IDEA

Innovations Deserving
Exploratory Analysis Programs

***Rail Safety IDEA Program***

# *Prototype System for Managing and Analyzing Enterprise Rail Transport Risks of Hazardous Materials*

Final Report for
Rail Safety IDEA Project 34

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***Prototype System for Managing and Analyzing***
***Enterprise Rail Transport Risks of Hazardous Materials***

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# EXECUTIVE SUMMARY

Hazardous material (hazmat) transportation by rail is a vital part of sustaining the modern lifestyle and economy. Hazmat shipments account for only a small portion of the overall freight traffic but any accidental or non-accidental release, although considered a rare occurrence, can have potentially significant impacts to the railroads, the public, and the environment. While railroads continually invest in improving the safety of overall rail transport, including hazmat transportation, there is a continued need to identify, evaluate, and improve options for further addressing the unique nature of the risks encountered in rail hazmat transportation. Existing risk assessment frameworks are currently suitable for evaluating safety risks for individual commodities and for specific routes. However, in their current state of development, they do not easily lend themselves to the development of a systemic understanding of risk that railroads need for making risk-based decisions and improving overall network safety.

This IDEA project resulted in a novel, web-based prototype system for freight rail carriers: Prototype System for Managing and Analyzing Enterprise Rail Transport Risks of Hazmat (SMARTER Hazmat$^{TM}$). This prototype provides a new capability for railroads to evaluate, quantify, and visualize the overall, aggregated safety risks from comprehensive hazardous material traffic flows. The unique concept that forms the basis of this prototype is the application of a quantitative framework for risk aggregation and accumulation (FIGURE 1a) resulting from multiple hazmat movements across a rail carrier's network, rather than evaluating risks on a route-by-route basis, which is the current state-of-the-practice. The developed prototype (FIGURE 1b) aims to provide a systemic understanding of risks which railroads need for supporting risk-based investments and resource allocation decisions to improve overall railroad safety.

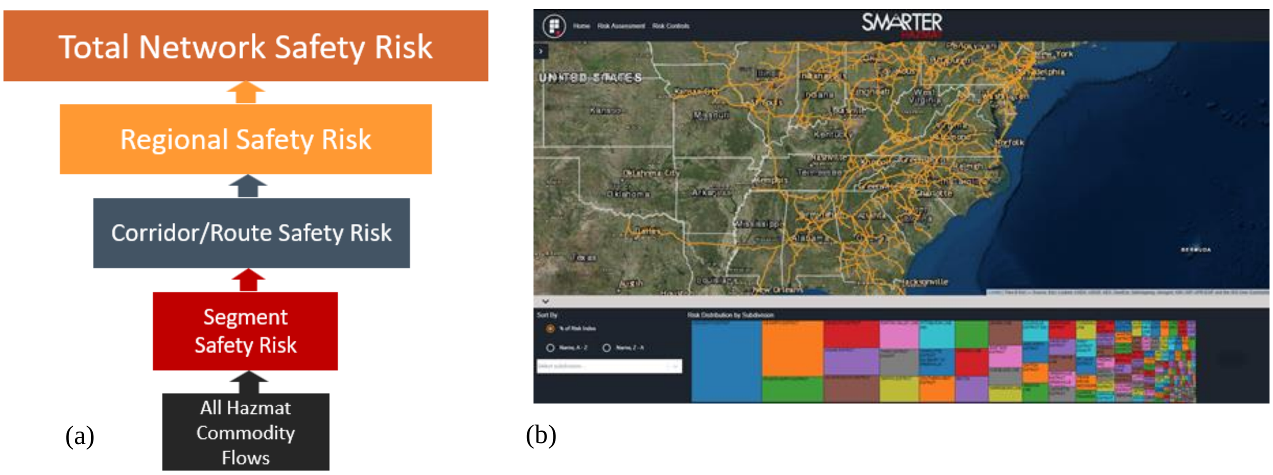


**FIGURE 1. Concept and innovation of the IDEA project: (a) the concept of safety risk accumulation from comprehensive hazmat movements to support a network-level measure of all-hazmat risk; (b) the IDEA product developed based on the concept, i.e., web-based, prototype SMARTER Hazmat$^{TM}$ for understanding hazmat risk distribution and supporting risk prioritization over rail networks.**

The tasks in this project were divided into two stages: Stage I and Stage II. The objective of Stage I was to lay the methodological framework for assessing hazmat safety risks to support network-wide decisions. This analytical task required assessing and comparing the railcar-based modeling approaches, commonly accepted as standard practice in rail hazmat risk assessment studies, and contrasting them with the more recently developed train / multicar release-based risk assessment models. We found that although the train-based methodology offers more nuanced features to evaluate hazmat safety risks, in general, the car-based and train-based methodologies were both consistent in identifying higher risk locations within the rail network resulting from multiple commodity flows. The more detailed train-based methodology allows better characterization of release likelihoods and accounts for potential multiple car releases but comes with additional data and analytical requirements. To meet the main objectives of the project, the car-based methodology was found to be sufficient and was selected to support Stage II activities.

Stage II activities included developing and testing the prototype system based on the results obtained from Stage I. We developed web-based user interfaces and data visualization capabilities with HTML5, React/Redux stack, and other modern web technologies to process and interact with network-level safety risk data and supporting datasets. Additionally, the prototype was enhanced to implement and quantitatively evaluate risk modification strategies for different sections of a railroad operational network. Through collaboration, testing, and review from our railroad partner, Norfolk Southern, we gathered feedback and insights to further improve the utility of the prototype system.

The prototype system was designed to support railroads with new risk data visualization and decision-making capabilities, including: (i) determination and prioritization of high-risk network areas by considering comprehensive hazmat movements across operational networks, (ii) evaluation of the impacts of introducing additional shipments from new hazmat customers; (iii) monitoring network safety risk for significant changes in trends; and (iv) comparison of the effectiveness of risk mitigation strategies and support with identification of the network locations at which those strategies potentially achieve the greatest benefit for finite safety investments.

Beyond the scope of the prototype phase, the overall vision is to enhance the developed product into a production-quality risk management tool that more directly integrates with existing railroad data management systems and workflows. This full-scale system will provide railroads with more customized views into critical hazmat safety risk information and support continued railroad safety improvement through application of the concepts of systems-based thinking.

# 1 IDEA PRODUCT

When making safety-related decisions and optimizing resource and investment allocations, railroads must consider the impacts those decisions will have on operations throughout their entire network and for all freight traffic. For example, railroads must routinely make decisions about improving overall network safety by identifying network locations to upgrade signalization, improve track quality, or install additional wayside detectors. These decisions are typically made by considering overall freight volumes, projected capacity changes, and high-traffic business service areas. While these considerations are fundamental to optimizing business and operational practices, incorporating the risks due to hazardous material movements as a decision support layer is a critical, if often-underutilized, component.

Existing frameworks for evaluating hazmat safety risks analyze individual hazmat movements that are applied to specific rail routes. These frameworks, however, do not provide railroads the holistic view of hazmat risks needed to support prioritization of infrastructure improvements and efficient allocation of finite resources to address the inherent risks. To extend the existing capabilities a quantified, all-hazmat picture of safety risks for the rail network must be developed. This quantitative framework must also allow understanding of how the overall hazmat safety risks are distributed in the network. Additionally, this comprehensive view of hazmat risk should also be able to support ranking and prioritization of network locations that may be considered for further safety investments which may otherwise have similar characteristics in terms of overall freight traffic volumes and other capacity considerations.

The overarching objective of this Type 2 IDEA project is to design and develop a prototype of the SMARTER Hazmat system. This prototype tool should be designed so that it supports railroad decision makers in including the concept of safety risk accumulation and amplification resulting from multiple hazardous material shipment movements throughout their operational networks. Beyond the prototype development stage, a fully developed SMARTER Hazmat system will represent an important advance to the state-of-the practice for the freight rail industry and is aimed at providing enhanced capabilities to understand, improve, and manage the comprehensive risks of hazmat transportation including:

- Quantitative estimation of the accumulated risks from all hazmat rather than only from individual shipment routes and for specific commodities
- Determination and prioritization of high-risk network locations by considering comprehensive hazmat movements across operational networks
- Monitoring network safety risks for significant changes in trends so that potential mitigation options can be applied over the timeframe that contributes most to the accumulation of hazmat risks
- Understanding the impacts of projected or future hazmat movements, such as the introduction of additional shipments for new hazmat customers
- Evaluation of estimated impacts of proposed or potential risk mitigation strategies in various portions of the operational networks
- Comparison of the effectiveness of proposed risk mitigation strategies and identification of the network locations at which those strategies potentially achieve the greatest risk reduction for finite safety investments.

