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&

NATIONAL TRANSPORTATION SECURITY CENTER OF EXCELLENCE (NTSCOE),
USDHS

Tools to Risk Analysis of Passenger Rail Security and Planning

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Abstract

We built three simulation models that can help rail transit planners and operators assess high and low probability rail-centered hazard events that could lead to serious consequences for rail-centered networks and their surrounding regions. Our key objective is to provide these models to users who, through planning and mitigation, can prevent events or react to them should they occur. The first of the three models is an industrial systems simulation tool that allows us to replicate rail passenger traffic flows between New York Penn Station and Trenton, New Jersey with a focus on Newark Penn Station, which is the key rail asset in the State of New Jersey. Second, we built and used a plume model to trace chemical plumes that might impact the rail line, as well as the surrounding areas. Third, we crafted an economic simulation model that allows us to estimate the regional economic consequences of a variety of rail-related hazard events through the year 2020. Each model can work independently of the others. However, together they provide a story of what could happen and set the stage for planning that would make rail-centered transport systems more resistant and resilient to hazard events.
Foreword and Acknowledgments

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1. INTRODUCTION

1.1 Background

The United States government has ambitious plans to expand and upgrade Amtrak passenger rail service. In the interim while these plans are being implemented and modified, the Northeast Corridor (NEC) between Washington, DC and Boston, Massachusetts remains as a critical asset carrying millions of passengers, and freight rail lines crisscrossing and paralleling the NEC carry an enormous amount of cargo. The corridor passes through and connects the major political and economic centers of the United States, arguably of the world. It is essential that disruptions to rail service be kept to a minimum and that service be restored in the case of an event as soon as possible. The work reported here was supported by CERL and the USDHS. The research was conducted by faculty members and staff from Rutgers University, especially the EJ Bloustein School, the School of Engineering, Robert Wood Johnson Medical School, and the Environmental and Occupational Health Sciences Institute. The initial and primary targeted users are New Jersey Transit and Amtrak, but we have a plan to distribute the ideas to other passenger rail systems in the region.

1.2 Objectives

Focusing on New Jersey’s rail transit corridor between Trenton, New Jersey and New York City, our primary objectives were to build and test a set of mathematical models that can be used by transportation planners to (1) assess their options assuming that rail operations are degraded by disruptions ranging from chronic minor delays to low probability high consequence events, and to (2) estimate the regional economic implications of these disruptions with and without mitigation.

1.3 Approach
This report summarizes the work accomplished by the group, which will continue. We will prepare scientific products worthy of academic publication; however, our most important goal is to work with federal and selected state agencies and transit authorities which manage rail systems in the United States to further develop and apply these tools to their operations and decision-making.

1.4 Scope and Body of Report

The report presents a lengthy report chapter below that provides more historical and planning context, discusses the three models, and presents the results and the limitations in detail. We refer the reader to that section.

1.5 Mode of Technology Transfer

We have already begun to develop relationships with New Jersey Transit (NJT) and Amtrak to further develop and apply the models. We have met with senior technology and planning staff of NJT, and they have made multiple suggestions to us that already have been incorporated into the rail security and planning model (sometimes abbreviated as rail security or RSAPM hereafter). Although we have had meetings with Amtrak staff, no one there has seen this report. It is our intent to present the key parts to Amtrak along with a plan to further develop it to meet their specific needs in the NEC, as well as elsewhere in the US. Our intent is to visit with key individuals in the major local commuter rail systems between Boston and Washington that feed into Amtrak (including Massachusetts, Connecticut, New York, Pennsylvania, Delaware, Maryland, Virginia). Our group has good contacts with these organizations. The primary objective of these meetings will be to persuade them to use the model as a framework to tie the NEC to their system of other rail and bus systems to their main local station (e.g., Union Station, DC). We would appreciate an opportunity to present these models to CERL staff and obtain their ideas about how it could be adjusted for defense-related as well as civilian purposes.
2. **Scope and Body of the Report**

2.1. **Historical Context**

The idea for this project began with the announcement that the US government was planning to substantially expand its passenger rail network focusing on high speed corridors. We wrote a proposal to the United States Department of Homeland Security (DHS). The proposal was funded and the project was further supported by the DOD funding provided to the University Center for Disaster Preparedness and Emergency Response (UCDPER). Both the DHS and the UCDPER recognized that New Jersey is a core part of the only national rail corridor with high speed service in the nation. While ten other systems were in the planning stages across the United States and were noted in President Obama’s year 2010 State of the Union speech (Obama 2010, Federal Railroad Administration 2009, US High Speed Rail Association 2011), New Jersey was not part of the original plan even though it is a key component of the existing 450 mile long system, of which almost 60 miles are in New Jersey. Notably, New Jersey has the largest public-operated mass transit system of any state, and Amtrak and NJT use many of the same system elements.

Not only does New Jersey have a large segment of the corridor, but in addition New Jersey is the most densely populated and second most affluent state in the United States. It produces critically important research and manufactured products and provides essential financial resources to the region, nation and world. New York City and Philadelphia, two of the largest metropolitan regions in the United States, are its immediate neighbors and the flow of people and goods through the state is among the highest in the nation, further increasing the intrinsic value of the New Jersey-centered study region. As we know and should not forget, this densely packed confluence of valuable attributes can be degraded by natural hazards, accidents,
or intentional human-initiated events and suffer serious local effects that could ripple across the US landscape.

Actions in New Jersey to understand and respond as quickly as possible to events could lead to prevention of attacks, build resilience, in other words, reduce risk, and as a consequence have a major impact on public health and the economy of our state, surrounding regions, and the nation. Nationally, our recommendations could add planning and additional security measures to projects that at this time are largely in the early design phases. If, as we believe, the work is transferable to the rest of the nation, the applications could reduce risk.

This report demonstrates what can be accomplished by building a multi-disciplinary team with backgrounds in systems engineering, physics, exposure science, urban planning, economics, public health, and transportation. This section is divided into multiple parts. After introducing a risk analysis framework, we present the models, and then discuss the results, including discussing some parts of the project that had to be modified because of data limitations and others that were added during the course of the project.

2.2 A Risk Analysis Framework

The literature contains many definitions of risk and risk analysis. Our project fits comfortably into a framework of three risk assessment and three risk management questions. (There are other versions that have more than 20 categories, but these six encompass the key elements, Greenberg 2009, Haimes et al. 2005a,b, Kaplan, Garrick 1981)

The essence of risk assessment is captured by three questions:

(1) What can go wrong?

(2) What are the chances that something with serious consequences will go wrong?

(3) What are the consequences if something does go wrong?

The three risk management questions are:
(4) How can the consequences be prevented or reduced?
(5) How can recovery be enhanced and operations maintained, if the scenario occurs?
(6) How can key local officials, expert staff, and the public be informed to reduce concern and increase trust and confidence?

Our project has focused directly on steps 1 (what can go wrong?) and 3 (what are the consequences?). It picks selected events and several realistic options to introduce resilience to manage the events. The descriptions that follow should be regarded as highlights. A full presentation of all the work would have required a book-length manuscript, and individual manuscripts are being prepared.

2.3 Choice of Events: What could happen on the rail line?

Before choosing the models, we engaged in lengthy discussions of possible events to be modeled, that is, the first part of risk analysis. The critical question was did we want to study very localized events, or events that had impacts beyond the rail line to the larger regions? This phase began by identifying events that could lead to consequences that ranged from some that we would characterize as chronic and routine to those that would be catastrophic.

There are large data bases and literature on rail system events. The Office of Safety Analysis of the U.S. Federal Railroad Administration (FRA) maintains a searchable web-list list of every reported accident since January 1975 that contains tens of thousands of events. Categories include collisions, derailments, and others; it is further subdivided into train accidents, high-rail grade crossing, and other incidents. The database includes about 500 different types of events, such as worn rail and defective and missing crossties. The most frequent are missing and broken crossties, switches, rails, fasteners, and other elements of the tracks and rail bed. The list also shows accidents related to workers failures, vandalism,
employees falling asleep, and other human factors. The number of reported events is also accompanied by a list of direct reportable economic damage. Hence, an analyst can see the direct economic impacts of washouts of tracks and rail beds, buckled and misaligned tracks, and failure to comply with signals.

For those looking for already digested analyses, Semmens (1994) and Kichenside (1997) books describe the worst train disasters. The BBC (2007) broadcasted a story about the world’s 17 worst rail disasters from 1981 through 2007. The popular literature shows that almost all were in Asia and Africa and include a range of causes from brake failures, collisions and derailments to gas explosions beneath two trains to cyclones toppling a train into a river. Some special studies have been done of terrorist-related events. Jenkins, Butterworth, and Clair (2010) examined the failed attempt to derail the French high-speed train in 1995, and they also examined 181 rail sabotage attempts. This interesting report provides insights into what terrorists might do. For us, the question is how relevant are these as illustrations for these models?

