TECH**BRIEF**

Integrating Building Information Management (BIM) for Infrastructure-Enabled Data With Highway Emergency Response: Technological Opportunities

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SUMMARY

This TechBrief summarizes a Federal Highway Administration (FHWA) study that investigated how Building Information Modeling (BIM) supports highway emergency response (ER) operations when using data managed by highway infrastructure asset and maintenance managers. The research focused on three agency business functions that overlap with regard to the data and information needed for ER and routine infrastructure management and maintenance. These business functions are situational awareness, asset resilience, and asset repair; these functions incorporate processes that comprise the ER management lifecycle, ranging from pre-event planning to postevent recovery. Coupling a review of agency practice with empirically observed effective industry practices in the areas of data governance and management for BIM, the research identifies relevant asset-related and asset-network-related data assets, data systems, and data integrations or exchanges that support ER. The findings will support integration of both ER and routine highway operations asset-related data and information to help agencies achieve a complete and efficient whole-life understanding on which to base asset management and investment decisions that consider ER needs and impacts.

INTRODUCTION

FHWA research examined opportunities for using technology to capture State departments of transportation (DOTs) asset information created as a result of highway maintenance in response to an emergency event.[(1)] Unplanned events, such as hurricanes or floods, often have significant impacts on the service and condition of DOT-controlled assets such as roads, structures, and ancillary equipment. The ER process requires managing the event, preserving public safety, and restoring operational capacity as quickly as possible. ER also involves significant coordination among other responding agencies at the Federal, State, and local levels.

While many of the processes needed to plan and execute asset maintenance during an emergency are the same as those for routine highway maintenance operations, significant differences exist in the information, techniques, tools,

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and types of personnel skills used. The urgent and multiagency nature of ER management makes routine capture of asset information challenging in a way that fully aligns and integrates with agency infrastructure asset management practices and processes during routine operations. Figure 1 illustrates the asset information capture challenge during the lifecycle of a highway asset. Figure 1 also shows how the periodic but random occurrences of emergency events during a highway asset's lifecycle can result in significant impacts as measured by a (temporary) change in asset condition and function and the repairs (and expenditures) that restore or potentially improve functionality. In the figure, those events contrast with planned routine operations and regular maintenance.

The integration of asset information from both ER and routine operations is an important goal toward obtaining a full and efficient whole-life asset understanding on which to base asset management and investment decisions. However, a framework for identifying, managing, and using the data is needed to achieve the goal.

RESEARCH OBJECTIVES

As part of this project, the research team used the following steps to develop a BIM framework for infrastructure asset management and ER:

- Identifying overlapping business functions in emergency and infrastructure (data) management.
- Reviewing existing practices in data creation, collection, modeling, integration, and use (analysis).
- Identifying opportunities for data exchange between emergency and infrastructure systems.
- Identifying opportunities for improvement in data management within and across business functions.

OVERVIEW OF STATE OF THE PRACTICE

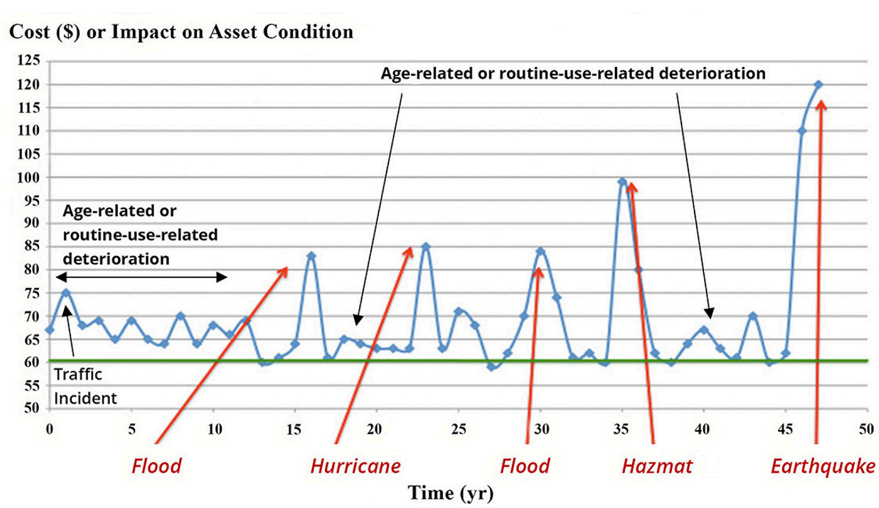
Tools To Support Emergency Management Data Management