## 2 CONCEPT AND INNOVATION

The novel concept that forms the basis for this project is the application of a quantitative framework for risk accumulation and aggregation for hazardous materials transportation (FIGURE 2). Although hazmat safety risks are typically evaluated for individual shipment routes, the underlying framework can be extended and applied at several levels including and up to a network-wide scope. Since risks at a route-level are typically aggregated from each segment (i.e., the smallest analyzable unit in the network) that comprises the route, the risks accruing from *all* hazmat commodity flows can be estimated by developing bulk processing capabilities for analyzing hazmat movement data on a segment-basis. These segment-level risk measures for all hazmat movements can then be aggregated up to different levels, such as to a route or corridor-level, or to subdivision or regional-level, and finally, to the entire network, based on the railroads' needs. The risk accumulation at all levels operates at both spatial and temporal scales, which enables identification of trends of risk distribution over network locations as well as over time.

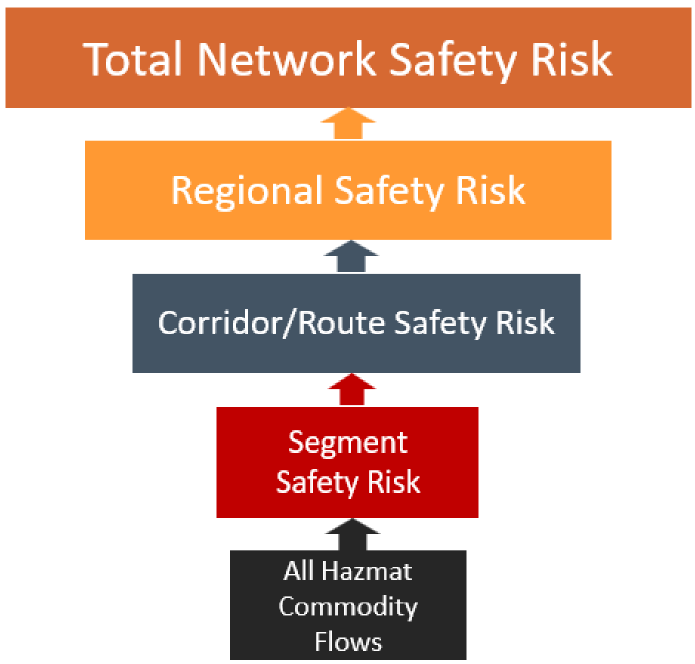


**FIGURE 2. Concept of safety risk aggregation for all hazmat movements to support development of network-wide measures of hazmat safety risk**

The key innovation of this project is the development of a functional prototype that implements the concept of risk accumulation as applied across a carrier's entire operational network and for all transported hazardous materials. This innovation requires a systems-based approach that is currently not available for railroads, along with advanced methods for processing and organizing large-scale commodity flow data; relating all traffic flows to a spatial representation of the operational network; ability to analyze risks at a segment-level, and then aggregating to the various levels of interest within railroad networks. Developing the prototype can then support an improved understanding of safety risk accumulation from multiple hazmat movements in the railroad network, which has the potential to offer a different and broader picture of overall risks than analyzing risks in segregation and for specific hazmat shipments.

## 3 INVESTIGATION

To lay the foundation for developing the prototype SMARTER Hazmat tool, the tasks for this IDEA project were categorized into two stages of effort. At a high level, Stage I included analytical evaluation tasks that compared two available methodological frameworks for calculating hazmat safety risks, and Stage II activities included designing and developing the prototype. The investigation and development activities in both the stages are summarized below.

### 3.1 STAGE I: EVALUATION OF EXISTING RISK METHODOLOGIES FOR INFORMING THE PROTOTYPE'S METHODOLOGICAL FRAMEWORK

Safety risks for transporting hazmat by rail are typically assessed by combining the track accident frequency (either train- or car-based frequency), the container release probability that is conditional upon the accident occurrence, and potential consequences (e.g., impacts to the nearby population, environment, railroad infrastructure) into a quantified safety risk value for each segment of interest (*1*). These segment-level risks are then typically aggregated up to the level of the routes to generate safety risk measures at the route-level. It is common to model the potential consequences to population by estimating the number of people within a simplified impact area, the shape and dimensions of which are determined by hazmat properties often derived from the PHMSA Emergency Response Guidebook's recommended protective action distances (*2*).

Existing modeling frameworks for quantifying railway hazmat safety risks can be categorized into railcar- and train-based methodologies. The railcar-based models typically utilize car-based derailment rates that account for a number of track-related (*3, 4*) and car-related factors (*5, 6*) including track quality, rail car characteristics, car speed, method of operation, and overall freight traffic density. However, these railcar-based frameworks do not consider relevant train characteristics, such as the influence of train length, composition, and consist position in estimating the accident frequency and the potential for release from tank cars. Additionally, the railcar-based frameworks do not readily facilitate evaluation of hazmat releases from multiple cars. Despite these drawbacks, the railcar-based frameworks have traditionally been used to support a priori risk assessments for hazmat transport without requiring more detailed train-specific knowledge (*7*). In an effort to overcome the limitations of railcar-based risk frameworks, several recent studies have developed and investigated intricate train-based models (*8, 9, 10, 11, 12*). These methodologies account for factors including train length, derailment speed, accident cause, point of derailment, tank car positions along trains, and heterogeneity of tank car make-up. These models require more detailed information about the train consist and potentially have a longer implementation period before large-scale practical application due to the difficulties with compiling train make-up data for hazmat cars and more intensive analytical requirements, among other data needs. Thus, it was required to evaluate if the more data-intensive, train-based risk framework provides a considerable benefit in the context of high-level, network-wide risk modeling and safety planning when compared with the railcar-based models.

The scope of Stage I evaluation in this IDEA project was focused on applying the two existing risk frameworks to a small example set of commodity movements. The primary objectives were to: (i) apply both the available risk frameworks to hypothetical corridors for notional, multiple commodity movements and compare the results to understand the potential differences in the frameworks in relative ranking of the corridors, (ii) further investigate if the methodologies identify similar corridor locations as possessing elevated risks when considering aggregated risk from multiple movements. This evaluation would then be useful in informing the SMARTER Hazmat prototype development in Stage II and to specifically address questions such as: which corridors/subdivisions should be prioritized for additional safety investments while considering overall hazmat safety risks? Additionally, the evaluation in Stage I would assist with deciding if both frameworks identify similar specific stretches of track within the corridors where the risks tend to concentrate when overall hazmat movements are considered.

In Stage I, we applied the car-based and train-based frameworks to two notional corridors, approximately 1500 miles long, that pass through populated areas. We evaluated two example commodity movements on these corridors: anhydrous ammonia on a manifest train and liquefied petroleum gas on a unit train. The emphasis was on understanding the aggregated risk from the combined consideration of these example commodity movements. The scope of analysis was focused only on these two movements because the risk evaluation using both the car and train-based frameworks is complex, with the train-based framework having much more extensive data and analytical requirements, especially when expected to be applied within the context of network-level, risk-based decision making.

The results from the evaluation study conducted in Stage I indicated that both railcar-based and train-based frameworks were consistent in their relative comparison of the corridors and performed similarly in identifying the individual higher risk locations within the corridors (shown in FIGURE 3 for one of the notional corridors). The rate of accumulation of safety risk along the corridors for the aggregated commodity movements were also consistent (FIGURE 4).