The literature also presents some attempts to assess the impacts of hazard events such as earthquakes on ports and other transportation systems (Chang 2000, Chang, Nojima 1998, Committee 1999). We consulted this literature but we relied to a large degree on staff at New Jersey Transit, Amtrak, and faculty and staff at our universities who worked for NJT to advise on what events would be illustrative and where these events should be staged. Some of our original ideas were dropped after initial analysis. For example, we did not build a cyberattack scenario for this area because our experts told us that while parts of the system are dependent on the technology, the system as a whole is not, so that it is not yet sufficiently dependent on the technology to make it vulnerable to an extremely destructive long period outage that would have extraordinarily consequential economic impacts. After much debate, we chose not to develop a terrorist-initiated event. We considered some, including anthrax, use of multiple conventional
explosions, dirty bombs and others of varying consequence. Ultimately, the goal here was to show that the models work and could simulate such events, not to provide information to individuals with bad intentions. Likewise, we did not build a scenario based on a tornado, hurricane or other natural hazard. We chose to simulate an industrial accident in an area with many industrial facilities. Had the project been developed in another region, the test scenarios likely would have been different. With more resources, some of the other scenarios described above would have been tested and certainly should be examined in the future.

With that caveat noted, we formally modeled several high probability, limited consequence events and several low probability high consequence ones to demonstrate the capacities of the models. It is imperative that the reader understand that these are illustrations, and the results are not to be taken at face value. The high probability low consequence event was the initial priority.

2.3.1. Relatively high probability events with limited consequences

The Federal DOT has focused on reducing delays, which it defines as a deviation from the schedule of 15 minutes or more for Amtrak trains (USDOT 2008, Bureau of Transportation Statistics 2005). DOT reports for the nation as a whole and for the Northeast Corridor (NEC) show wide variations by location and year. There has been a long term decrease in delays compared to 20 to 30 years ago, but as service expands delays increase. For example, the NEC master plan (2010) reports that in 2008 the average delay for a 150 mile trip, which is the average trip, was 7 minutes. The longer the ride, the longer the average delay. Acela Express trains along the NEC reported on-time performance as 94.1% in March 2012 and 93.7% for the last 12 months (Amtrak 2012). Northeast Regional Trains report a similar record. The primary causes of delay are track and signal issues (33%), interference by other trains (30%), and equipment malfunctions (11%). Notably, the NEC report calculates delay-related dollar losses at
$19 per hour, which we believe is remarkably low, given that in New Jersey the median family income of train riders provided to the authors by NJT based on a survey of their customers was $124,500 in 2012 dollars. Assuming that on average two people contribute to median family income, the loss per hour is about $31 per hour (2000 hours per person x 2 persons).

Grynbaum and Gebeloff (2010) report that the commuter railroads that serve New York said that 96% were on time. The authors, writing for the New York Times and based on data gathered by the New York Times from the three commuter lines, say that the reality is different, and that 1 in 10 trains entering NY Penn Station arrived late, and 2/3 of these were late by 10 minutes or more. During the rush hour, they report that 2 in 5 were late by at least 15 minutes. New Jersey Transit was reported as the line with the most delays. The explanations are limited platforms, limited tunnels and bridges, and priority for Amtrak service.

Amtrak and NJT have web-based connections that report on delays; delays of an hour or more are infrequent but not unexpected. Given the reality that rail-transit-related delays are frequent, our economic model has them implicitly built into the historical equations. That is, the economic model is a portrait of the economic history of the region, which includes these delays. We needed a test event that would be relatively infrequent and yet would be felt in the economy. It should be more than 15 and 30 minute delays and less than a one week loss of service.

After discussions with rail system staff, we chose a one hour delay twice a week on a weekday starting at 7:30 a.m. (during rush hour). This event had two versions. One version kept all riders on the train, that is, every rider faces two one-hour delays twice a week, and yet they stay on the train. Given that we doubt that all passengers would choose that behavioral response, our resilient version would keep 40% on the train, 40% would shift to automobiles or buses, and 20% would telecommute. The telecommuters would suffer no delay-related costs; they would work the same number of hours. The group that switched to the highway would be impacted
twice and they, in turn, would impose congestion and time-delay costs on everyone else. As the reader will see, resilience through more auto traffic in this region has negative economic consequences.

2.3.2 Major system failure caused by natural or human-caused events: one week outage

While highly unlikely, our discussions with experts suggested that a variety of low probability events could eliminate rail service for a week. This event is meant to be an extended version of the previous one, with the same resilience options. Although we tested it, we do not show the results as they do not add materially to the conclusions.

2.3.3 Bridge failure: Low probability high economic consequences: One year outage

A much more serious event would be a collapse of the Dock Bridge, a pair of vertical lift bridges crossing the Passaic River at Newark just north of the Newark train station or the Portal bridge (further north), which lasts for a year with limited resilience, that is, 40% ride train and lose 2 hours a day during the workweek; another 40% shift to auto and bus and lose two hours a day; and the remainder telecommute. The resilience for the rail riders is provided by adding shuttle buses to the PATH station or to the Secaucus rail station, so that the average loss of the rail riders is reduced to 1 hour rather than 2. This is an extremely serious event, and yet there is a practical way of adding resilience, which we tested.

2.3.4 Chlorine Tank Leak: Low probability, high consequence with health impacts

Using a plume model and GIS tools, we created a scenario in which a single rail car loaded with liquid chlorine failed to contain the chlorine, which was emitted, impacting the surrounding areas and those on trains and on platforms at nearby stations. This accident is described in detail below, and would constitute a very low probability event with extraordinarily serious public health consequences.

2.4 Rail Simulation Model
The user community told us that they wanted a tool that they could use in routine planning, or paraphrasing what one senior staff member said: We would want to be able to use this for planning for the Super Bowl and for periodic outages of an hour or more. They advised us against a model that could only be applied to the worst events, which they viewed as a black box computer tool that would not be used.

We developed a rail simulation model with the ARENA simulation tool developed by Rockwell Software (Altiok, Melamed 2007, Rossetti 2010). It allows the user to not only build a systems model but also generate statistics and accompanying animation. The user community’s preferences implied that the model had to figuratively replicate the on-the-ground rail system. ARENA allows the user to incorporate multiple components of the operating rail network into the mathematical model. These include the following: number of trains in service, number of cars per train, number of boarding-deboarding passengers, or time spent at a station for boarding/deboarding operations differ during rush hour (AM and PM) and non-peak hours, the tracks, the stations, bridges, and other physical elements.

Given our limited financial resources, it was not feasible to build out the entire system, that is, incorporate all of the rail, light rail, bus and road links that connect to the NEC line. After much discussion with the user community, they advised us to focus on the NEC rail line between Trenton, New Jersey and Penn Station, New York City, while also simulating the movement of trains and passengers along the NJT branch lines connecting to the NEC. It is clear from these discussions that the Newark Penn Station in New Jersey was the most important asset in New Jersey for both Amtrak and New Jersey Transit. Consequently, with considerable assistance from senior staff of New Jersey Transit, we focused the detailed modeling and the events around Newark Penn Station train station. Figure 1 shows the system that we included in the model.
2.4.1 Rail Network

The simulation model includes three service providers (NJ Transit, Amtrak, and Port Authority of NY and NJ). They offer train line services that stop at Newark Penn Station (Table 1): nine Amtrak and six New Jersey Transit, including the Light Rail, and the PATH that runs to Jersey City, Hoboken and New York City. We also included three NJT trains that do not stop at Newark Penn Station but could serve as alternative paths in the event of a serious problem at the Newark train station. Table 1 lists all 19 services: the colors in the figure and in Table 1 represent different services. For example, the Raritan Valley Line is yellow and the NEC is red.
in the animations. The trains appear as colored moving dots on the screen. When we cause an event the dots stop moving in the impacted segment. In some runs, some of the trains are moving and others are stopped because the event can be effective on a sub-group of services.

When we began this work, the December 2010 timetables were in use, and we incorporated those into the model. Separate schedules were prepared for weekdays, and weekends/holidays for both directions. NJT and Amtrak gave us the number of cars per train and number of passengers per car. For example, NJ Transit trains, with exceptions for services with less passenger capacity, have ten cars during rush hours and 8-10 cars the rest of the day (we randomized these). The maximum car capacity for NJ Transit trains is 140 people during rush hours and it is assumed that car capacity has a uniform distribution between 120 and 140 during non-rush hours. We incorporated similar data for Amtrak, PATH, Light Rail and the others.

Train speed was estimated by dividing distance by travel time. We also learned that the track structure between Trenton and Newark are different from those between Newark and New York City. Consequently, the model changes train speeds at Newark to reflect destination.