Prior FHWA research on ER and asset management studied the need to improve asset information capture during ER by investigating tools and technologies and agency best practices to integrate ER with maintenance management systems or enhance maintenance asset management in the ER context.[(1)] The research identified approximately 65 technologies or tools that transportation and emergency management agencies use as aids in data capture and during ER processes, ranging from planning and preparedness before an emergency event to response and recovery postevent. These technologies and tools include vulnerability and risk assessment, resource planning, budget forecasting, work program management, and critical information tracking for situational awareness. However, the research generally found that no technology or tool that bridges ER and routine asset management processes is ready for adoption or refinement for general use by all agencies. The research recommended the development of tools that would integrate ER and routine operations in the areas of damage assessment and reporting. Ultimately, the state of the practice is characterized by two relatively delineated sets of processes wherein ER data systems have limited or no data exchange with highway infrastructure data systems, resulting in a missed opportunity for integrated information capture and business operations efficiencies.

BIM for Infrastructure

FHWA has conducted considerable research on BIM for infrastructure (referred to hereinafter as BIM) practices within transportation agencies in the United States

Figure 1. Graph. Integrating emergency and routine operations and maintenance data across an asset lifecycle.[(1)]



Source: FHWA.

and Europe.[2] The research established a process for integrating data from design and construction data models into asset management. FHWA, the American Association of State Highway and Transportation Officials, and the National Cooperative Highway Research Program have carried out complementary research on highway agency data systems and data management practices. In addition, FHWA developed a BIM data governance framework that includes the following components:[3]

- Data portfolio: A catalog that lists the datasets used in a process.
- Data supply process:
  - Identifying the system wherein data will be created.
  - Determining who will create the system.
  - Setting forth the ways the different authoritative sources will be managed.
  - Deciding on the data models that will be created.
  - Establishing the data quality control process.
- Data delivery and use process: The exchange, integration, and provisioning of data created and stored in various authoritative sources for stakeholder use in analysis and decision support.

The research structured a BIM framework for infrastructure asset management and ER by using these framework components.

DETAILS OF RESEARCH APPROACH

ER and Infrastructure Management Business Functions

To study opportunities for data integration, exchange, and management between ER and routine infrastructure management, researchers focused on three business functions. The researchers identified business functions by examining the processes involved in the emergency management lifecycle from pre-event planning to postevent recovery and comparing them with similar processes for routine infrastructure management in which planning and asset repair or maintenance operations take place. The three business functions are as follows:

- Business function 1: Situational awareness—Asset inspection, damage assessment, and incident management.
- Business function 2: Asset resilience—Vulnerability analysis and adaptation planning.
- Business function 3: Asset repair—Maintenance, rehabilitation and reconstruction, and work and project execution.

Table 1 lists example sets of activities typically performed as parts of ER management and routine highway infrastructure management. Examining the respective lists under each business function reveals the overlapping nature of the business function carried out under both ER and highway infrastructure management. For example,

Table 1. ER and infrastructure management business functions and activities.

Activity Type To Be Managed	Business Function 1: Situational Awareness	Business Function 2: Asset Resilience	Business Function 3: Asset Repair
ER management	• Incident information collection. • Preliminary reports and DDIRs using mobile applications and UASs. • Emergency TSMO tactics.	• Hazard impact assessment (e.g., flood plains and hurricane tracks). • Vulnerability analysis. • Criticality assessment. • Asset resiliency and adaptation planning.	• Adaptation projects and repairs. • Event-based asset repairs. • Project funding, budgeting, and financials tracking. • Resource management.
Highway infrastructure management	• Routine asset inspections (bridge inspections, pavement roughness distress, culvert condition, etc.); UAS inspections. • Construction inspections: as-built assets. • TSMOs.	• Health, safety, and mobility performance analysis. • Risk-based lifecycle analysis for transportation asset management plan development.	• Capital projects: construction, rehabilitation, and replacement. • Maintenance work management. • Project funding, budgeting, and financials tracking. • Resource management.

DDIR = detailed damage inspection report; UASs = unmanned aerial systems; TSMO = Transportation Systems Management and Operations.

for situational awareness, routine asset inspections are performed to maintain awareness of asset condition. The counterpart activity during ER involves asset inspections that determine the extent of damage caused by the hazard. Opportunities exist to integrate the data collected under both scenarios. Similar opportunities exist for other activities within each business function.