It was noted that although the train-based methodology offered more nuanced features to evaluate hazmat safety risks, in general, the car-based and train-based methodologies were both consistent in identifying higher risk locations within the rail network resulting from multiple commodity flows. The more detailed train-based methodology likely allows better characterization of the overall release likelihoods involved and accounts for potential multiple car releases but comes with additional data and analytical requirements. These requirements include but are not limited to compiling knowledge of exact train composition, placement information of hazmat cars on every train carrying hazmat, data collection systems for parsing and storing such data, and more advanced computational requirements for performing large-scale analyses. The car-based methodology was found to be sufficient to meet the main objectives of the project and was selected to support Stage II activities for prototype development.


**FIGURE 3. Comparison of risk frameworks: profiles of safety risks using rail car-based (above) and train-based (below) frameworks for an example corridor using notional aggregated commodity movements**

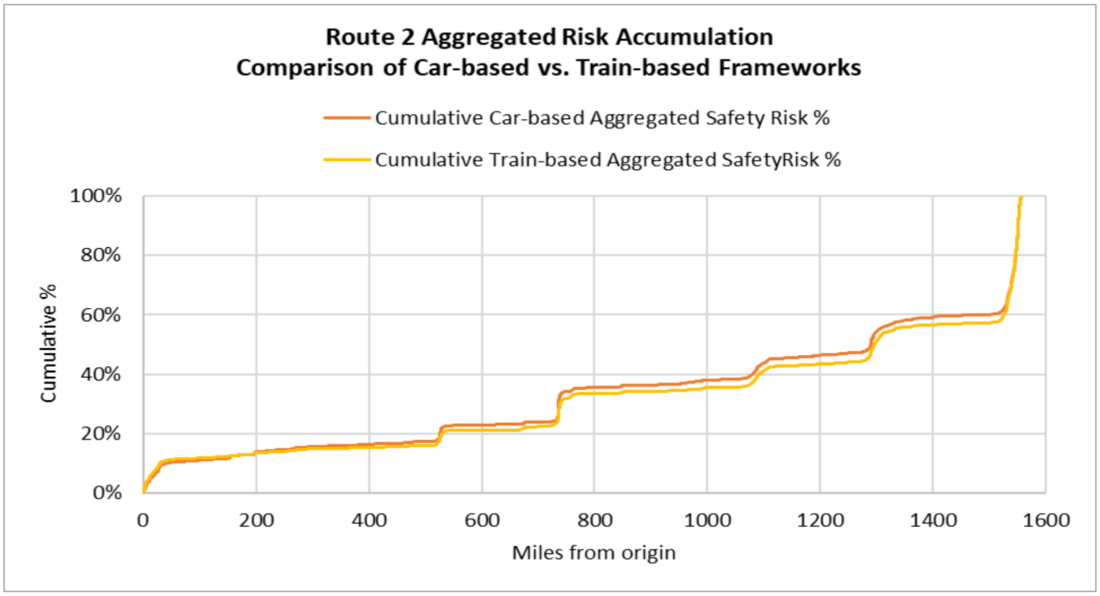


**FIGURE 4. Aggregated safety risk accumulation for car-based and train-based frameworks for an example corridor**

## 3.2 STAGE II: PROTOTYPE DEVELOPMENT

The primary goal of Stage II activities was to develop the prototype SMARTER Hazmat using the concepts of risk accumulation and amplification resulting from multiple hazmat traffic flows while being informed by the risk framework selected from the Stage I tasks. The prototype was to be designed to support addressing questions including but not limited to: (i) which subdivisions or corridors in the network present elevated concentration of hazmat safety risks? (ii) where in the network would upgrading track infrastructure provide maximum benefit for addressing risks? (iii) what is the expected impact of adding new hazmat service in a specific network corridor?

To support addressing these questions, the desired software capabilities in the prototype were to process and visualize network-wide hazmat safety risk data, to quickly render output from large datasets, to conduct "what-if" analyses to assess impacts on hazmat safety risk, etc. The underlying data structures that need to be supported include spatial and tabular data. Additionally, it was necessary for the prototype's internal workflows to be aligned with data formats that are commonly used by railroads for managing commodity flows (e.g., XML-based formats).

When initiating the development of the prototype tool, two software implementation options were available: to design the tool as a desktop-based application or as a web-based application. The web-based design path was selected because a web application:

- Is readily accessible over standard internet browsers
- Requires no installation on user machines
- Relies on server hardware rather than local infrastructure on user machines
- Offers potential for scalability and enhanced performance over time to take advantage of continually improving server infrastructure and efficiency
- Does not depend on the end-user computer's operating system (e.g., Microsoft Windows vs. Apple iOS)
- Offers capabilities for richer and more interactive user experience.

The overall design for the prototype along with the developed prototype tool and its components will be described in the following sections. *All of the data and visualizations presented in this report are completely notional* and include randomly generated, example commodity flows assigned by the project team to a demonstration network for the purposes of internal testing and gathering feedback. The data structures developed in the prototype are such that, beyond the prototype phase, in a full-fledged SMARTER Hazmat system, railroads will have the ability to use realistic data and interact with the results specific to their operational networks.

### 3.2.1 Design and Development of the Prototype System

The initial designs of the prototype SMARTER Hazmat tool were created using Adobe XD Creative Cloud software. These designs were iteratively refined to align with the core objectives of the prototype. The generated designs from this phase allowed the project team to share the envisioned framework for the prototype along with anticipated long-term capabilities. This activity facilitated guidance from the expert review panel prior to initiating the development phase.

Based on the outcome of the design phase, we developed the prototype SMARTER Hazmat system as an HTML5 web application which is accessible through standard internet browsers (e.g., Google Chrome, Microsoft Edge). The prototype was constructed with primary components written in React JavaScript that communicates with a Microsoft .NET Core application programming interface (API) as the back end. The API is programmed in the C# language, and all the required spatial and tabular data are stored in a Microsoft SQL Server database. The prototype application is deployed in a basic Amazon Web Services server to promote application scalability. The prototype application presents a variety of data visualizations through mapping and chart elements; the mapping functionality has been implemented using the Leaflet JavaScript library; the application states of various modules are maintained and programmed using Redux. The primary graphical presentations for charts have been implemented using Data Driven Documents (D3). All of the abovementioned web components are well-documented, based on open source technology for easier adoption, longevity, and scalable deployment. In addition to these technologies, our team also investigated 3-D mapping using Cesium JavaScript library but ultimately focused the prototype development using 2-D mapping functionality.

The prototype was designed with three separate modules:

- The *home module* which provides summary and detailed views of overall network risk from aggregated hazmat traffic movements as well as provides understanding of the distribution of the risks in the network
- The *risk controls module* which provides the ability to modify safety risk factors and perform “what-if” analyses to understand potential impacts on risk
- The *risk assessment module* enables analysis of a new or future business or planned hazmat movement and understanding of its impact on the existing distribution of risk

The features included in these modules are summarized below.

#### *3.2.1.1 Home Module*

The home module (FIGURE 5) was designed to provide information regarding the distribution of overall hazmat safety risks in an operational network. The home module consists of several areas: (i) the network risk index panel (FIGURE 5a; page left); (ii) map area (FIGURE 5b); (iii) the risk distribution panel (FIGURE 5c; page bottom).

The *network risk index panel* (shown in greater detail in FIGURE 6) provides users with the overall hazmat safety risk index in the network resulting from comprehensive hazmat movements (not just individual movements), along with features to display the risk hotspots on the map, and a graph view of the trend of the overall risk index over time. The overall hazmat safety risk index shown in the prototype snapshot in FIGURE 6a represents the risk index for a given timeframe, which is currently modeled in the prototype for a specific year. The data structures in the prototype tool, however, have been created in such a way that any timeframe of choice such as monthly, quarterly, or yearly format can be supported. When commodity flow data with multiple timespans are processed in the prototype, the network risk index panel will also display the temporal trends in the overall risk index.

