A Set of Blended Risk-Based Decision Support Tools for Protecting Passenger Rail-Centered Transit Corridors Against Cascading Impacts of Terrorist Attacks

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Abstract

We are building three simulation models that will help us better understand the kinds of events that can cause serious cascading impacts in passenger rail and interconnected light rail, bus and road systems, the consequences of those events, and investments that could increase system resilience. An industrial systems model will allow us to simulate rail passenger traffic through a key rail station in New Jersey under normal operating conditions. Then, using plume and other models, several serious spatially and temporally characterized events will be introduced that will upset normal operations. Impacts of these events will be followed into the surrounding environment as they disrupt light rail, bus, and other auto traffic in the region. The economic model will be used to estimate the economic consequences of the events and also the consequences of making investments that could reduce the impact of these events over both short- and long-term horizon.

Keywords: mass transit, risk analysis, disruption, consequences, simulation

Introduction

On April 16, 2009, President Obama released a strategic plan that outlined a vision for high speed rail in America (Federal Railroad Administration, 2009). The report identified 10 high-speed rail corridors as potential recipients of federal funding (See figure below). The Northeast Corridor that runs over 450 miles from Boston to Washington is not one of the "designated" corridors. However, it will be able to compete for funds to improve the nation's only existing high-speed rail service. The Northeast Corridor is the most heavily travelled by ridership and service frequency in the United States, and arguably is the most likely target for terrorist activity, given the volume of passenger and freight traffic, the historical and political significance of the cities and sites along the route. For example, in New York's Penn Station during rush hour, more than 1,600 people per minute move through station (Bushue, 2006). The major cities along the Northeast Corridor are also highly vulnerable due to the variety of interoperable and connecting services feeding into these nodes.

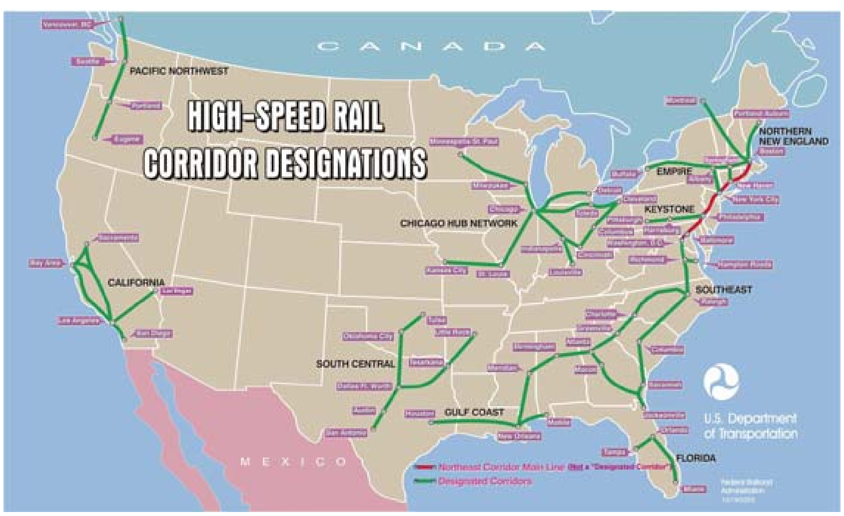

Figure 1: Map showing 10 proposed high-speed rail corridors

In view of this proposed national program, we proposed a project focused on resilience of high speed passenger rail corridors using the Northeast Corridor as our test bed. We are constructing a set of complementary simulation models that will allow us to better understand the kinds of events that can cause serious cascading impacts in rail and connected transportation systems, the consequences of those events, and investments that would increase system resilience. The end result will be tools that will aid all types of corridor decision-makers to improve resiliency from accidents and attacks, and will also especially be valuable for educational and training purposes and for application to other rail corridors.