State DOT Practice Review

To uncover and validate technological opportunities for the integration of BIM data with ER focused on the identified business functions, researchers conducted an agency practice review that included interviews with two State DOTs—Ohio DOT and the Vermont Agency of Transportation (VTrans)—along with studies of other DOTs such as New York and North Carolina.[4,5] The practice review examined components of the agencies' observed BIM frameworks that offered insights into tools, technologies, applications, and processes for data collection, modeling, exchange, integration, and analysis. The interviews included demonstrations of tools when relevant.

The research team narrowed the set of emergency events considered in the practice review to those most commonly addressed across a wide range of agencies in the past 5–10 yr: hurricanes, floods, landslides, and rockfalls. However, the research findings are broadly applicable to a larger cohort of emergency events, including other natural hazards (e.g., winter storms, wildfires, and earthquakes), technological hazards (e.g., bridge collapses and hazmat releases), and human caused hazards (e.g., terrorist acts).

RESULTS

Data Portfolio

The research identified eight data asset domains that can categorize all relevant data assets. The data portfolio includes descriptions of items that comprise the data and why the data assets are either created or used as parts of one or more of the ER management business functions. Establishing the data requirements enables transportation agencies to determine the types of data supply systems needed for creating and managing data assets and the data exchanges to enable provision of data for use in analytics and decision support systems. Table 2 lists the data asset

Table 2. Data asset domains and example data assets.

Data Asset Domain	Example Data Assets for Business Function 1: Situational Awareness
Roads (routes) inventory	• Linear reference system routes (roads), intersections.
Asset inventories	• Bridges, culverts, tunnels, retaining walls. • Traffic assets: Signs, signals, intersections. • Intelligent transportation system assets: Cameras, detectors, sensors.
Hazard or incident data	• Floodplains and hurricane track data. • Weather and water sensor data. • UAS photos, images, videos. • Crowdsourced public observations.
Asset or site inspections and damage assessments data	• DDIRs. • Site or asset-specific inspections: Rockfalls, landslides, bridges, culverts, tunnels, pavements. • UAS inspection data on bridges, roads (routes). • Internet of Things sensor data on bridges, tunnels, roads.
Traffic and safety data	• Road and/or asset incidents. • Crash data.
Geohazard data	• U.S. Geological Survey and Federal Emergency Management Agency floodplains. • UAS inspections of floods, landslides, rockfalls.
Weather data	• Weather forecasts. • Real-time weather and water sensor data.
Projects, contracts, and work orders	• Survey, UAS inspection project. • Critical asset repairs or treatments for preparing asset for hazard.

domains and gives examples of specific assets for one of the business functions: situational awareness.

Data Supply Systems

The research identified management information systems, applications, and tools used for creating (modeling) data and preserving data associated with the ER business functions. Those systems may create data, update data, or read and use data. The systems will exchange and integrate data so that the data can be used for analysis and decision support. Table 3 summarizes a primary set of management information systems, applications, and tools by ER business function.

Table 3. Management information systems used for data creation, modeling, and storage in each of the business functions.

Management Information Systems, Apps, and Tools	Business Function 1: Situational Awareness	Business Function 2: Asset Resilience	Business Function 3: Asset Repair
Asset management systems	X	X	X
GIS and LRS	X	X	X
PPMS	—	—	X
Design and construction management systems	—	—	X
Financial systems	—	—	X
Enterprise business intelligence systems, data repositories (warehouse and hub)	X	X	X
Emergency management systems	X	X	X
Traffic management systems	X	X	—
Road weather information systems	X	X	—
UAS data management and analysis systems	X	—	—
Vulnerability assessment tools	—	X	X
Asset inspection and damage assessment applications	X	X	X

—No data.

PPMS = project planning and programming management systems; GIS = geographic information system; LRS = linear referencing system; X = applicable.

Data Use: Data Exchanges and System Integration

Because these data are created and stored in disparate systems, the data have to be exchanged and integrated within systems before being made available for analytics and decision support.

Findings from research on existing practice and a detailed review of VTrans' and Ohio DOT's authoritative data supply systems, applications, and tools form the basis for identifying a set of key data exchanges and system integrations related to the three ER business functions.[4,5,6] The data exchanges and system integrations in turn can support certain data uses for analytics and decision support during ER that can enhance routine infrastructure asset management. The research identified a set of nine data exchanges and system integrations, summarized in table 4.