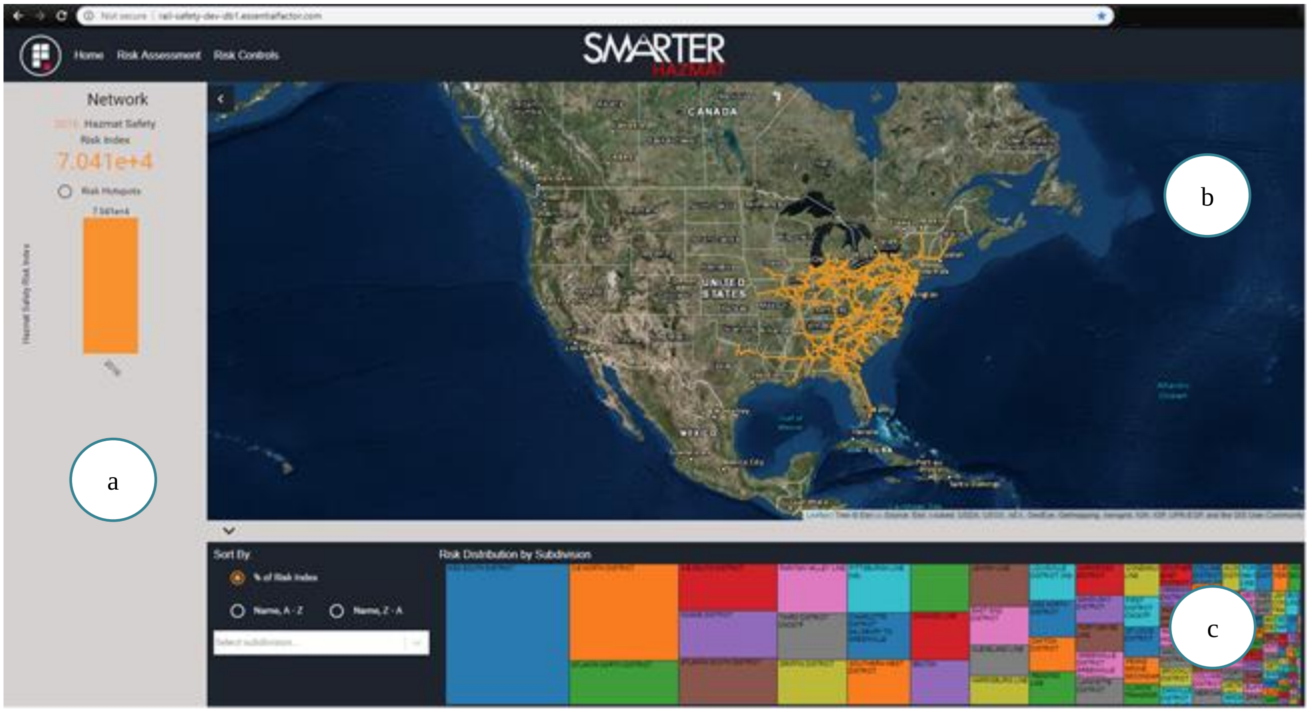


**FIGURE 5. The home module and its components in prototype SMARTER Hazmat: (a) network risk index panel; (b) map area; (c) risk distribution panel with overall risk distribution by subdivision**

The primary value of the overall network risk index lies in understanding its distribution and concentration both spatially in the network and over time. The *risk hotspots* feature in the network risk index panel currently turns on the display of the top ten ranked subdivisions by overall hazmat safety risk in the map area (FIGURE 6b). The map area functions to display the spatial extent of the operational network as well as for visualizing risk distribution in the network from multiple hazmat traffic flows. The panel at the page bottom, the *risk distribution panel,* presents a *treemap* (a graph for displaying hierarchical data) for visualizing how the overall hazmat safety risk index is distributed over the network subdivisions (FIGURE 7). This bottom panel also allows viewing the relative contribution of hazmat risk to the overall network risk index along with its risk-based rank/prioritization order in the network. The treemap in the risk distribution panel indicates the subdivision information along with its contribution to the overall risk index, and its relative rank based on accumulated hazmat risk for a given timeframe. In other words, the size of the individual boxes in the treemap represents the subdivision's percentage contribution to overall hazmat risk, and the tree map organizes from left to right the subdivisions from highest to lowest risk.

In addition to viewing the distribution of overall hazmat safety risk at the subdivision-level, the prototype allows users to select any subdivision from the risk distribution panel to view the distribution at an underlying segment level – using either the treemap or by entering the name and searching for the subdivision name in the auto-find textbox (located at the left side of the risk distribution panel in FIGURE 7).

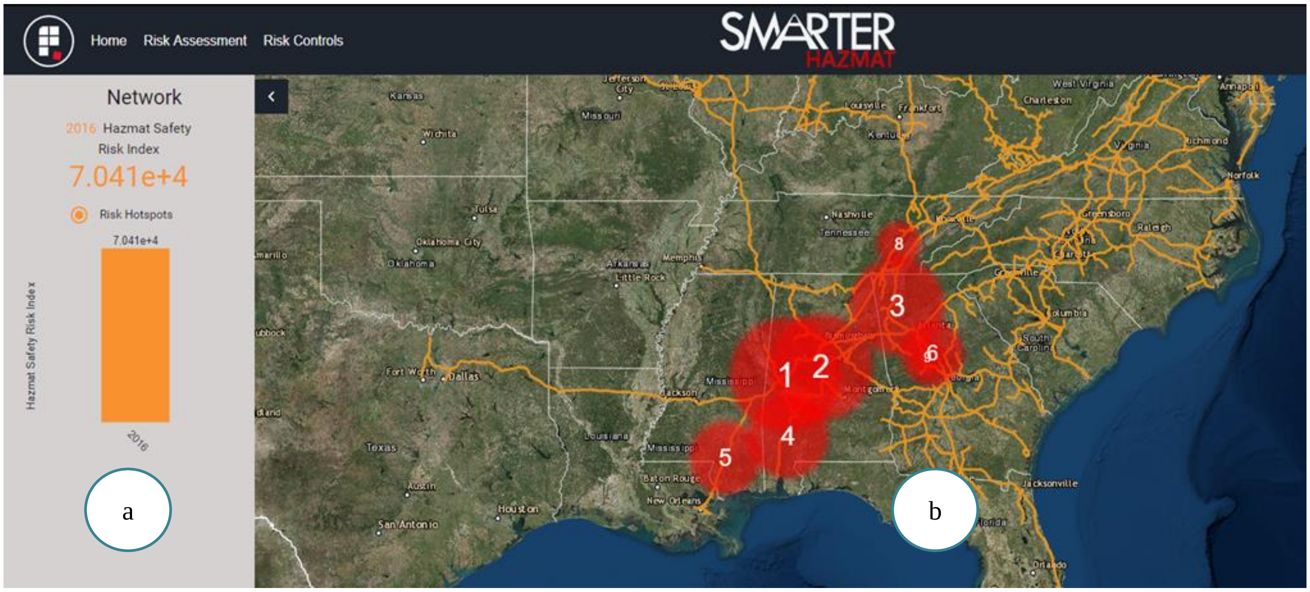


**FIGURE 6. Home module: (a) network risk index panel and (b) map area displaying overall risk hotspots and subdivisions**

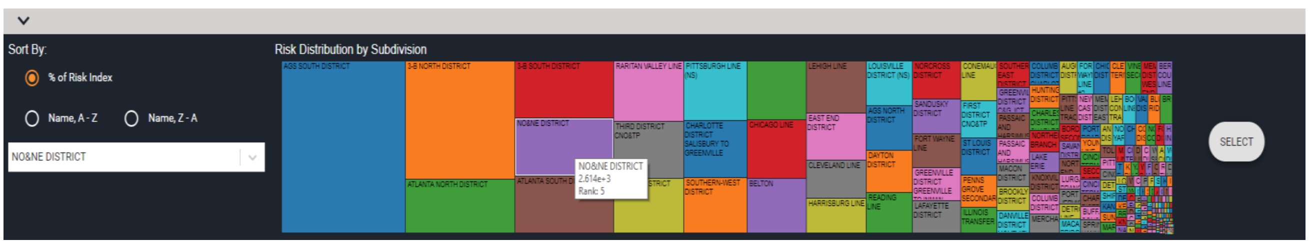


**FIGURE 7. Home module: Risk distribution panel (page bottom) with overall hazmat risk distribution by network subdivision**

When a specific subdivision is selected, the map area automatically zooms to the extent of the subdivision and displays the segments therein along with visualization of the higher and lower risk segments based on the overall hazmat movements that occurred within the subdivision for the selected timeframe (FIGURE 8). The calculated segment-level risk indices can also be viewed in greater detail in the map area (FIGURE 9). Additionally, a supplementary graphical view area displays the distribution of the subdivision risk by the hazardous commodity transported (page bottom in FIGURE 8). This type of data visualization can be extended further to include additional data graphs, such as distribution of risk in the subdivision by urban vs. rural areas, tank car types, etc. These data graphs can provide additional context and information to the users on the various facets contributing to the buildup of the overall risk in the subdivision.