Table 1. Service providers included in the model

<table>
<thead>
<tr>
<th>Service Provider, NJT</th>
<th>Color</th>
<th>Actual Terminuses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast Corridor</td>
<td>Red</td>
<td>Trenton, NJ - New York Penn, NY</td>
</tr>
<tr>
<td>North Jersey Coast</td>
<td>Blue</td>
<td>Long Branch/Bay Head, NJ- New York Penn, NY or Hoboken, NJ</td>
</tr>
<tr>
<td>Raritan Valley</td>
<td>Yellow</td>
<td>Raritan or High Bridge Station, NJ - Newark Penn, NJ</td>
</tr>
<tr>
<td>Atlantic City Express Service</td>
<td>Red</td>
<td>Atlantic City, NJ - New York Penn, NY</td>
</tr>
<tr>
<td>Newark Light Rail</td>
<td>Orange</td>
<td>Grove Street, NJ- Newark Penn, NJ</td>
</tr>
<tr>
<td>Newark Light Rail Extension</td>
<td>Orange</td>
<td>Broad Street, NJ- Newark Penn, NJ</td>
</tr>
<tr>
<td>Service</td>
<td>Color</td>
<td>Destination</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>Montclair - Boonton</td>
<td>Brown</td>
<td>Hacketstown, NJ - New York Penn, NY or Hoboken, NJ</td>
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<tr>
<td>Morristown</td>
<td>Green</td>
<td>Hacketstown, NJ - New York Penn, NY or Hoboken, NJ</td>
</tr>
<tr>
<td>Gladstone</td>
<td>Green</td>
<td>Gladstone, NJ - New York Penn, NY or Hoboken, NJ</td>
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**Amtrak**

<table>
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<tbody>
<tr>
<td>Acela Express</td>
<td>Red</td>
<td>Washington, D.C. - Boston, MA</td>
</tr>
<tr>
<td>Cardinal</td>
<td>Red</td>
<td>Chicago Union, IL - New York Penn, NY</td>
</tr>
<tr>
<td>Crescent</td>
<td>Red</td>
<td>New Orleans, LA - New York Penn, NY</td>
</tr>
<tr>
<td>Carolinian</td>
<td>Red</td>
<td>Charlotte, NC - New York Penn, NY</td>
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<tr>
<td>Keystone</td>
<td>Red</td>
<td>Harrisburg, PA - New York Penn, NY</td>
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<tr>
<td>Northeast Regional</td>
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<td>Washington, D.C. - Boston, MA</td>
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<tr>
<td>Pennsylvanian</td>
<td>Red</td>
<td>Philadelphia, PA - New York Penn, NY</td>
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<tr>
<td>Silver Service/ Palmetto</td>
<td>Red</td>
<td>Georgia or Florida - New York Penn, NY</td>
</tr>
<tr>
<td>Vermonter</td>
<td>Red</td>
<td>Washington, D.C. - St. Albans, VT</td>
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**Port Authority of NY and NJ**

<table>
<thead>
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<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>PATH</td>
<td>Dark blue</td>
<td>Newark Penn, NJ - Manhattan, NY</td>
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</table>

As suggested by the user community, Newark’s Penn Station is the heart of the model and this is reflected in how we modeled that station. Indeed, they urged us to focus on the Newark Penn Station Terminal Building. Based on data provided to us, some travelers leave the station at Newark, while others wait there to transfer to another train, Light Rail, PATH or bus and others arrive at the Newark station by auto, bus or on foot. We have built the model to randomize the waits in the station based on historical data. A graphic visualization shows people deboarding and boarding trains.

A set of assumptions was made about waiting time, boarding, and other operations based on actual data and conversations with operators. For example, we assigned and randomized passengers at each station based on historical data and randomized between peak passengers and off-peak; we also added upper and lower limits ±10 percent of the mode. Each train has its own
deboarding and boarding proportions based on historical data. Given the random variations that can occur in the model, when some passengers cannot board a train because of capacity constraints, they wait for the next one. If there is a service disruption less than an hour, people are assumed to wait, if the service disruption is more than one hour, only 50% of people will continue to wait and in two hours everybody will leave. It is also assumed that the rescue time for passengers held on disrupted trains is 60 minutes. (Please note these are educated guesses based on staff experience.)

All rail stations in the Northeast corridor from Trenton to New York Penn Station are part of the model. From west to east these stations are Hamilton, Princeton Junction, Jersey Avenue, New Brunswick, Edison, Metuchen, Metropark, Rahway, Linden, Elizabeth, North Elizabeth, Newark Airport, Newark Penn, and Secaucus. Stations that are not a part of the NEC but located on other lines such as PATH, Light Rail, Morristown Line, Gladstone Line, Montclair – Boonton Line and Raritan Valley Line where passengers can board/deboard and join the NEC are also incorporated, including Harrison, Broad Street, Grove Street, Union, Roselle Park and Hoboken Stations (please note that other stations of these lines, except these six are not modeled). In addition to the regular stations, we assigned some stop points as locations where trains can stay on standstill position when there is a system problem. These stop points are only placed between stations that are more than 4 miles apart. A total of 10 stop points were added.

The rail system includes 2 to 7 tracks, with the densest network at the major junctions (e.g., Raritan Valley and North East Corridor). Given the reality of limited resources to build the model, the simulation model does not include all these details but is close enough to replicate the performance of the system. This is also true for the light rail system, PATH, and the other rail systems that come into the Newark train station. (As noted above, the users preferred that the
focus our attention on the Newark Penn Station rather than provide the detail on all the tracks and stations South and West of Newark Penn Station.)

The Newark Penn Station, which opened in 1935, is the key node, and its track structure is modeled in detail, allowing us to illustrate what is possible in the ARENA system. By 2010, it had a daily average of 1800 Amtrak passengers, 6180 for Light Rail, and weekday passenger boardings for NJ Transit and PATH were over 26,000 and 29,000, respectively (Amtrak 2010, NJ Transit 2010, Fels 2010). December 2010 data showed that over 1000 trains stopped at Newark Penn Station on an average day; 290 NJ Transit, 104 Amtrak, 250 PATH and 386 Light Rail.

The main part of the station has five platforms and seven tracks. Normally, each has a set of trains that stop, yet tracks are reassigned during rush hours and can change if the managers change the operational priorities. All of these platforms and tracks were incorporated into the model, and the animation described below shows how complex the operations can be on a given day.

The headquarters for New Jersey Transit is located across the street from Newark Penn Station (the operations center is located in Kearny, NJ), and many of us visited and took tours with New Jersey Transit police so that we could better understand normal operations as well as what happens during disruptions.

The station has an elaborate protocol for routing and rerouting passengers when there is a problem, and the operation managers showed us their spreadsheets. The spreadsheets work up to a point. They provide limited options and lack the dynamic capacity of the rail security and planning model. If our rail model were to be adopted by the rail systems, it might replace the spreadsheets. Or perhaps an interface would be built between our model and set of spreadsheets.
The model allows us to stop the trains and then operators can adjust the system, while the model keeps track of how many people are stranded at what locations in the system. When the system recovers, the model resumes and trains start running again. If the model is valid (see below for validation), then we can figuratively stop the system at any time and watch what happens.

Figure 2 shows a more detailed view of the network of rail around Newark Penn Station. The different colors of the rail lines in Figure 2 represent the different lines, with red, for example, representing the NEC. Figure 3 shows the Newark Penn Station from above and the specific screen shows two trains in the station and passengers on the platform. While not visible in these shots, the model accumulates the number of people in each station and at platform in Newark Penn Station as trains come in and out.

Figure 2. Screenshot of the study area
2.4.2 Validation

It was abundantly clear to the research team that the potential users were not interested in any of the model unless they could be shown to represent reality. Accordingly, we ran the model at high speed to simulate a 25-year timespan and compared the average results to the data provided to us by the rail system managers for number of trains, average travel time, and average number of passengers boarding and deboarding at Newark Penn Station. Please note that these simulations are based on the data provided by the managers in late 2010, and would no longer be considered appropriate without updating. Table 2 shows very close agreement between the actual and simulated number of trains at Newark Penn Station.

Average travel times, which include speed of trains and time to board and deboard were also very close (Table 3) for both westbound (WB heading toward Trenton) and eastbound (EB toward New York City).

Table 2. Validation results, number of trains at Newark Penn Station, daily average