Discussion

State the Problem

Destructive cascading impacts occur when an event(s) at one node or link in the system disrupts the transportation function and spreads beyond the spatially-impacted area to others. In the case of a rail passenger corridor event, the impact of a serious terrorist-initiated event could be felt for hundreds of miles along the corridor, spreading out like a wave from the rail line to connected light rail, bus, and highway networks. This issue will become more salient if the plan to build up to 10 high-speed rail corridors in the United States moves ahead, thereby increasing dependency on these networks.

Potential Solution and Research Methodology

We are building three distinct hybrid mathematical-simulation models, linking them using a risk analysis framework, and applying them to the passenger rail corridor system in New Jersey. The models will also provide immediately useful information to managers and serve as a prototype for other passenger rail corridor systems that seek to do preemptive planning and investment.

The first is an industrial systems model that simulates the normal operation of a passenger rail corridor at a critical station and then perturbs it with events. The developers of this model have had considerable experience in building simulations for port-related activities (Altiok & Melamed 2007; Uluscu et al. 2009). In the case of terrorist-related events, it is prudent to assume that multiple events could occur, and then to determine their impact and how they can be prevented or mitigated. However, before building and testing complex terrorist-related scenarios, we need to validate the model by testing its ability to reproduce less catastrophic events that occur with some frequency, such as power outages and suicides that halt the system.

After validating the systems model, we will disrupt the system with serious events. Currently, our colleagues at the Mineta Transportation Institute are developing several examples of natural hazard and terrorist-related events based on actual United States and international incident. We also have cooperation from our New Jersey transportation experts and have had initial meetings with Amtrak. Our working group will meld their international and local experiences and select several of these examples to build into full scenarios for testing using our industrial systems model.

Further, we will employ our expertise in air plume modeling, used in the World Trade Center case, among others (Lioy 2010a,b). These plume models will allow us to examine potential health impacts on passengers and workers at rail stations, as well as on people living and working in the surrounding environment, and in multi-modal transit systems connected to the rail corridor. The number and severity of casualties will be evaluated for impact on health care system. Envision, for example, terrorist bombers detonating explosives and one radiological dispersion device at a rail station, on a train arriving at the station, and near other transit systems at the station. Combining Models 1 and 2 will yield estimates of deaths, injuries, physical damage to assets, environmental effects, and economic impacts concentrated on the rail-centered transportation system.

The immediate and localized human, ecological and property impacts are quite serious, and we will estimate these with our models. Yet a key focus will be disruption to passenger traffic along this heavily trafficked corridor. Our expectation is that the economic consequences of some of these events would be serious and long lasting. Our third model will concentrate on monetary estimates of deaths, injuries and ecological impacts, as well as economic impacts from failure of the transportation system to deliver people and products to their intended destinations. Cascading effects are especially likely to involve heavy economic impacts beyond the rail system, including pressure on other transport systems, which might cause other bottlenecks and failures in local, regional and national transport and supply chains. In particular, there will be congestion effects that will slow down commuting as many people try to get to work on highways that will be crowded.

We are building a computable general equilibrium (CGE) model to simulate the impact of events on the New Jersey economy and then to examine options to reduce these impacts. CGE models contain the basic economic flows in an economy by major economic sector. When the economy is disrupted by serious events, businesses and the public choose alternative paths to conduct business. For example, if a major rail station were disrupted for a lengthy period of time by both a blast and dispersion of radioactivity, the economy would adjust with a lag. People would try to use alternative mass transit paths to their destinations. However, those paths may be limited, that is, the mass transit system may lack capacity to transport people. Consequently, many people may be left with only the limited alternatives of driving their personal auto or carpooling, changing their working hours, or working from home.

Following the propagation of the adjustment process through the economy should reveal some obvious and less obvious impacts. For example, if the average commuter spends 1-2 hours more five days a week commuting, we would expect reduced labor productivity and changes in gasoline use and prices as more people drive. If the labor productivity decline is sufficiently noticeable and persistent, then some businesses could opt to relocate some of their activities, which could have a substantial long-term economic impact (Greenberg et al. 2007a,b). The CGE model will allow us to estimate the likely set of choices that people in aggregate will make.

