT, SUMMIT will be used to retrospectively model the Hopkinsville, KY tornado and provide an analysis that closely matches the actual damage caused by the incident. SUMMIT allows specification of several tornado parameters, including the maximum velocity, which in the case of a prediction model, can be estimated at 123 mph for a high-end EF2 tornado, similar to the one that occurred in Hopkinsville, KY. The tornado width is pre-set to 834 ft for an EF-2 scale tornado but can be adjusted by units of one foot. Optionally, a maximum-wind parameter can be adjusted to optimize the tornado wind fluctuation to conform to the real-world scenario. The SUMMIT Tornado Building Damage Parametrization interface is depicted below.

4 SIMULATIONS RESULTS AND DISCUSSION

Upon execution of the tornado model, SUMMIT provides a visual representation of the damage path delimited by census block, as shown in Figure 7). Consistent with real-world scenarios
concentrated to the core of the tornado, with the blocks on the outskirts experiencing the least damage. The inner-most census blocks experience a moderate damage expectation level of 50%, with two predicted buildings damaged, amounting to $1,616,514. In addition, SUMMIT provides detailed charts and tables, describing damage by building type, building loss in dollars, and damage by square footage.

The SUMMIT tornado model utilizes two separate algorithms (or models) for its final output. The first is the University of Wisconsin Tornado Path Model which provides estimates of wind levels based on the

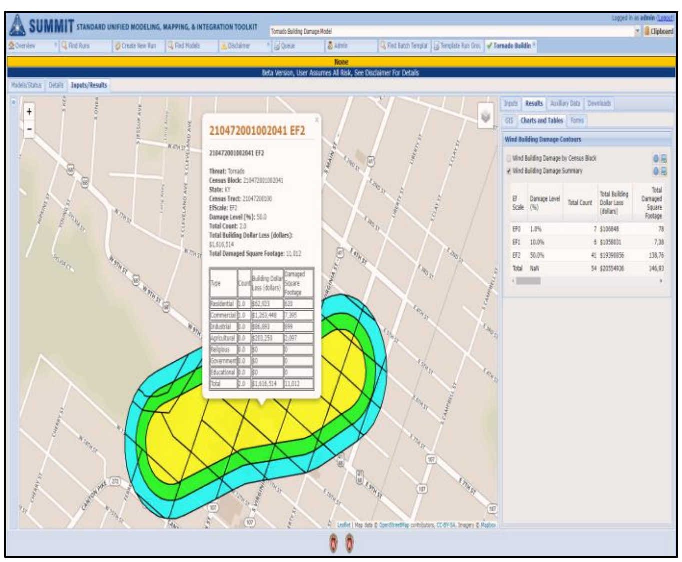


Figure 7: SUMMIT Tornado Building Damage Model Output.

Burgers-Rott vortex model. The result of this calculation is input to the University of Wisconsin Tornado Damage and Loss Model which estimates wind-induced building damages and losses based also on the Burgers-Rott vortex model. In addition to providing features to develop models and incorporate existing model algorithms, SUMMIT provides features for linking one model's data output as input to another, integrating and streamlining the model development and execution workflow. The SUMMIT GIS maps provide a visual tool for planning emergency response.

To make predictions that more accurately resemble real-world scenarios, SUMMIT provides a batch execution feature, which allows adjusting parameters for the input model to obtain a more realistic prediction via multiple model outputs. As an example, SUMMIT provides an easy-to-use feature to execute the prediction model for the Hopkinsville, KY tornado multiple times with slight variations to the tornado path or the wind speed. These model executions with slight variations allow identifying how to best allocate resources given uncertainties.

5 CONCLUSION

As depicted in this tornado model example, SUMMIT enables exercise and planning communities to effectively predict and model potential disaster events and increase their organizations effectiveness and capability in responding to such events. In addition, SUMMIT's model linking capability can be used to create data pipelines that link multiple models to enable greater insight and analytical capability and align exercise goals to objective predictions.

The SUMMIT results viewer enables exercise planners to visualize damage prediction models in the form of maps, charts, tables, and reports. The results viewer enables sharable views allowing collaborators to effectively communicate regarding predictions and align resources where they are needed. In addition, SUMMIT's distributed capabilities allow external EPM tools to gain access to result outputs such as historical data, which are accessible via web service endpoints. The usage of SUMMIT framework's parameterized, real-time modeling capabilities allows addressing potential disaster events via comprehensive risk mitigation and actionable intelligence. The detailed outputs provided by the SUMMIT results viewer, such as tooltips, tables, and reports enable examining potential damage dynamically, and across multiple timelines. SUMMIT enables effective estimation of manpower and resource requirements through its visualization components, along with the ability to share and collaborate views, findings, and reports, with other personnel.

By using SUMMIT, the emergency preparedness community is able to reuse both scenarios and model results in subsequent exercises, either by the same agency or other agencies. For example, the earthquake simulation template that was created for NLE 11 was reused in the Utah ShakeOut 2012 exercise. SUMMIT can now support regional, national and international exercises, help with "what-if" analysis of response operations, and can be a source of synthetic disaster data (simulated) for teaching, learning, and decision making, and strategy development.

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