To summarize, the home module enables railroad users to understand where in their network the overall hazmat safety risks are distributed at various levels of interest (at the network scale, at the subdivision scale, and the individual segment scale). Additionally, the prototype allows visualizing distribution of risk by commodity (and other categorizations, if desired). Furthermore, when commodity flow data is supplied across multiple timespans, the prototype also allows visualization of the shifts in risk based on the timeframe chosen - a feature that helps users gain understanding of the evolving trends in overall risk.

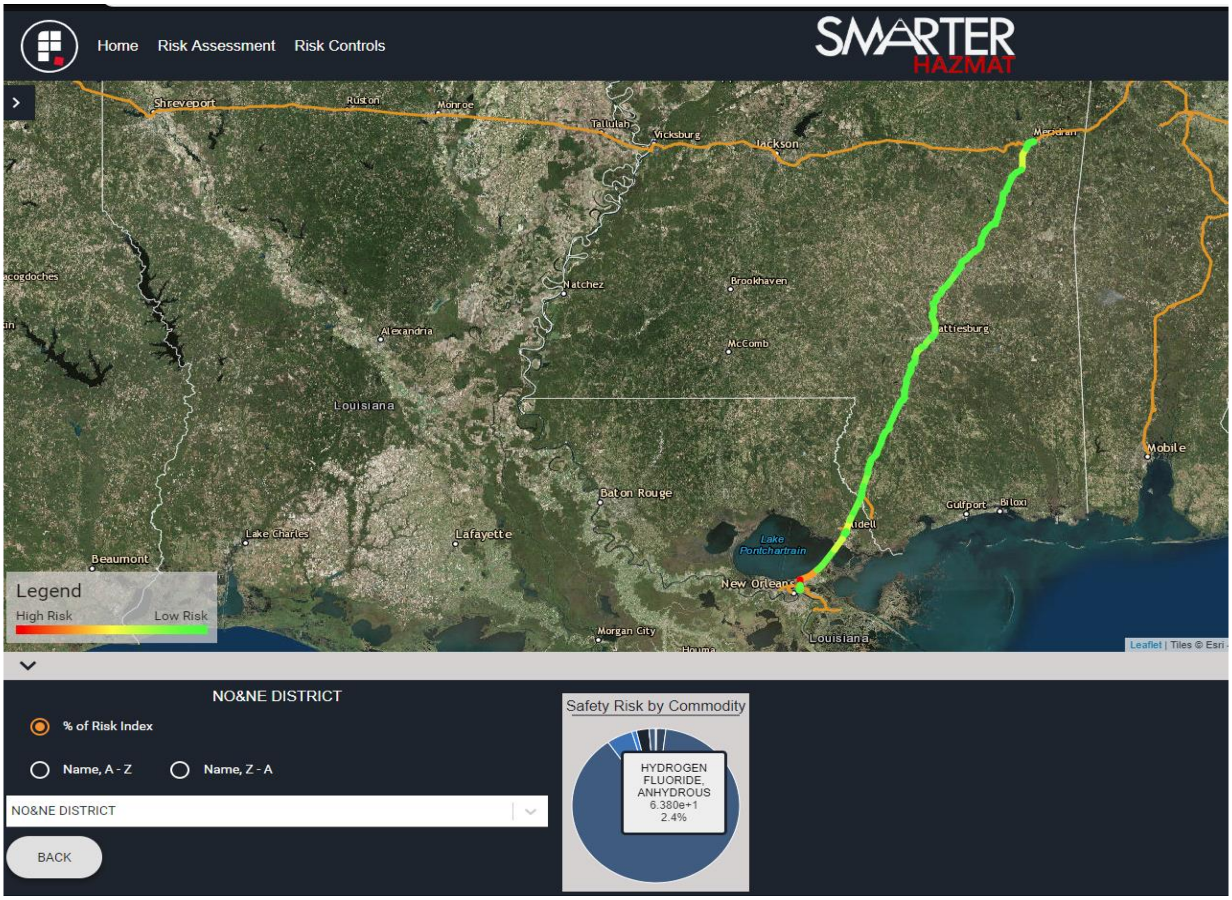


**FIGURE 8. Home module: segment-level risk data visualization from example, multiple hazmat movements depicted for a subdivision**

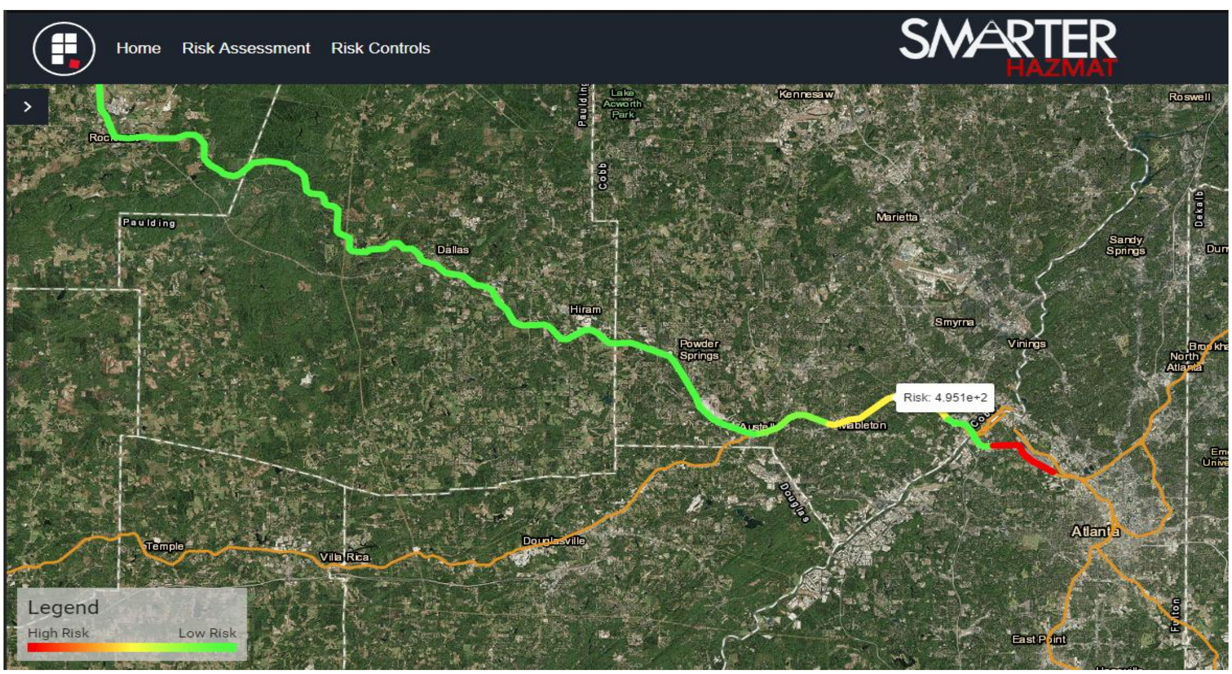


**FIGURE 9. Home module: location-based, segment-level distribution view of overall subdivision hazmat risks**

#### *3.2.1.2 Risk Controls Module*

One of the desired features in the prototype system is the ability to conduct basic "what-if" analyses; for example, calculating the benefit of and visualizing the impact of potential risk mitigation strategies. The risk controls module provides users with this capability (FIGURE 10). The users can select a subdivision of interest (which can be guided by the subdivision's relative rank based on overall contribution to the network risk index) and conduct analyses by applying any combination of risk modification factors that are currently supported. These factors currently include track class (an indicator of track quality and frequency of maintenance), speed of operations, method of track control (i.e., signalized or non-signalized track) and overall traffic density. These factors are well documented as being among those that influence the overall hazmat safety risk components, specifically the track accident rates and conditional probability of release from tank cars. The type of tank car is an important factor for risk considerations that is currently not supported in the risk controls module.