<table>
<thead>
<tr>
<th>Train</th>
<th>Simulation</th>
<th>Real Data</th>
<th>Relative Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>NJ Transit</td>
<td>289.62 ± 0.0223</td>
<td>290</td>
<td>-0.0028</td>
</tr>
<tr>
<td>Train and direction</td>
<td>Simulation</td>
<td>Real Data</td>
<td>Relative Error</td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td>------------</td>
<td>-----------</td>
<td>----------------</td>
</tr>
<tr>
<td>EB Northeast Corridor</td>
<td>28.28</td>
<td>28</td>
<td>0.0088</td>
</tr>
<tr>
<td>WB Northeast Corridor</td>
<td>30.55</td>
<td>30</td>
<td>0.0075</td>
</tr>
<tr>
<td>EB North Jersey Coast</td>
<td>28.50</td>
<td>28</td>
<td>0.0136</td>
</tr>
<tr>
<td>WB North Jersey Coast</td>
<td>28.34</td>
<td>28</td>
<td>0.0040</td>
</tr>
<tr>
<td>EB Raritan Valley</td>
<td>17.60</td>
<td>17</td>
<td>0.0074</td>
</tr>
<tr>
<td>WB Raritan Valley</td>
<td>12.66</td>
<td>13</td>
<td>-0.0035</td>
</tr>
<tr>
<td>EB North Jersey Coast to Hoboken</td>
<td>45.07</td>
<td>44</td>
<td>0.0175</td>
</tr>
<tr>
<td>WB North Jersey Coast from Hoboken</td>
<td>41.11</td>
<td>42</td>
<td>-0.0207</td>
</tr>
<tr>
<td>EB ACES</td>
<td>75.80</td>
<td>75</td>
<td>0.0163</td>
</tr>
<tr>
<td>WB ACES</td>
<td>78.49</td>
<td>80</td>
<td>-0.0145</td>
</tr>
<tr>
<td>Light Rail from Broad to Newark</td>
<td>10.88</td>
<td>11</td>
<td>0.0360</td>
</tr>
<tr>
<td>Light Rail from Newark to Broad</td>
<td>9.86</td>
<td>10</td>
<td>0.0376</td>
</tr>
<tr>
<td>Light Rail from Grove to Newark</td>
<td>21.85</td>
<td>22</td>
<td>0.0162</td>
</tr>
<tr>
<td>Light Rail from Newark to Grove</td>
<td>21.85</td>
<td>22</td>
<td>0.0160</td>
</tr>
<tr>
<td>EB Acela</td>
<td>35.37</td>
<td>35</td>
<td>0.0088</td>
</tr>
<tr>
<td>WB Acela</td>
<td>27.92</td>
<td>27</td>
<td>0.0185</td>
</tr>
<tr>
<td>EB Cardinal</td>
<td>64.22</td>
<td>64</td>
<td>-0.0005</td>
</tr>
<tr>
<td>WB Cardinal</td>
<td>55.73</td>
<td>55</td>
<td>0.0087</td>
</tr>
<tr>
<td>EB Carolinian</td>
<td>64.00</td>
<td>63</td>
<td>0.0119</td>
</tr>
<tr>
<td>WB Carolinian</td>
<td>58.99</td>
<td>58</td>
<td>0.0127</td>
</tr>
<tr>
<td>EB Crescent</td>
<td>63.24</td>
<td>63</td>
<td>-0.0001</td>
</tr>
<tr>
<td>WB Crescent</td>
<td>63.25</td>
<td>63</td>
<td>0.0000</td>
</tr>
<tr>
<td>EB Keystone</td>
<td>57.40</td>
<td>57</td>
<td>0.0009</td>
</tr>
<tr>
<td>WB Keystone</td>
<td>53.37</td>
<td>53</td>
<td>-0.0001</td>
</tr>
<tr>
<td>EB Northeast Regional</td>
<td>58.84</td>
<td>58</td>
<td>0.0081</td>
</tr>
<tr>
<td>WB Northeast Regional</td>
<td>57.39</td>
<td>57</td>
<td>0.0052</td>
</tr>
<tr>
<td>EB Pennsylvanian</td>
<td>64.53</td>
<td>63</td>
<td>0.0203</td>
</tr>
<tr>
<td>WB Pennsylvanian</td>
<td>52.45</td>
<td>52</td>
<td>0.0038</td>
</tr>
<tr>
<td>EB Silver Service</td>
<td>64.40</td>
<td>65</td>
<td>-0.0028</td>
</tr>
<tr>
<td>WB Silver Service</td>
<td>58.51</td>
<td>58</td>
<td>0.0161</td>
</tr>
<tr>
<td>EB Vermonter</td>
<td>33.61</td>
<td>34</td>
<td>-0.0188</td>
</tr>
<tr>
<td>WB Vermonter</td>
<td>39.07</td>
<td>40</td>
<td>-0.0109</td>
</tr>
<tr>
<td>EB PATH</td>
<td>3.59</td>
<td>4</td>
<td>0.0260</td>
</tr>
</tbody>
</table>
Finally, average daily passenger boardings and deboardings are summarized in Table 4. Again, this is a comparison of the actual 2010 data with our simulation results.

<table>
<thead>
<tr>
<th></th>
<th>Simulation</th>
<th>Real Data</th>
<th>Relative Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>NJ Transit Boardings</td>
<td>26525 ± 4.6761</td>
<td>26449</td>
<td>0.0029</td>
</tr>
<tr>
<td>Amtrak Boardings</td>
<td>1800 ± 0.4107</td>
<td>1800</td>
<td>0.0000</td>
</tr>
<tr>
<td>Subway Boardings</td>
<td>6103 ± 0.8924</td>
<td>6152</td>
<td>-0.0079</td>
</tr>
<tr>
<td>PATH Boardings</td>
<td>29805 ± 4.8177</td>
<td>29923</td>
<td>-0.0039</td>
</tr>
<tr>
<td>NJ Transit Deboardings</td>
<td>26405 ± 5.9433</td>
<td>26449</td>
<td>-0.0017</td>
</tr>
<tr>
<td>Amtrak Deboardings</td>
<td>1803 ± 0.4881</td>
<td>1800</td>
<td>0.0021</td>
</tr>
<tr>
<td>Subway Deboardings</td>
<td>6252 ± 1.1593</td>
<td>6215</td>
<td>0.0061</td>
</tr>
<tr>
<td>PATH Deboardings</td>
<td>29622 ± 4.1459</td>
<td>29923</td>
<td>-0.0101</td>
</tr>
</tbody>
</table>

The last validation exercise was to try to capture the ebb and flow of passengers during 24-hours. No one has an actual count, nevertheless the NJT staff have considerable experience. The
average number of people waiting at the Newark Penn Station was 204 and the maximum was 2562. The AM peak is about half of the PM peak because many people deboard at the AM peak and many more board in the evening rush. NJT staff felt that our first effort underestimated the AM peak and provided data to us that was used to adjust the simulations. We made appropriate modifications. While the model results clearly are valid for 2010, it would need to be updated to capture current passenger flows.

Given these simulation results, we conclude that the model, assuming that is appropriately updated, does closely replicate reality and can be used to model disruptions.

2.4.3 Output Metrics

The following performance measures were defined and obtained from simulation run of each scenario.

- The probability that system is down P(D), (i.e. the proportion of the time that the service is stopped in a year)
- The probability that a person is affected by any failure P(E), (i.e. the ratio of people affected on trains or stations to the total number of people using the system)
- Total number of people using the system, NJ Transit, Amtrak, Light Rail and PATH trains.
- Average and maximum number of people waiting at Newark Penn Station
- Number of disrupted and cancelled trains during an incident
- Average man-hour loss during short service disruptions (the time between the arrival of passenger to the station and the end of the incident), its economic consequences and its distribution for eastbound and northbound NJ Transit, Amtrak, Light Rail and PATH trains.
- Number of passengers held on disrupted trains and its distribution for eastbound and northbound NJ Transit, Amtrak, Light Rail and PATH trains.
- Number of impacted passengers waiting at stations

2.5 Air Pollution Simulation Model

2.5.1 Context

Plume models assess how gases and particles disperse from a source. Sources can be a single point (factory, power plant), a moving line (motor vehicles, trains), or a large area with many emitters (residential neighborhood). Emissions can be continuous such as from a sulfur scrubber at a petroleum refinery, or they can be episodic, such as fires, explosions, and leaks from a factory, tank car, and others. The impacts of emissions depend on a set of attributes at the site.

1. biological, chemical, and physical attributes of the substance emitted
2. velocity, temperature, rate of release and height of the emission source
3. characteristics of the surrounding environment, such as buildings and hills that could redirect and absorb some of the emitted material
4. human and ecological receptors directly exposed because they are outside or in nearby schools, hospitals, houses, enclosed arenas and others
5. immediate environmental conditions, notably wind direction, speed and turbulence, and
6. capacity of local responders to evacuate and/or direct shelter in place

2.5.2 Chlorine Tank Leak Scenarios and the SCIPUFF Model

The scenario presented here is based on a hypothetical leak of liquid chlorine from a rail car that is traveling from a major chlorine production facility in northern New Jersey. We picked chlorine because it is a ubiquitous substance, widely used for purifying potable water and wastewater, and as an intermediate chemical in many other products (American Chemistry
Council 2012). Chlorine and ammonia account for much of chemical shipments by rail in the United States. There have been incidents. In 2005, a train derailment near Graniteville, South Carolina, ruptured a tank car with chlorine and nine people were killed, 75 injured, and over 5000 people living within a 1 mile radius were evacuated for several days. The estimated cost of this event was $126 million (FRA 2008). A simulation study that assumes a chlorine railcar rupture near the Washington, DC mall during a major public event was reported to kill 17,500 people (Boris 2003).

Several dozen air dispersion models are available. We chose SCIPUFF (Second-Order Closure Integrated Puff) which has been validated both in the field and laboratory (Sykes, et al. 1999, Sykes, Gabruk 1997). SCIPUFF is a Lagrangian model which uses a collection of Gaussian puffs to describe time-varying three-dimensional concentration profiles, and predicts both the average concentration and the concentration variance out to regional scales. For our purposes, the SCIPUFF model formulation allows for predicting short and long-term concentration profiles from a moving source (a freight train), in conjunction with time-varying meteorological inputs. This model also uses adaptive multi-grid and time-stepping schemes, and captures sharp changes in concentration fields over both space and time, while being computationally efficient. Concentration estimates can be obtained either at specific locations, over a regular grid, or as contours of concentration profiles. Notably, the model permits adjustment for terrain, particle and gas movement, degradation, short and range transport, and direct input of meteorological information.

The SCIPUFF implementation used in this simulation was from the Hazard Prediction and Assessment Capability (HPAC) system (DTRA 2003), which provides dispersion modeling in addition to chemical, biological, and nuclear databases for source definitions. The HPAC system can utilize user-specified weather data, from National Weather Service (NWS) and
military providers. (DTRA 2003). Local topography is incorporated into the model via
generation of an interpolated wind field with data from any number of surface and upper-air
measurements, but the surface roughness is required to be constant over the entire domain. It
uses a modification of the Dense Gas Dispersion Model (DEGADIS) when the source gas is
heavier than air. HPAC has been tested in the URBAN 2000 field experiment (Allwine, Shinn et
al. 2002) and in various other comparative evaluation studies (Chang, Hanna et al. 2005; Warner,

2.5.3 Scenarios

We ran four versions of the model that varied by point of origin, train path, and plume
direction. Figure 4 shows the location of the four freight rail routes considered in the simulation.