Table 4. Data exchanges, data delivery, and system integration: State practices.

Data Exchange ID	Data Exchange and System Integration Summary	Ohio DOT	VTrans	Other DOTs
01	Roads and asset data from GIS-based State, local, and Federal road inventory systems to DOT LRS, AMS, PPMS, and data hub for identifying and locating assets.	X	X	Arizona, California, Idaho, Kansas, Minnesota, New York, North Carolina
02	Asset inventory, condition (current and past), and work history data from AMS to vulnerability assessment tools, data hub (stand-alone tool or part of AMS) for vulnerability score calculations, repair project planning, and adaptation project planning.	X	X	—
03	Asset damage and inspection data from GIS-based asset inspection and damage assessment applications to GIS-based AMS and GISs for integration of all asset condition assessment data for assets during their lifecycles.	X	(X)	New York, North Carolina
04	Survey, inspection data (photos, videos, lidar, mosaics) from UASs to AMS, GIS, design and construction management systems, data hub for situational awareness, and condition assessment and planning repairs.	(X)	—	Idaho, Kentucky, New York
05	Incident information and traffic and asset data from weather, traffic, and asset data systems to data hub and GIS-based business intelligence systems for situational awareness.	—	—	Idaho, Kentucky, New York
06	Resiliency projects and repair work plan and request data from vulnerability assessment tools and DDIR applications to AMS and PPMS to inform decisionmakers on work to be done, potential mitigation projects, and repair needs identified for assets before, during, and after an emergency event.	(X)	(X)	—
07	As-let and as-built project, asset, and financials data from design and construction management systems to AMS and LRS for creating or updating asset inventory, tracking work history, and conducting asset lifecycle analysis.	(X)	—	Iowa, Minnesota, New York, Utah
08	Integrated and processed asset inventory, condition, damages, work (active and historical), traffic, weather, UAS, design and construction data from data hub to data warehouse, and enterprise databases for analytics and business intelligence.	X	X	Colorado, Idaho, New York
09	Routes, assets, projects, and DDIR data from DOT LRS/GIS, PPMS, and AMS to FHWA databases so as to support data and performance reporting requirements.	X	X	Arizona, California, Colorado, Idaho, Iowa, Kansas, Minnesota, New York, North Carolina

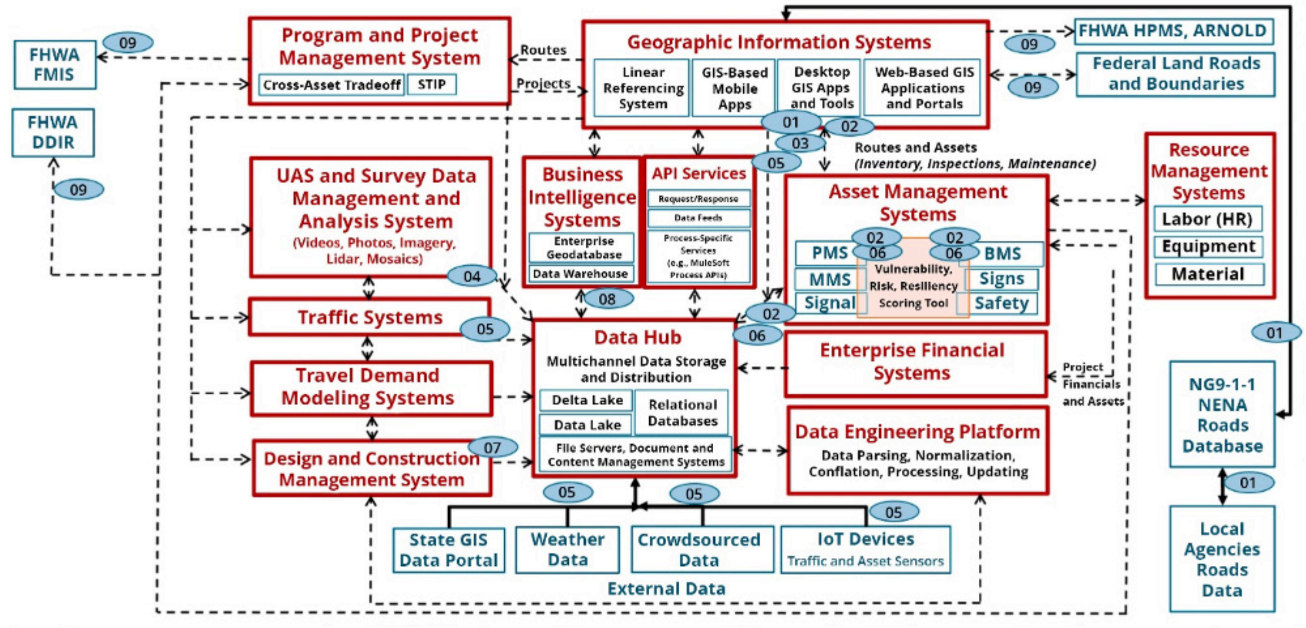
AMS = analysis modeling and simulation; X = fully or predominantly incorporated; (X) = planned or acknowledged as desirable for the future.