Similar to the home module, the risk controls module also includes a panel on the left and a map area (FIGURE 10). The panel allows the users to select a subdivision of interest and displays its current risk index. The map area displays segment-level detail of the distribution of hazmat safety risk within the subdivision. The left panel also houses an area to select and modify the risk control factors mentioned above.

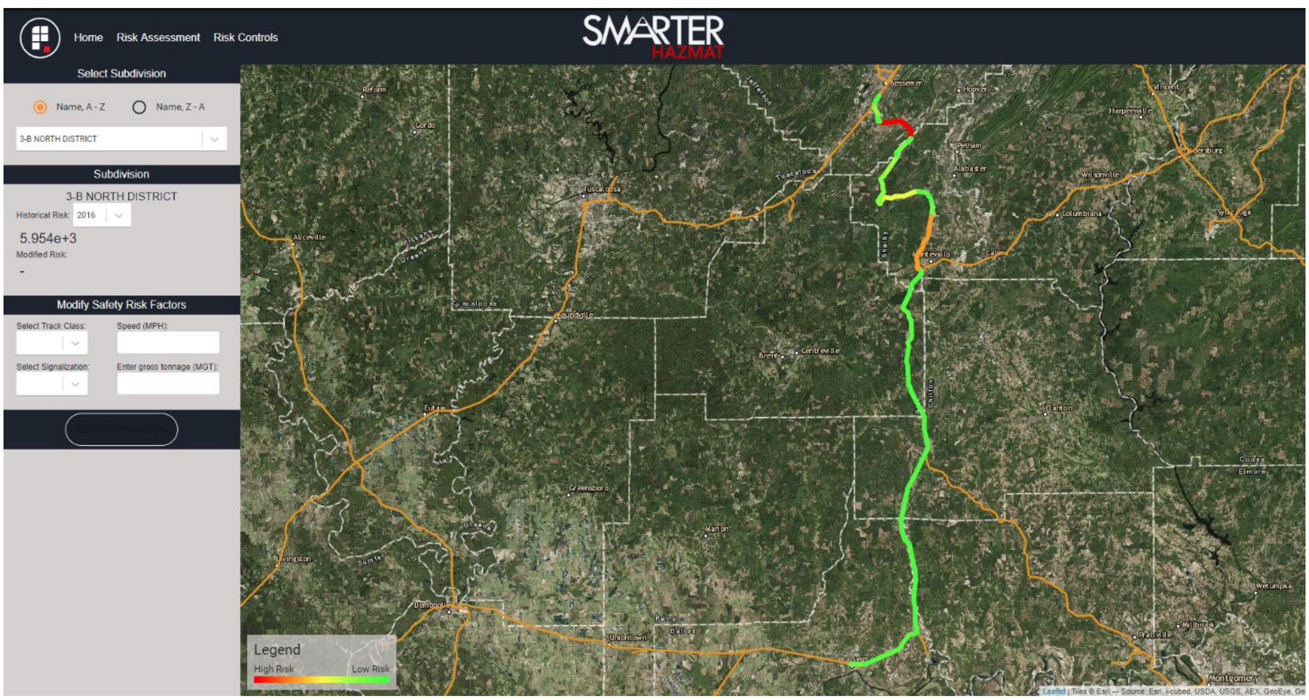


**FIGURE 10. Risk Controls module in the SMARTER Hazmat prototype**

When a user selects a single factor or any combination of factors that influence hazmat safety risk and runs an investigation in the risk controls module, an active calculation process is triggered and the prototype generates the results of the "what-if" analysis (FIGURE 11) within a few minutes of initiating the investigation. The results of the calculation are then displayed in two different areas in the module: within the left panel, the modified subdivision risk index based on the applied factors is displayed under the current risk index along with the percent of change overall; the impacts at the segment-level are displayed as percentage change from existing risk values in the map area (see map legend in FIGURE 11). The key takeaway is that the same combination of factors can have different effects based on the subdivision on which they are applied. Furthermore, based on the attributes of the specific segments that comprise the subdivision, the applied factors can have a non-uniform effect at the segment-level in terms of impact on their current risk. By successive application across the subdivisions, the features in the risk controls module enable railroad users to not only understand the estimated benefit from a potential mitigation strategy (e.g., upgrading the track quality in a specific subdivision), but also to evaluate where in the network such a strategy may offer better risk reduction, in terms of potentially mitigated risk.

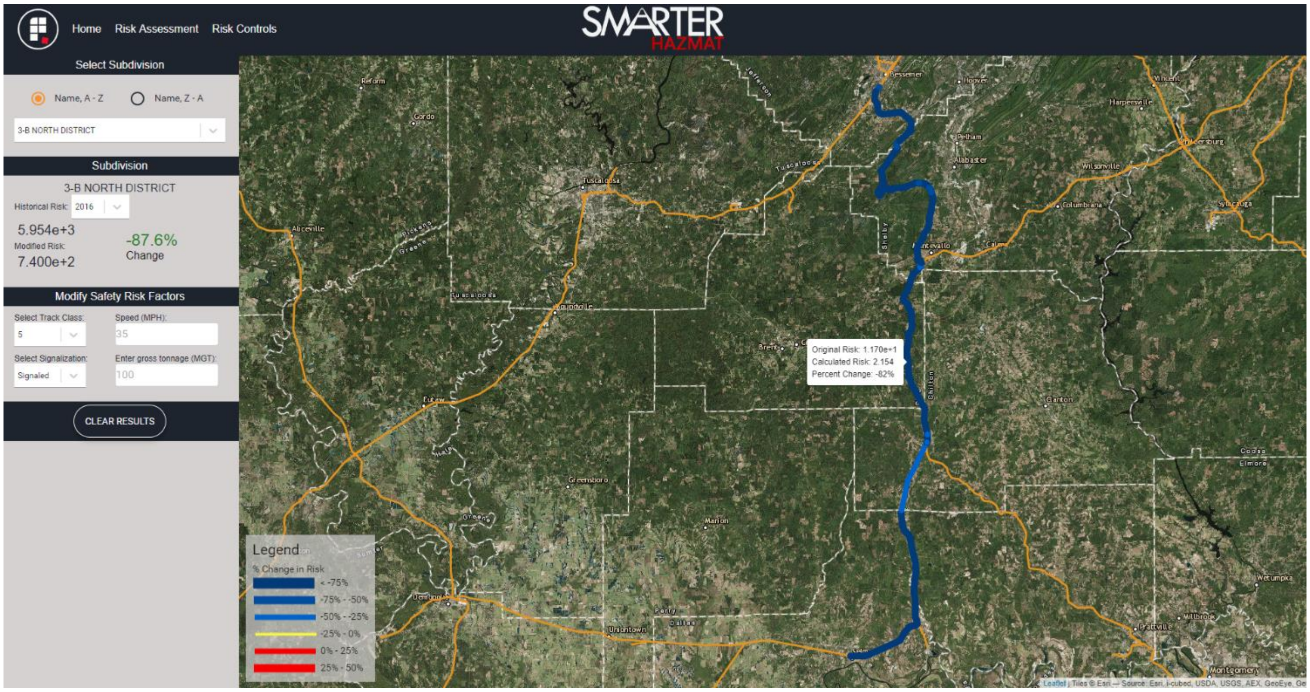


**FIGURE 11. Application of risk modification factors and display of results within the risk controls module**

### *3.2.1.3 Risk Assessment Module*

The risk assessment module (FIGURE 12) enables railroad users to apply future or projected hazmat commodity flows in the prototype SMARTER Hazmat tool. This capability is useful for understanding the impacts of introducing a new hazmat service over a portion of the network. Specifically, it would be beneficial to understand the impact of the new business on the overall network risk index as well as for the portion where the new service is anticipated.