The economic model will also allow us to estimate the potential drag on the economy by reducing damages through investing in additional monitoring and surveillance, barriers, and other prevention modes, although there may be possibilities of inexpensively developing alternative ways of moving people and goods around the key damage transportation paths. While it may take time to divert traffic to exploit these underutilized assets, such an effort could mitigate a long-run economic slide.

There are good reasons to assume that an economic model used along with the two other models will provide valuable insights to decision-makers. More specifically, an outage of a transportation segment has system-wide effects. These effects can be observed on the individual and aggregate levels; economic impacts – which include both direct and indirect economic effects – may disrupt production both at the firm and sector levels. Estimating the short-, medium, and long-term effects of lifeline outages – such as a commuter rail system – has important implications in determining economic and social losses. Lee and Kin (2005) identify spatio-temporal models as a suitable approach to analyze network loss due to natural disasters, looking to travel distances and to output by sector to determine the economic loss over time. Nojima and Sugito (2000) use simulation and incremental assignment methods to evaluate post-disaster performance of transportation network systems, identifying vulnerable ‘origin-destination’ pairs within transportation facilities. Sohn et. al, (2003) use final demand loss and transport cost increase to analyze the economic impact of natural disaster on a transportation network; looking at the intra-zonal flow of commodities, the modal share of traffic, and the average travel distance on the network, they are able to determine the transportation network resiliency of economic sectors – and further identify which segments on the transportation network are more significant.

Looking specifically at earthquake disasters, Chang and Nojima (1997) identify two post-disaster measures of highway system performance: total length of highway open and total ‘connected’ length of highway open; with these measures, they were able to explain post-disaster traffic volumes and the economic impacts of reduced transportation system through-put. Chang and Nojima (1998) were also able to use these measures to make comparisons across events, using measures of the system’s pre-disaster performance to estimate post-disaster consequences; thereby, they are able to compare the performances of transportation networks across earthquake disasters, and to assess economic activity in relation to transportation volumes. Later, Chang and Nojima (1999) assessed aggregate transportation system performance – including both highway and rail networks – to measure economic effects subsequent an earthquake disaster in Kobe, Japan; they used these performance measures to determine the ability of port facilities to re-establish services, and the short- and long-term impacts of the disaster on the local, national, and regional economies. They conducted comparative analyses of system performances in Kobe (Japan), Loma Prieta (California), and Northridge (California), and demonstrated that comparisons and assessments may be made in levels of damage, disruption, and restoration timeframes across systems. Chang (2000) goes on to quantify the lasting economic impacts on

Kobe's container shipping industry, and the long-term economic losses that resulted from the earthquake disaster; she demonstrates that during the two-year restoration period subsequent the earthquake disaster, the Port of Kobe lost 20-30% of its total volume container cargo to regional competitors (such as Pusan (Korea), Hong Kong, Singapore).

Rose, et.al, (1997) look to the impact of an earthquake disaster on electricity lifeline disruptions; they develop a methodology to estimate economic losses by sector through the use of economic model simulations of production losses. Van der Veen, et.al, look at the total structural economic effects of a flood disaster on households and government, quantifying production interruption, substitution effects, and direct, indirect, and 'ripple' effects; they identify three scenarios, with varying effects on changes in final demand – ranging from none to lasting structural changes in the economy.

None of these approaches consider a singular, unplanned disaster on a specific segment of commuter rail network – and its subsequent effect on the local economy, namely on patterns of fuel consumption and of GDP. Consumption and economic impact models were chosen for our analysis because of their abilities to reflect the structures of the local economy, and to estimate the short-, medium-, and long-term effects of service disruptions to the rail network. Looking to the immediate- and long-term effects of motor gas consumption and price that result from rail disruption, we can make observations about the effects of productivity on growth, and thereby make some predictions on economic losses. In addition, by looking at ratio of employee compensation to income in current year to the income of the previous year $[(w / Y) / Y_{(t-1)}]$, we are able to determine the impacts of changes in efficiency and productivity in the workplace subsequent rail disruptions.