Data Use: Analytics and Decision Support

Figure 2 combines the practice review findings from VTrans, Ohio DOT, and other States' DOTs to illustrate a full set of proposed data exchanges and system integrations among data supply systems and sources. (Data exchanges from table 4 are shown in circles.) This generalized set of data and information management systems, data flows, and data sources idealizes the integration of ER and routine infrastructure asset management business functions and enables a wide range of data uses for analytics and decision support.

To provide an example of analysis and decision support within the asset resilience business function (business function 2), table 5 identifies a set of data use activities and compares them with VTrans' practice review findings.

Figure 2. Graphic. Proposed BIM data delivery and data exchange for ER and highway infrastructure management.



Source: FHWA
API = application programming interface; ARNOLD = All Road Network of Linear Referenced Data; BMS = bridge management system; FMIS = financial management information system; HPMS = Highway Performance Monitoring System; HR = human resources; MMS = maintenance management system; NENA = National Emergency Number Association; NG911 = Next Generation 9-1-1; PMS = pavement management system; STIP = State transportation improvement program; IoT = Internet of Things.
Note: Circled numbers are the data exchange ID numbers defined in table 4.

Table 5. Asset resilience data uses example.

Data Use Activities: Analysis and Decision Support	VTrans' Transportation Resilience Planning Tool Practice[4]
Identify and characterize threats: Screen threats for potential to result in asset damage and service disruption. Estimate threats' frequency, magnitude, and geographical coverage within a given period.	A focus on inundation, erosion, and deposition damages caused by 10-, 50-, and 100-yr floods.
Evaluate asset vulnerability: Evaluate impacts of specific threats, their intensities, and probabilities by using statistical analysis of historical damage or simulation studies.	Vulnerability scores based on exposure and the severity of potential damage by asset type in consideration of previously damaged assets as documented in FHWA detailed damage inspection reports and Federal Emergency Management Agency public assistance worksheets.
Evaluate asset criticality: Indicate the relative importance of the asset to the network in serving the essential functions of accessibility, mobility, connectivity, and economic vitality.	Criticality scores based on impacts on local and regional travel, access to critical facilities (e.g., hospitals), and locally identified important roads, as reported by residents.
Estimate user consequences: Quantify the impacts (e.g., operational, socioeconomic, safety, and health costs) on users due to service disruption.	Risk as the average of the vulnerability score and criticality score.
Select adaptation measures and projects: Evaluate the economic effectiveness of feasible adaptation measures from both agency and societal perspectives.	Tools suggesting mitigation strategies depending on contributions to the scores. Also used for project selection decisionmaking in the project selection process when a resilience component represents 10 percent or more of the project scoring.

CONCLUSIONS AND RECOMMENDATIONS

This research proposes a BIM framework of data assets, data systems, and data integrations or exchanges to facilitate analytics and decisionmaking for ER that enhances existing highway infrastructure asset management business functions. Specifically, the framework suggests nine data exchanges that would advance such an outcome—most significantly integrating road inventory data, asset data, survey and inspection data, incident data, and project repair data to support asset situational awareness, asset resilience, and asset repair business functions. By applying data management improvements as suggested by the framework, agencies could take better advantage of underused data in the context of ER with regard to resilience planning, situational awareness, and postevent recovery and repair operations.

In each of the three components of the BIM framework, further study and development are warranted. Within the data portfolio, the research identified an initial set of data asset domains, data assets, and applications. Additional research could explore how the data are modeled (i.e., structured in specific formats). Under data supply, authoritative data systems were identified and described. Further research would establish the required data modeling and data quality standards. Lastly, data exchange, integration, and analytics were discussed as parts of data use and delivery. Additional research could examine data-sharing and data delivery platforms, data security, and storage and archiving, among other elements.

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