Figure 4. Four Freight Routes for Chlorine Event Simulations
The concentration profiles predicted by the plume model were examined within the Acute Exposure Guideline Levels (AEGL) framework, which describes the dangers to humans in non-occupational settings resulting from short-term exposure to airborne chemicals. The National Advisory Committee for AEGLs develops these guidelines to help both federal and local authorities, as well as private companies, respond to emergencies involving spills, or other accidental releases of hazardous chemicals. The AEGL values are intended to serve as planning
values for the safety layout of industrial plants for which the possibility of a hazardous incident is relevant. Additionally, measures for alert and emergency response planning as well as for disaster control can be projected more accurately on the basis of the AEGL framework (NRC 2001).

AEGL values represent toxicologically substantiated ceiling exposure levels for different relevant exposure periods (e.g. 10 minutes, 30 minutes, 1 hour, 8 hours, etc.). They are generally specified for three different degrees of severity of toxic effects according to the scale of action laid down in planning for the various areas of application. AEGL1 is the threshold for notable discomfort, AEGL2 is threshold for serious, long-lasting effects or an impaired ability to escape, and AEGL3 is the threshold for lethal effects. The actual percentage of people effected above each value depends upon the age, sex, infirmities and susceptibility of the population placed at risk. Thus, each AEGL can be used to provide estimates of the impact on public health. It must be noted that in order for health effects to manifest, the concentrations at any location have to persist beyond a threat level over the corresponding time duration. For example, considering the 10 minute AEGL2 level for chlorine, the exposed individual experiences exceeds an average concentration over a 10 minute interval at $\geq 2.8$ pm. Therefore, if we consider a specific location, the risks associated with that location for an individual will greatly depend on whether the high levels of concentrations persist, and whether the individual was present at that location during the period of high concentrations (See Figure 5).

Figure 5. Schematic of impact from a hazardous release (Hauschild 2000). (Isopleths in the downwind direction show the spatial extent for the area where the AEGL levels are exceeded)
Table 5. AEGLs for chlorine (NEC, 2004)

<table>
<thead>
<tr>
<th>ppm</th>
<th>10 mins</th>
<th>30 mins</th>
<th>60 mins</th>
<th>4 hours</th>
<th>8 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEGL1</td>
<td>0.5</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>AEGL2</td>
<td>2.8</td>
<td>2.8</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>AEGL3</td>
<td>50</td>
<td>28</td>
<td>20</td>
<td>10</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Reiterating, red on the maps that follow show a potentially lethal dose of chlorine without medical treatment, orange implies a high level of exposure that might require medical treatment, and yellow may be associated with watery eyes and odors.

The simulation starts near Kearny, New Jersey, where the train including chlorine tankers merges with along the Northeast corridor line. Traveling at 5 miles/hour with low wind speed, a rail car begins to leak chlorine at 10 kg per second. Figure 6 shows five stages as the train travels south and west. Stage 1 is a small plume at 10 minutes, with a high dose near the train. At 30 minutes the plume has reached Newark Penn Station and the surrounding area. At 40 minutes
the slow traveling train and its plume are heading southwest toward Newark International Airport. The dose in the lethal zone is diminishing because of diffusion and chemical reactions, but is still potentially lethal. At one hour, the plume has drifted over the New Jersey Turnpike, Route 1 and is on the edge of Newark International Airport. And the last slide shows that the cloud is starting to dissipate at 90 minutes as it heads toward Elizabeth. The five slides summarize 194 stages of the plume as it heads southwest along the NEC.

Such events can be prevented by shipping the chlorine in solid form, rather than in liquid form, by closing the rupture as soon as it is noticed, and by not using the path that is sometimes used. Even if the event occurs, health effects can be minimized by rapid evacuation and/or shelter in place, which depends upon the location of the plume relative to the receptors. There have been two incidents with rail cars carrying chlorine in this area during the last few years. Neither resulted in a serious problem, and notably the last of these was on April 4, 2011 when the authors were working on incidents to simulate.

While this is a low probability event, it most certainly is not implausible, and indeed we could have made it much more severe, which is one of the reasons why the Chlorine Institute has developed its own Rail Transportation Security Plan, and why this particular region of the Northeast corridor has merited so much attention from the New Jersey Department of Homeland Security. Frankly, we do not think that this event would occur, and yet by demonstrating that it is plausible for a lethal dose of a common chemical to occur over a highly used rail line, major train station, and nearby major airport, we have demonstrated the value of using not only the rail model but combining it with the plume models. This combination of models is directly applicable to a variety of scenarios not only in this region but in many other locations in the United States and the rest of the world, and the pair of models can assist in planning the location
of future freight train routes and track construction and the location of businesses and residences.

The results section will suggest some health and economic impacts.

Figure 6. Path of Chlorine Plume in Simulated Event
2.6 Regional Economic Impact Simulation Models

2.6.1 Context

The objective of our regional economic impact tools are to estimate the economic consequences of events, especially major negative ones, and follow the ripples of the events through the regional economy, that is, beyond the local area where the event originates. People see the immediate impacts of a bridge collapse, an accident and derailment. They may not see other impacts, at least not immediately. A serious prolonged rail-related disruption would lead some people to be late to work and/or lose sleep and time at home. Some would drive to work, increasing traffic congestion, and even potentially leading to local gasoline price increases. A prolonged event would add pressure on the capacity of other surface transportation options.
Some people may not be able to get to work, and some freight may not be delivered or be shifted to other modes. If the flow of supplies is disrupted because the same rail network carries freight, then products in commerce will decrease. If the problem lingers, workers will be furloughed and reduce consumption, especially of items that they can defer. Government tax collections would drop because of business losses and consequent reductions in worker earnings. And most important, decision makers could choose to relocate their businesses (see below).

### 2.6.2 Study Area

The study area for the rail security and planning model was the state of New Jersey with a focus on Newark Penn Station, which is the most vital passenger rail asset in the state. The plume model scenarios centered on the Newark Penn Station and areas to the immediate south and west. In 2010, New Jersey had a population of 8.7 million spread over 7,417 square miles, and the highest population density of any U.S. state, more than 1,100 people per square mile. The highest density of people and commercial activity is along the corridor between New York City in the northeast and Philadelphia in the west central part of the state, which closely follows the Northeast Corridor Line.

Given the fact that a large proportion of the passenger traffic that flows along the Northeast Corridor Line passes through New York City, the group chose to build the economic model around New Jersey and New York City, and the eastern and northern suburbs that tie in through Metro North and the Long Island Railroad (see below).

### 2.6.3 Two Models

Econometric, input-output, computable general equilibrium, inoperability input-output models, and Regional Economic Model (REMI) could all produce the regional estimates (Greenberg et al. 2007, Haimes et al. 2005a,b, REMI 1997, Robinson et al. 1999, Rose et al.)
2.6.3.1 Econometric models

Econometric simulation models have a long history and they are relatively easy to understand. Analysts gather data that link historical relationships among gross national product, consumer spending, labor, and other key elements of the economy. For example, if wages and salaries increase and the record over the last 20 years shows that 10% of wages and salaries is spent on consumer products, then we can estimate the impact of a wage and salary increase on consumer spending is 10%. While a model uses a number like 10%, the analyst can deviate from the historical coefficients by changing the coefficient and estimating the results.

Econometric models, as well as the other options, may not contain all the necessary information in the set of equations to forecast all aspects of the economy, especially when that economy spans more than one region. As an example, New York still has a large portion of the US financial industry, yet while this influential region has an impact on the United States as a whole, the larger United States has a major impact on the regional economy. Hence, growth forecasts of the national economy should be factored in the regional analysis. Other critical externally determined elements are federal and state tax rates, monetary policy, and federal and state government investment choices.

Our model links an updated econometric model of the State of New Jersey to an econometric model of the New York City region built for this application. The New York Region is comprised of ten counties in southern New York State: the 5 counties (boroughs) in New York City (the Bronx, Kings (Brooklyn), Manhattan (New York), Queens, and Richmond (Staten Island), the 2 counties on Long Island (Nassau and Suffolk), and 3 counties in the lower
Hudson Valley (Westchester, Rockland, and Putnam). This area is within commuting distance of New Jersey and would be affected if, for some reason, a transportation hub in New Jersey were to suspend operations for a significant time period. The data used in the model is quarterly and extends, for the most part, from 1990 to 2010 for New Jersey and the US and from, for the most part, 2001 to 2010 for New York.

The New York Regional Model includes 78 stochastic equations as well as 29 identities. The equations model the regional economy in terms of employment, prices, output, and labor income by industry, consumer prices, personal income by type (labor income; interest, dividends and rent; transfer payments; social insurance; and residence adjustment), population and labor force, household employment, and the unemployment rate. The industries included in the model are mining, construction, manufacturing, information, transportation and utilities, retail trade, wholesale trade, finance, real estate, professional and business services, education, health services, leisure services, hospitality services, other services, and government.