End Users/Customers Who Would Benefit

The most direct beneficiaries would be New Jersey Transit (the nation's third largest provider of rail, light rail, and bus service, linking major points in New Jersey, New York and Philadelphia.) and Amtrak and Conrail. They will receive tools that can be used by staff to understand the vulnerabilities of their systems. A second group of beneficiaries is other rail system owners and operators who would be able to build simulation models that parallel what we are doing in this study area. The same simulation approaches being developed for this study can be scaled for newer systems and other states and regions. A third group of beneficiaries is state departments of homeland security, law and public safety, health and environmental protection who are charged with responding to such events. In New Jersey, for example, we envision the models being used as part of state-wide strategic planning exercises focused on response to rail-centered mass transit disaster events. The fourth and a critical group of beneficiaries include the businesses and people that depend upon a functional rail system for continuity of their business and commercial operations. In previous analyses, several of the authors have examined the economic consequences of businesses choosing to relocate because they do not trust that the infrastructure will continue to operate as required (Greenberg et al. 2007a). These estimated relocation impacts were much larger than direct economic consequences of the events. Finally, the last group of beneficiaries include educational programs in transportation security rather model developed in this research will serve as tools and case studies in courses. One such program exists at Rutgers, the “Transportation Management: Vulnerability, Risk and Security Certificate,” and we anticipate incorporating these models into classes in courses that focus on transportation security, risk analysis and simulation modeling. We believe that strategic planning that includes these types of risk-based and economics simulation models can contribute to a regional culture that anticipates and plans for hazard events rather than primarily reacts to them.

Challenges to Attaining the Solution and Results

We face several major challenges. One is collection of data. The variety of data is impressive. The industrial systems model is built by obtaining data from NJ Transit, Amtrak, and local and state experts. The plume scenario models require making assumptions about amount of hazardous materials and meteorological conditions, and merging them with data collected to build the first model. None of the data we are using are privileged, and they will be realistic in size and scope of immediate and long-term impacts. However, building these two models takes different disconnected public data files and reshapes them into a form that after we run the simulations can be valuable to attackers as well as defenders. Consequently, the second challenge is to make sure that the files of results are secure and presented in ways that will not divulge critical information, except to appropriate officials. The economic model is built from publically available data. However, to build the CGE model we have made a limited series of assumptions about how the economy might respond to events. This model, as well as the other two, must balance the desire to base results on the best theory and data and maximize usefulness to the defender community that will use them for pre-emptive security and transportation planning. Hence, the third challenge is to avoid making the results and the models themselves too complex to be useful (Greenberg et al. 2011). The fourth challenge is that the three models will not present a complete portrait of the impacts, but can be used as a template for others. In other words, this set of models is a prototype, but future improvements can make the models even more useful. This requires building strong connections with the users.

References

Altiok, T. and B. Melamed. (2007). *Simulation Modeling Using Arena*, New York: Springer Verlag.

Bushue, S. (2006). Transit and Over-the-Road Bus Security. Statement of Sandra Bushue, Deputy Administrator before the Subcommittee of Highways, Transit and Pipelines Committee on Transportation and Infrastructure, U. House of Representatives.

Chang, S. (2000). Disasters and Transport Systems: Loss, Recovery and Competition at the Port of Kobe after the 1995 Earthquake. *Journal of Transport Geography 8*, 53-65.

Chang, S. & Nojima, N. (1997). Highway System Performance Measures and Economic Impact. *Proc. Of the 7th U.S.-Japan Workshop on Earthquake Disaster Prevention for Lifeline Systems,* Seattle, Washington, USA.

Chang, S. & Nojima, N. (1998). Measuring Lifeline System Performance: Highway Transportation Systems in Recent Earthquakes. *Proc. Of the 6th U.S. National Conference on Earthquake Engineering, Seattle, USA,* Paper No 70.

Chang, S. & Nojima, N. (1999). Measuring Post-Disaster Transportation System Performance: The 1995 Kobe Earthquake in Comparative Perspective. *Transportation Research Part A: Policy and Practice. 35(6),* 475-94

Federal Railroad Administration, U.S. Department of Transportation. (2009). *Vision for High-speed Rail in America: High-speed Rail Strategic Plan*.