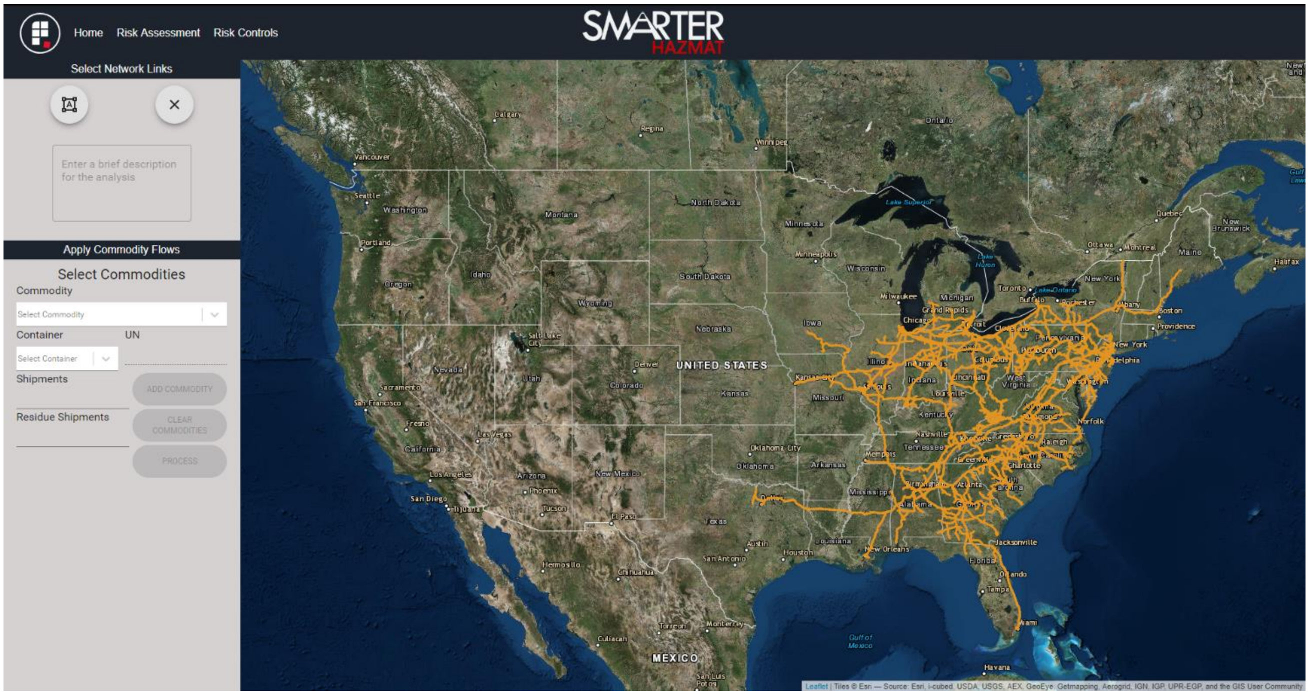


**FIGURE 12. Risk assessment module in the SMARTER Hazmat prototype.**

The risk assessment module follows the design principles set forth in the other modules by including a map area and a page-left panel for data entry. At the top of the page-left panel, the *Select Network Links* area enables users to access the spatial tools to select or clear/unselect any portions of the network. Using the network link selection tool, users can identify and locate the portions of the network where potential new or projected hazmat flows are anticipated to occur (FIGURE 13). Users can also make notes about the risk assessment in a description area located under the spatial tools.

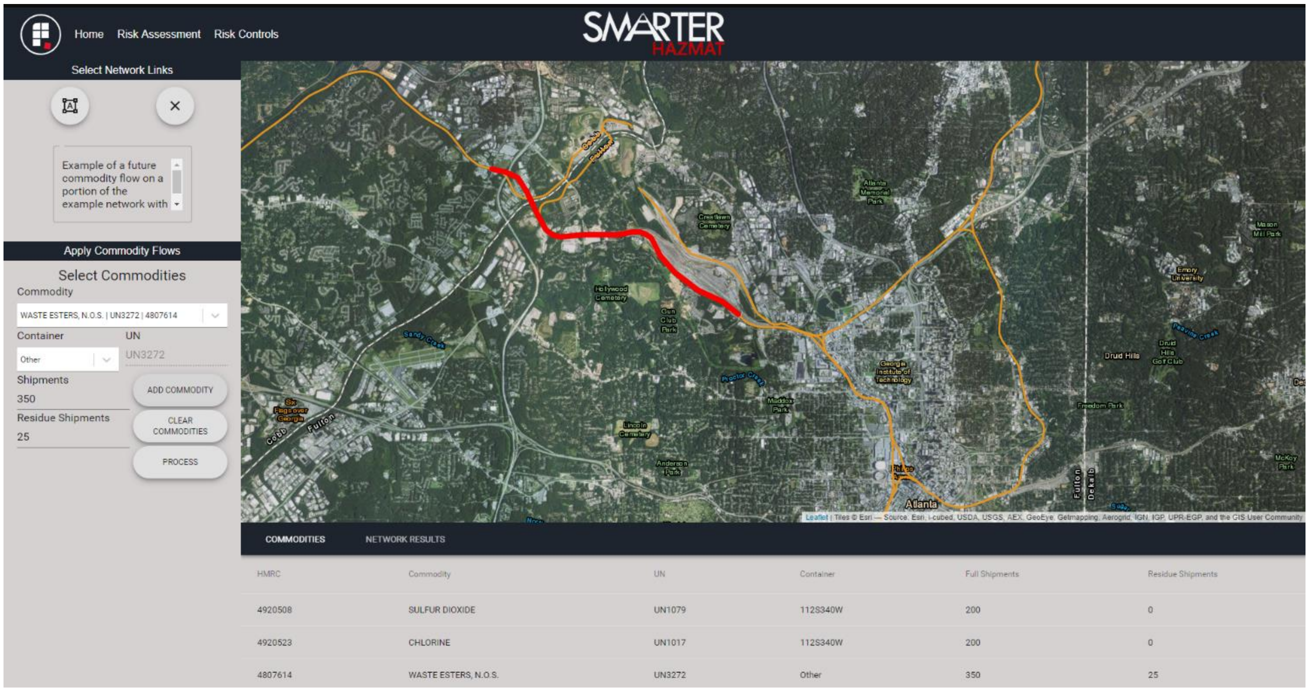


**FIGURE 13. Risk assessment module: selection of portions with projected hazmat flows.**

In addition to selecting the locations or portions in the network where newer hazmat service is anticipated, users can select and apply the projected commodity flows from the *Apply Commodity Flows* area in the left panel. The prototype facilitates entry of the number of loaded or residue shipments that are expected to be used for the analysis timeframe. The prototype also supports including as many additional commodities as required for the selected regions for any single analysis run. When the users complete selecting both the portions of the network and the desired commodities to be analyzed, they can initiate a risk assessment by clicking the activated *process* button. This action triggers the analysis workflow and generates the results. The time taken to process the results depends on the extent of the network selected and the number of commodities analyzed; the module can currently handle individual hazmat movements in a few minutes.

The results from the analysis are currently organized in a simple graphical output form in the page bottom panel (FIGURE 14). The graphical presentation can be further expanded to include other features when customizing the prototype for carrier use, such as profiles of overall hazmat safety risk for the analyzed section. The output currently provides potential users with information on the estimated risks due to the newly introduced hazmat traffic flows. This information is presented in terms of impacts both on the overall network risk score and on the specific portion selected. This presentation of the output facilitates improved understanding of the impacts at these two scales of interest and addresses questions such as: does the new movement add significant risk to the overall network index? and, does the new movement add/introduce substantial new risk locally in the area that is being investigated? Such information can support evaluation of new hazmat flows and identify if additional investigations or risk mitigation exercises are warranted.