The data for population, labor force and household employment, and personal income were created as the sums of the county data, while the consumer price index used in the model is the CPI for New York, New Jersey, and Connecticut. The data for employment by industry was created as the sum by industry over the three metropolitan statistical areas in the region (New York City, Nassau-Suffolk, and Westchester-Rockland-Putnam). Data was constructed for the other industry variables in a more complex way.

Gross State Product (GSP) is available for the New York metro region which includes the counties in our New York region as well as the Newark metropolitan statistical area in New Jersey. To use the New York area alone we needed to share the data for the larger region using data that was available for both the larger and smaller areas. We shared real regional GSP (GSPR) by industry down to the metro region (GSP\textsubscript{MSA}) using the ratio of labor income by
industry in the New York region to labor income in the larger region. We define labor income in
an industry as the sum of wages and salaries, other labor income, and proprietors’ income.
Overall, $GSP_R$ rose from 70 percent of real output in the region in 2001 to 72 percent in 2009.

We created deflators for the region by dividing nominal $GSP_{MSA}$ in an industry by real
$GSP_{MSA}$ in an industry. We did not try to create deflators for the smaller region.
In a state model we would create wage rates by industry by dividing wages and salaries in the
state by wage and salary employment in the state. That was not possible for the New York
region as the labor income data available at the county level includes both wages and salaries and
proprietors’ income. Thus in the model we developed used an earnings rate (wages and salaries
plus proprietors’ income plus other labor income divided by industry employment) rather than a
wage rate. This clearly overstates the actual earnings rate by industry but it is as close as we can
come without using unpublished data for the number of proprietors by industry.

The heart of the model is the industry sector—particularly employment. Employment in
an industry is modeled as depending on US employment in the sector, output in the sector, the
earnings rate, and other important factors (for example the mortgage rate in the construction
sector). Output in an industry depends on sector prices (deflators), and some indicator of
demand (for example US output, or regional income or population). The earnings rate in an
industry depends on US wage rates in the sector as well as some indication of labor market
conditions. Finally, sectoral prices depend on earnings rates, US sectoral wholesale prices or
deflators, or the ratio of the regional to the national CPI.

The rest of the model variables are used primarily to influence the industry sector. Thus,
for instance, personal income influences output in retail trade which in turn influences several
other variables, and population influences output in several industries.
The New Jersey model is much more complex, including 210 stochastic equations as well as 58 identities. The sectors included in the model are: employment and gross state product for 40 industries, wage rates and price deflators for major industries, consumer price index (New Jersey), personal income and its components, population, labor force and unemployment, housing permits and construction contracts, energy prices and usage, motor vehicle registrations, and State tax revenues by type of tax, and current and capital expenditures.

The heart of the New Jersey model is a set of equations modeling employment, wages, and prices by industry. In general, employment in an industry depends on demand for that industry’s output, and on the state’s wages and prices relative to the nation’s wages and prices. Demand can be represented by a variety of variables including (but not limited to) New Jersey personal income, population, or US employment in the sector. For example, demand for retail trade employment is represented by New Jersey retail sales. Demand for construction employment is represented by the value of construction contracts. Growth in population is driven by total employment in the state and by state wages and prices relative to national wages and prices.

As part of our interest in energy and transportation, the New Jersey model was extended to include a large number of equations related to the energy sector. The equations in this new model sector are for electric, natural gas, and fuel oil prices and usage for residential, commercial, industrial, and other sectors, as well as for motor fuel and diesel prices and usage.

2.6.3.2 Connecting the two regions

We assume that the two regions are primarily connected through a shared work force for some particular industries as well as shared media, culture, and history. The specific industries where we have tried to link employment are construction, finance, information, manufacturing, wholesale trade, and professional and business services. Generally rising employment in these
industries in one region is related to rising employment in the other industry. Further, rising total workplace employment in New Jersey is related to rising household employment in New York, and household employment in New York is positively related to household employment in New Jersey. There is also a positive and direct link between the residence adjustment in New Jersey and that in New York as well as indirect links in the residence adjustments in the two areas through household employment. Finally, there is a direct link between the Consumer Price Index for NY-NJ-CT with the CPI for New Jersey alone.

Given these connections, major disruptions to New Jersey’s economy should also impact on New York, although probably to a smaller extent. Thus, using this model we should be able to gauge the impact of a disruption in New Jersey and in the larger region as well. The data sources for these models are the US Bureau of Labor Statistics: Consumer price Index, non-agricultural (workplace) employment, labor force and household employment; US Bureau of Economic Analysis: Income and its components, gross state product; US Department of the Census: Population; and IHS Global Insight: US history and forecast. To reiterate, the major limitation of econometric models is the historical relationships may produce misleading results if the economy is rapidly changing.

2.6.3.3 Computable General Equilibrium (CGE) models

CGE models adjust to a changing economy by assuming that the economy mirrors the most efficient decisions by producers and consumers in response to markets and prices subject to capital, resource, and labor constraints (Conrad 1997, Rose, Liao 2005, Rose, Lim 2002, Rose 2004). We built and tested a CGE model for New Jersey. Notably, during the course of the literature search, no article was uncovered that considered a disaster that focused on a single, specific segment of a commuter rail network and its subsequent effect on the local economy. Still, the existing literature does provide some guidance. Sohn et al.’s (2003) focus on the
relationship between final demand and transportation costs is quite instructive, for example. In the case of a discontinued transit segment, it suggests closer examination of fuel consumption (the change in final demand) due to a change in commute mode. But we could not find a solid statistical relationship in the historical data between increase in demand and gasoline prices, a result that will not shock readers who think that other factors drive gasoline prices.

The second impact we were concerned about that could be elucidated by the CGE model was the costs of added commuting time. The econometric model equations allow us to estimate the costs to the economy and a turning point at which the loss of time becomes a serious competitive disadvantage. That is, do commuting workers decide to keep pre-disaster work hours and let the added commute time eat into time that would otherwise be committed to leisure, or do they instead opt to reduce his/her work hours at least somewhat and thereby reduce her/his workplace productivity?

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. Munnell (1992), by comparing output elasticities of public capital across several studies, found that as the level of aggregation narrows (from nation to state to metropolis), the [positive] productivity impact of public infrastructure becomes smaller—even as public infrastructure continues to demonstrate a significant and positive effect on productivity. Jara-Díaz (1986) described the relationship between individuals’ benefits and transportation processes, showing that transportation surplus (i.e. lack of congestion) had positive economic effects. Fernald (1999) examined the relationship between road network capacity and productivity performance, looking at trends between 1953 and 1989, and addressing the endogenous and spurious relationships between transportation and productivity. He found that an increase in productivity nationwide resulted from the “technology shock” of government-provided roads. Further,
Fernald observed that only after the completion of the highway system in 1973 did congestion become empirically important to productivity. Congestion has negative effects on productivity—with those industries with greater vehicle intensities experiencing larger productivity slowdowns due to congestion.

Boarnet (1998) explored the locational effects of changes in a road system, finding that public capital investment in one district (city, county, state, etc.) attracted additional resources which seek to benefit from the increased productive capacity, which leads to negative spillovers in adjacent or comparable districts. Increased output and productivity was observed in districts with increased capital investment, thereby drawing a connection between the productive capacity of a transportation system and output. Baird (2005) discussed the productivity of transportation infrastructure by looking at contrasting theories on spillover effects: positive spillover effects theory posits that a transportation network will be more productive if it is part of larger transportation network, and negative spillover effects theory posits that investments in public infrastructure in one jurisdiction result in losses of productivity in neighboring jurisdictions—notably both theories observe a clear link between productivity and transport systems. With the movement of goods and people as the primary factor in defining mobility, impediments to this movement due to a rail system failure compromise productivity.

2.6.2.4 Congestion Effects: A Question of Commuter Productivity

As mentioned previously, any required diversions from rail transit would undoubtedly increase usage of New Jersey’s road infrastructure, causing congestion on freeways, motorways, arterials, and surface streets between the homes and workplaces of former rail commuters. We would expect that all commuters’ travel times, not just those of rail commuters, would rise due to the increased demand on the roadway network. This is because traffic slows and accident frequencies rise as roads exceed their capacities. In the short-run, this increase in travel time
would leave commuters three possible options: work from home, reduce their leisure time, or reduce work hours. In the longer run, however, they can change jobs.

While flex-place is a policy in which many firms participate when emergencies arise, the policy is generally temporary. Typically about half the day is considered core time when everyone is expected to be present. But the remainder of the time is negotiable. An exception can be the set of workers who engage in project-based work activities that are not heavily team-oriented. For the most part, however, heightened congestion is likely to have a negative impact on productivity; either individuals are likely to become increasingly fatigued at their workplace due to declines in leisure activities or they wind up spending less time in the workplace, essentially counting time in transit as work hours. Companies could adjust work hours to accommodate the situation in ways that would minimize travel time.

After much experimentation, we have chosen to feature the econometric model results because the model itself is easier to understand and the temporal distribution of the results is a major advantage. We will also continue working on the CGE model and test the comparable results against those produced by the econometric model.

2.6.2.5 Simple CGE Model

To date we have built a small 11-sector CGE model for New Jersey and tested it by modifying labor-capital and trade elasticities, and then with several rail events. However, given the limited number of sectors, we regard the model as too crude for purposes of this analysis (Lahr, Guerra, et al. 2012). The model is be upgraded by adding more equations and a New York area similar to the econometric one we have built and have used for the study. That model will then be used to compare the results produced by the econometric model we have used here.