Greenberg, M., Mantell, N., Lahr, M., & Felder, N. (2007a). Short and intermediate impact to new Jersey's economy of the loss of electric power in new Jersey's Urban industrial corridor. *Energy Policy*, 35:722–733.

Greenberg, M., Lahr, M., Mantell, N. & Felder, N. (2007b). Understanding the economic costs and benefits of catastrophes and their aftermath: a review and suggestions for the as-federal government. *Risk Analysis*, 27(1):83-96.

Greenberg M., Lowrie K., Mayer H., Altiok T. (2011) Risk-Based Decision Support Tools: Protecting Rail-Centered Transit Corridors from Cascading Effects. Risk Analysis: An International Journal, in press. .

Lee, J. S., & Kim, T.J. (2005). A Spatio-Temporal Model for Network Economic Loss Analysis under Unscheduled Events: A Conceptual Design, Presented at Symposium in Honor of Professor Komei Sasaki, Tohoku University, Japan.

Lioy P. *DUST: The Inside Story of Its Role in the September 11th Aftermath*. Lanham, MD: Rowman and Littlefield.

Lioy, P. J. (2010). Exposure Science: A View of the Past and Milestones for the Future." *Environmental Health Perspectives.* 118(8): 1081-1090**.**

Nojima, N. & Sugito, M. (2000). Simulation and Evaluation of Post-Earthquake Functional Performance of Transportation Network. *Proc. Of the 12th World Conference on Earthquake Engineering, New Zealand,* Paper No. 1927.

Phimister, J., Bier, V., and Kunreuther, H., Editors. (2004). *Accident Precursors Analysis and Management: Reducing Technological Risk Through Diligence*, National Academy of Engineering, The National Academies Press, Washington, D.C.

Posner, R. (2004). *Catastrophe: Risk and Response*. New York: Oxford University Press.

Rose, A.,& Liao, S.-Y. (2005). Modeling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions. *Journal of Regional Science*, 45(1):75–112.

Rose, A., Oladosu, G., & Lia, S-Y. (2007). Business Interruption Impacts of a Terrorist Attack on the Electric Power System of Los Angeles: Customer Resilience to a Total Blackout**,** *Risk Analysis*, (27)3:513-531.

Rose, A., Benavides, J., Chang, S., Szczesniak, P. & Lim, D. (1997). The Regional Economic Impact on an Earthquake: Direct and Indirect Effects of Electricity Lifeline Disruptions. *Journal of Regional Science,* 37(3), 437-458.

Sohn, J., John Kim, T., Hewings, J., Lee, J.S., & Jang, S-G. (2003). Retrofit Priority of Transport Network Links under an Earthquake. *Journal of Urban Planning & Development* 129(4), 195-210.

Ulusçu, Ö.S., Özbaş. B., Altıok, T. & Or, I. (2009) Risk Analysis of the Vessel Traffic in the Strait of Istanbul. *Risk Analysis*, 29(10):1454-1472.

Van der Veen, A., Steenge, A.E., Bockarjova, M., & Logtmeijer, C.J. (2003). Structural Economic Effects of Large Scale Inundation: A Simulation of the Krimpen Dike Breakage. *Delft Cluster Publication DC1-233-12.*

Weng WG, Ni SJ, Yuan HY. (2007). Modeling the dynamics of disaster spreading from key nodes in complex networks. International Journal of Modern Physics, 18(5): 889-901.

Westrum R. A typology of resilience situations. (2006). Pp. 49–60 in Hollnagel E, Woods DD, Leveson N (eds). Resilience Engineering: Concepts and Precepts. Aldershot , UK : Ashgate Press.

Woods D.D. (2006). Essential characteristics of resilience. Pp. 21–34 in Hollnagel E, Woods DD, Leveson N (eds). Resilience Engineering: Concepts and Precepts. Aldershot , UK : Ashgate Press.