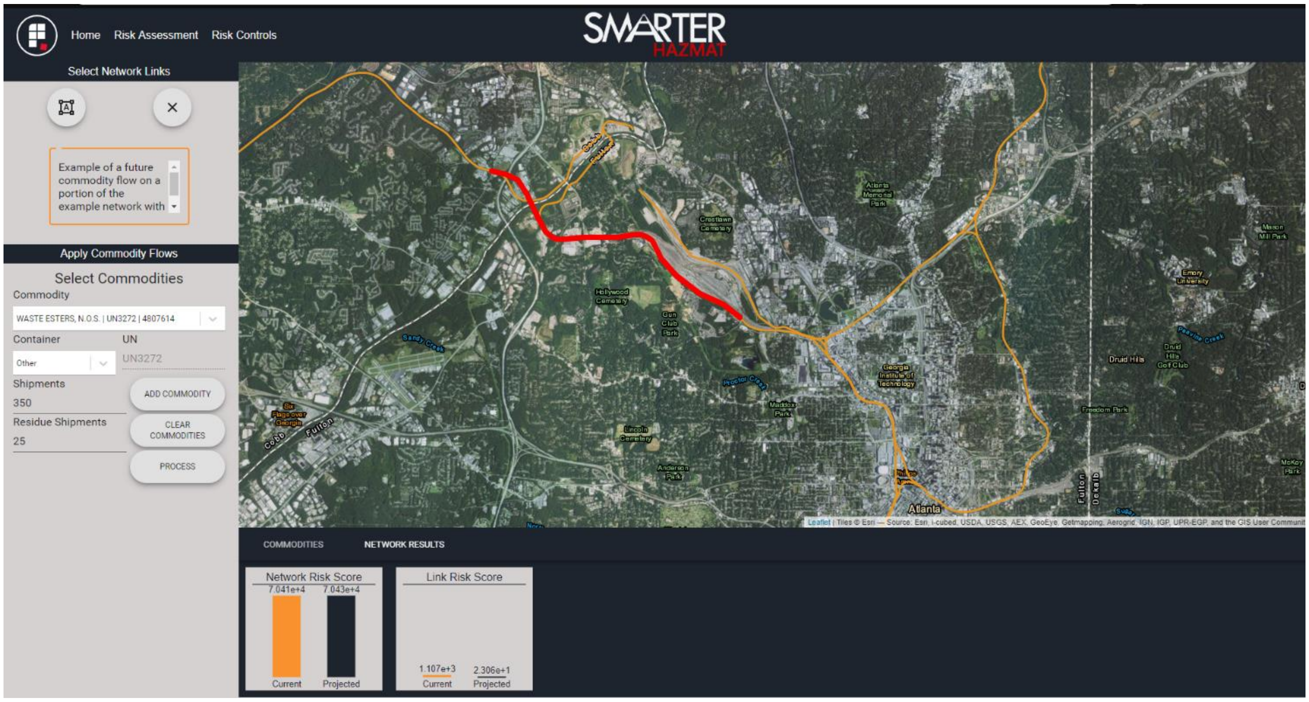


**FIGURE 14. Risk assessment module: output of analysis located in the page bottom panel.**

# 4 PLANS FOR IMPLEMENTATION

## 4.1 TESTING AND REVIEW OF THE PROTOTYPE

Following the design and development tasks in the investigation phase, we sought feedback from our rail partner, Norfolk Southern Railway (NS), on identifying areas to further enhance the prototype for practical implementation. The objective of review and feedback from our railroad partner was to help gather insights on the prototype, and to ensure that the developed system, with further enhancements, can be ultimately positioned to integrate well with existing railroad data management systems.

The following summary presents the observations and suggestions collected from the railroad feedback:

- The overall design and data presentation in the various modules of the prototype tool is aligned with the goal of the effort and provides a newer and more holistic view of hazmat safety risks at various scales of interest

- The prototype can consume the commodity flow data through the underlying databases in a format that aligns with existing railroad systems; however, including a data injection module as part of the user interface would make the tool more usable and prepare it for wider adoption

- In addition to the current data presentations in the prototype, a system-wide map view that normalizes and presents location risks would further enhance the understanding of overall distribution of hazmat risks in an operational network. Furthermore, creating system maps of commodity flow movements would also be helpful.

- Including features or capabilities to export data, graphical output, mapping areas, etc. from the system would improve tool usability

- Ability to save and store multiple analyses runs will improve in the risk assessment module in the prototype

- Including a feature for switching between the scientific notation and common numeric notation for the risk indices would be helpful in acclimatizing potential new users to the system

Beyond the abovementioned comments, the railroad partner also indicated that the prototype may be enhanced in the future to provide additional support to hazmat routing decisions between potential alternatives. The railroad partner also added that the prototype, or an enhanced version in the future, is not expected to replace any existing railroad systems currently employed for the purpose of making routing decisions but can be used as a supplementary tool that provides additional context for making a more informed choice for selecting between alternate hazmat routes.

# 5 CONCLUSIONS

## 5.1 PROJECT SYNOPSIS

The main outcome of this Type 2 IDEA project is a novel prototype system for freight rail carriers to evaluate network-wide safety risks for comprehensive hazmat traffic flows. The unique concept employed is the application of a quantitative framework for risk accumulation and aggregation occurring from multiple hazmat movements within a rail carrier's network rather than evaluating risks only on a route-by-route basis and for a few high-hazard hazmat (e.g., toxic by inhalation products or flammable substances). The product application was aimed at providing a systemic understanding of risks which railroads can then leverage for making risk-based investments and resource allocation decisions to improve overall railroad safety.

The project team organized the effort in this project into two stages. In Stage I, the methodological foundations for the prototype were laid down after comparing the current state-of-the-practice in risk assessment to recent advances in risk evaluation frameworks. To meet the main objectives of the project, although the recently developed train-based / multi-car release risk frameworks allow nuanced characterization of the release likelihoods, the current car-based methodological framework was found to be sufficient for prioritizing the network locations in terms of overall hazmat safety risks. In Stage II, the project team designed and developed the prototype with several user interfaces that support enhanced visualization and presentation of the network-level risk data. Three unique modules were developed within the prototype that contain features to facilitate: (i) viewing map-based and graphical output of quantified overall hazmat risks,(ii) viewing distribution and trends of comprehensive hazmat risks within the network, (iii) understanding the concentration points and hotspots of risks in terms of subdivisions or even at the segment-level, and (iv) conducting simple what-if scenario analyses to visualize the impacts of changing safety risk factors and potential new hazmat service areas.

Through collaboration and testing with our railroad partner, we gained valuable insights into how this prototype can be scaled-up and enhanced to mesh with existing commodity flow systems and prepared for a potential wider adoption. The project was guided from inception and through the two stages of performance by the participation of the expert review panel and our railroad partner.

## 5.2 PLANNED NEXT STEPS

Beyond the scope of the current project, the project team's vision is to enhance the SMARTER Hazmat$^{TM}$ prototype into a production-quality, web-based system that provides railroad customers advanced capabilities to review their network's critical hazmat safety risk information and supports continued railroad safety improvement through systems-based approaches. Based on the feedback gathered from our railroad partner and additional comments from the project team, we envision the following activities to enhance the usability and adoptability of the prototype by the industry:

- Implement the suggestions and create features recommended by our railroad partner

- Create security protocols and login-based access to the enhanced prototype so multiple users can access the system and customize their interaction and view their data within the website

- In addition to injecting past commodity flow data through an extensible markup language (XML) format as suggested by the railroad partner, create supporting XML formats to process future commodity movements in the prototype. This functionality will allow users to automatically process larger sets of projected hazmat movements in the risk assessment module, thereby minimizing manual effort on their part.

- Include additional data export features of the datasets maintained in the prototype. This capability is critical for supporting railroad communication with external stakeholders.

- Furthermore, investigate advanced 3-D map visualization of network and infrastructure data to support planning and training activities with hazmat first responders

- Create additional capabilities to study the effects of more risk modification factors; in particular, the capability to conduct “what-if” analyses by modifying the mix of rail cars to evaluate the impact on overall hazmat risk

- Work with our railroad partner to study the use of the prototype system to supplement the justification for hazmat routing decisions

- Conduct demonstrations of the prototype and explore the interest within other railroads for use as planning tool to support railroad service design units

- Explore the creation and use of a cost-benefit estimation module in SMARTER Hazmat for implementing risk modification and mitigation strategies

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