2.7 Results
2.7.1. Initial Results

This section summarizes the first run we made with the rail security and planning model, which tests the system with a one hour delay, once a week and then the baseline (pre-major event) economic simulation results.

2.7.1.1 Preliminary Results: Rail Line Scenario Baseline Case

Table 6 provides daily results for the simplest high frequency, low consequence event, which is a once a week, one hour delay that starts at 7:30 a.m. It is assumed that the services that pass through the Newark Penn Station are impacted by the incidents. We ran the model 25 times and averaged the results. The model estimates how many trains are disrupted, cancelled, the average number of people held on disrupted trains, and the average number of passengers waiting at stations.

More specifically, Table 6 shows how many passenger trains are disrupted and cancelled, and how many people are impacted by a once a week one hour delay. The impacts of a 7:30 a.m. event are concentrated on the eastbound trains headed toward New York City and primarily in New Jersey Transit trains. Passengers along the NEC corridor are impacted at every station, especially Newark Penn Station, Linden, Elizabeth, and Secaucus. The event would logically

<table>
<thead>
<tr>
<th>Performance Measures</th>
<th>One hour in a week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average number of trains disrupted</td>
<td>25</td>
</tr>
<tr>
<td>Average number of train cancellations</td>
<td>100</td>
</tr>
<tr>
<td>Average number of passengers held on disrupted trains*</td>
<td>9142</td>
</tr>
<tr>
<td>Average number of impacted passengers at stations</td>
<td>44702</td>
</tr>
</tbody>
</table>

*Table notes: disrupted trains represent the trains stopped in actual service; data for all stations are not presented.
cascade to impact passengers at Harrison (PATH) and Broad Street (Newark Light Rail) which likely would have their schedules disrupted and face crowding by the event as managers and passengers try to change their.

### 2.7.1.2 Results: Economic Simulation Baseline

Table 7 shows the baseline econometric simulations. We show the actual data for 2001, 2005 and 2010. Then we provide annual results through 2020. To reduce the amount of data we present the historical data, as well as the simulations for 2012, 2016 and 2020. The reader will see that the New York part of our region suffered less during the recession and is expected to continue to perform slightly better than New Jersey. For purposes of this research, the key is the impact of the events on this economic performance. For some applications it is appropriate to review the simulation results of all of these indicators. However, for this we have concentrated on two of the indicators: nonagricultural employment, and real gross domestic product. In other words all of the comparisons that follow will compare these forecasted results and the post event results.

Table 7. Baseline economic simulation results

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New Jersey</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3996.9</td>
<td>4038.9</td>
<td>3854.1</td>
<td>3923.7</td>
<td>4088.5</td>
<td>4181.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Unemployment rate, %</td>
<td>4.3</td>
<td>4.5</td>
<td>9.4</td>
<td>7.2</td>
<td>5.0</td>
<td>5.0</td>
<td>-6.2</td>
</tr>
<tr>
<td>Population (000)</td>
<td>8451.4</td>
<td>8601.0</td>
<td>8791.9</td>
<td>8880.5</td>
<td>9049.7</td>
<td>9192.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Personal income ($bill)</td>
<td>336.6</td>
<td>379.7</td>
<td>450.4</td>
<td>482.0</td>
<td>565.3</td>
<td>672.8</td>
<td>4.1</td>
</tr>
<tr>
<td>Wage rate ($000)</td>
<td>44.3</td>
<td>49.5</td>
<td>56.6</td>
<td>59.5</td>
<td>65.7</td>
<td>73.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Performance Measures</td>
<td>One hour in a week</td>
<td>Twice a week for one hour, (people stay on trains)</td>
<td>Twice a week for 1 hour, 40% shift to auto and 20% work from home</td>
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<tr>
<td>----------------------------------------------------------</td>
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<td>--------------------------------------------------</td>
<td>---------------------------------------------------------------</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Average number of trains disrupted</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of train cancelled</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of passengers held on disrupted trains</td>
<td>9142</td>
<td>18284</td>
<td>7314</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of impacted passengers at stations</td>
<td>44702</td>
<td>89404</td>
<td>35762</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of passengers shifted to auto and bus</td>
<td>--</td>
<td>--</td>
<td>43075</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of passengers work at home</td>
<td>--</td>
<td>--</td>
<td>21538</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8 shows what happens to the passengers if the event occurs twice a week, and 40% shift to automobile, 20% work from home, and the other 40% stay on the train. Over 100,000 people are impacted each time.

Table 9 compares the baseline results for employment and regional gross domestic product for these events. Before examining the results, it is imperative that we review several critical assumptions built into the economic model results. The first assumption is that the outputs from the rail simulations in Table 8 are incorporated into the economic model. That is, the events occur at 7:30 a.m., which means that 60% of the passengers at that time are headed east toward New York. This means that we are delaying many more people heading into New York City than we would be if we were starting the simulation at another hour. A second key assumption is that for the resilience version 40% of the riders will ride in automobiles or in buses and 20% will telecommute. Given that the state of New Jersey has the highest automobile traffic density in the United States, the 40% diverted from the trains will cause congestion as described above. Furthermore, these congestion effects are in both directions, hence the negative impacts of the "resilient" solution should be more negative to the economy than the non-resilient option which keeps people on the trains, and there is no delay later in the day. In other words, those who stay on the train face the delays only in one direction. Those who drive face it in both directions, and everyone that travels on those highways is affected. The 20% who telecommute to avoid the delays face no delays. Suffice it to say that these proportions of 40%, 40%, and 20% are educated guesses based on conversations; it would be useful to have a survey to support these kinds of assumptions.
Table 9. Comparison of baseline economic results and impacted results: twice a week, one hour delay  

(Baseline provided in each table for reader convenience)

<table>
<thead>
<tr>
<th>Region &amp; metric</th>
<th>2010</th>
<th>2012</th>
<th>2020</th>
<th>difference between baseline and impacted, 2010-2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BASELINE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Jersey</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3854.1</td>
<td>3923.7</td>
<td>4181.3</td>
<td>---</td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$bill)</td>
<td>438.7</td>
<td>459.6</td>
<td>560.3</td>
<td>---</td>
</tr>
<tr>
<td>New York region</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>5169.5</td>
<td>5265.7</td>
<td>5951.7</td>
<td>---</td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$bill)</td>
<td>778.9</td>
<td>816.8</td>
<td>942.7</td>
<td>---</td>
</tr>
<tr>
<td><strong>IMPACTED, NO RESILIENCE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Jersey</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3854.1</td>
<td>3923.7</td>
<td>4179.5</td>
<td>-1.8</td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$bill)</td>
<td>438.7</td>
<td>459.6</td>
<td>560.2</td>
<td>-0.1</td>
</tr>
<tr>
<td>New York</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>5169.5</td>
<td>5265.0</td>
<td>5950.5</td>
<td>-1.2</td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$bill)</td>
<td>778.9</td>
<td>816.7</td>
<td>942.4</td>
<td>-0.3</td>
</tr>
<tr>
<td><strong>IMPACTED, RESILIENCE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Jersey</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3854.1</td>
<td>3923.3</td>
<td>4179.0</td>
<td>-2.3</td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$bill)</td>
<td>438.7</td>
<td>459.6</td>
<td>560.2</td>
<td>-0.1</td>
</tr>
<tr>
<td>New York</td>
<td></td>
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</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>5169.5</td>
<td>5265.0</td>
<td>5950.3</td>
<td>-1.4</td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$bill)</td>
<td>778.9</td>
<td>816.7</td>
<td>942.3</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

As expected, there are very small negative impacts. For example, the employment impact for New Jersey is -1800 for the nonresilient solution and -2300 for the resilient one. In reality this event is sufficiently small to escape detection, with the exception of those directly involved.
2.8.2 Scenario: Loss of Major Bridge for a year

A major event would be loss of one of the main bridges between Newark Penn Station and New York City. Adding the 24 million people who use PATH (which uses a different bridge) every year to the over 70 million that ride on NJT, 9 million on Amtrak, and 4.5 million that use Newark light rail means that over 100 million passenger rides that pass through Newark Penn Station would be disrupted by loss of a major asset that could not be replaced for a year. The Dock Bridge, lying just north of Newark Penn Station and the Portal Bridge over the Hackensack River not far from the Secaucus rail are key assets.

The region and US as a whole could not afford to lose these kinds of major assets even if there were no injuries or deaths. To estimate the number of people inconvenienced, we first assume that each person is making a round trip (not always the case), which reduces the estimate to 55 million passengers. Many of these NJT, Light rail and PATH riders make the trip 5 days a week, but not all. Using a multiplier of 4.8 for those that do not go twice a week reduces the number of people to a little over 10 million. Even if all of the people on PATH and Light Rail (less likely for Light Rail) at Newark Penn Station also rode NJT, there are more than 7 million riders involved. The 9.4 million Amtrak trips involve more single trips a week, and likely 2-3 million different riders would feel the impact of a major year-long outage.

We ran four economic simulations to test plausible options. Of these, the last, we think, is most likely. Our first assumption is that there will be efforts to provide resilience to the system. In other words, a no resilience scenario is inappropriate. It is simply inconceivable to us that Amtrak and New Jersey Transit would not respond. Hence, the first set of analyses assume that the railroads and the local governments provide a shuttle service from the Newark Penn Station to the PATH rail line in Harrison, New Jersey, to Broad Street station in Newark, or to Secaucus that goes around the Dock Street bridge failure. This plausible solution, however, is not without
complications. The most obvious is the need to provide carefully supervised boarding and
deboarding from Newark Penn Station to buses (assuming their availability) that would travel to
Harrison, and traffic control. Indeed, this is not a long distance. However, for riders of this
system and other rail systems know, there will be substantial crowding, frustrated people,
equipment limitations, annoying weather conditions and other circumstances that will slow down
the transfer of the riders. It is reasonable to expect that the average trip would be delayed one
hour in both directions, that is, a total of two hours a day. A much better result is that the delay
would only be one half hour in each direction--or a total delay of one hour. These were the first
two simulations of this low probability and high consequence bridge failure. A key missing piece
of the scenario is that no one who runs a business or works in one decides to leave the region as a
result of this disruption.

A more probable option is that only 40% are willing to accept a one hour per day delay,
another 40% drive in their autos or take buses, and the remaining 20% telecommute (helicopters
are not considered in these simulations). Again, these simulations assume that no one who
operates or works in a business leaves over this event. The issue is the impact on road
congestion, which adds to the commute time and/or cuts into leisure time for those who drive.

The fourth and last result is by far the most painful and likely the most realistic
behavioral response. It is the first option (two hour a day delay) with one-third of the job losses
associated with the event not replaced in the region and the economic impact of those loses begin
to accumulate. That is, businesses in the area permanently relocate their activity outside of the
study area. No one knows how many jobs would permanently be lost. However, following the
events on 9/11 at the World Trade Center over 100,000 jobs were lost. The Fiscal Policy Institute
(2001) reported that most of these had relocated elsewhere in New York City, but that 22,000
relocated outside New York City, principally in New Jersey. Notably, the vast majority of the
jobs lost had been held by people who held less skilled positions: janitors and cleaners, maids and housekeeping workers, and apparel workers were the hardest hit.

Before reviewing the simulation results, context is in order. This is a massive economic region of over 21 million people, 9 million jobs, and a real gross domestic product of $1.3 trillion in 2005 dollars. Because this region is so massive and multi-faceted, it has enormous capacity to adjust to negative events, whether they are natural hazards, human-initiated problems, financial miscalculations, and others. This region is the polar opposite of some others we have studied that have been dependent on a single major employer. For example, we modeled the economic impact of reducing investments in environmental management cleanup programs in some the rural regions where nuclear weapons were developed, tested, and built and where nuclear waste is stored. In these small economic regions, a relatively small reduction in a single government program causes a local recession (Greenberg, Miller, Frisch, Lewis 2003). A region like NJ-NYMR has the ability to absorb major events, especially over time. One of the strengths of econometric models is that they play out the event while at the same time continuing regional economic growth. Internally, as in this case, an initial economic blow is delivered but unless it is accompanied by decisions that permanently remove economic activity from the region, the region rebounds. In this set of simulations, we caused the event to occur in the year 2012 and the big economic hit occurs in 2013. Gradually, the national and regional economies grow, and the impact is absorbed, unless there is a major permanent loss of jobs caused by decisions that the region is no longer viable. Readers will observe this in these results.

Table 10. Comparison of baseline economic results and impacted results: Full year loss of major bridge asset

<table>
<thead>
<tr>
<th>Region &amp; metric</th>
<th>2010</th>
<th>2012</th>
<th>2020</th>
<th>difference between baseline and impacted,</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010-2020</td>
<td></td>
<td></td>
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<tr>
<td><strong>BASELINE</strong></td>
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<tr>
<td><strong>New Jersey</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3854.1  3923.7  4181.3</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$Bill)</td>
<td>438.7  459.6  560.3</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>New York region</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>5169.5  5265.7  5951.7</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$Bill)</td>
<td>778.9  816.8  942.7</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IMPACTED, LIMITED RESILIENCE, 2 HOUR DELAY PER DAY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>New Jersey</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3854.1  3899.0  4175.6</td>
<td>-5.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$Bill)</td>
<td>438.7  459.2  558.9</td>
<td>-1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>New York</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>5169.5  5257.0  5947.7</td>
<td>-4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$Bill)</td>
<td>778.9  815.8  941.7</td>
<td>-1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IMPACTED, RESILIENCE, 1 HOUR DELAY PER DAY</strong></td>
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<tr>
<td><strong>New Jersey</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3854.1  3910.7  4179.4</td>
<td>-1.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$Bill)</td>
<td>438.7  459.2  559.1</td>
<td>-1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>New York</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>5169.5  5261.3  5948.5</td>
<td>-3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$Bill)</td>
<td>778.9  816.2  941.9</td>
<td>-0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IMPACTED, RESILIENCE, 1 HOUR DELAY (40%), SHIFT TO AUTO &amp; BUS (40%), AND SHIFT TO TELECOMMUTE (20%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>New Jersey</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3854.1  3903.7  4177.1</td>
<td>-6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$Bill)</td>
<td>438.7  459.2  559.0</td>
<td>-1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>New York</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>5169.5  5258.7  5948.0</td>
<td>-3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$Bill)</td>
<td>778.9  816.0  941.8</td>
<td>-0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IMPACTED, 2 HOUR DELAY AND NO REPLACEMENT OF JOB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>2013</td>
<td>2014</td>
<td>Difference</td>
</tr>
<tr>
<td>---------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>New Jersey</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3854.1</td>
<td>3899.0</td>
<td>4151.7</td>
<td>-29.6</td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$bill)</td>
<td>438.7</td>
<td>459.2</td>
<td>558.6</td>
<td>-1.7</td>
</tr>
<tr>
<td><strong>New York</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>5169.5</td>
<td>5257.0</td>
<td>5940.6</td>
<td>-11.1</td>
</tr>
<tr>
<td>Real Gross domestic product (2005=100,$bill)</td>
<td>778.9</td>
<td>815.8</td>
<td>940.8</td>
<td>-1.9</td>
</tr>
</tbody>
</table>

With this context, the 2-hour delay with resilience shows job and GDP loses by 2013. By the year 2020, the economy has come back. But about 10,000 jobs are lost by 2020. New Jersey, where the event occurs is disproportionately impacted. Assuming decision-makers feel that the problem would be fixed and commuters could tolerate the loss of time for a year, the impact in a region of this size is relatively modest. It becomes even more modest if the time loss were cut from two hours to one hour. The job loss drops to 5,100 and the GDP loss is reduced.

Resilience is viewed as a positive attribute. Our 40%-40%-20% resilient solution produces some predictable results. If 20% of the loss can be replaced by telecommuting, that results in no job loss for one-fifth of the commuters, which is perhaps an optimistic assumption. The one hour loss of time because the rail system is able to transfer people to another rail option is a constructive response and as just discussed does cut the negative impact. The third “resilient” alternative is a problem, which is people get into their cars and a few take buses to work. The congestion effects impact is felt by everyone else on those already busy paths. Adding thousands more to the bridges and tunnels that link New York and New Jersey is a problem. The job loss, even taking into account, the telecommuting and reducing the delay on rail to one hour, is higher than the two hour delay scenario because so many people are delayed.

The last scenario is the one we believe is the most likely for an event that lasted for a year without an clear ending date. Some decision-makers would figure out ways to provide temporary housing for their employees and shuttles around the problem. But others would not have the
patience or the budget. We assume for purposes of this simulation that among those who are losing productivity, 1/3 would choose to leave the area. The job loss estimate compared to the baseline is 41,000 of which three fourths are in New Jersey.

A total of 41,000 jobs in a region with 10 million does not seem like much, only 0.4%, but in an era when the unemployment rates is over 9% and we expect it to be 5% by 2020, which may be an optimistic baseline forecast, these jobs would be noticed. But is this a major loss? For context, New Jersey lost 114,000 jobs from December 2007 through December 2008, which makes this loss seem small measured over almost a decade. A major difference was that the losses during 2007-2008 were part of a series of international events that have not been fully addressed and required major actions on the part of the US government, the financial and housing industries and other nations. Arguably, the great recession that began in 2008 could have been prevented or mitigated, but only with a complex policy consensus by various parties. In contrast, our event, a single bridge failure is virtually preventable by the owners and operators of the bridge in question. Furthermore, we deliberately picked one of the simplest problems to overcome by shuttling people a short distance. There are other bridge and road failures in this region that would be hard to work around. If this were a terrorist attack, we could anticipate attempts to damage multiple links in the rail system and highways system, which would be extraordinarily difficult to overcome without a substantial investment. In short, in contrast to other rail structure events we could have tested, this one is relatively modest, albeit painful.

Again, however, we reiterate that economic simulation models depend upon assumptions, and in this case these results are assuming the U.S. economy and within it the NJ-NYMR will be growing at a steady rate. For example, the NJ unemployment rate is assumed to be 5% by 2016.

2.8.3 Scenario: Chlorine Leak Event
Before presenting the results of the chlorine tank car release scenario, it is imperative that the reader understand that this is an illustration of what the research team did. To reiterate, we modeled four scenarios. Space does not permit a full presentation of what was done, and several of the authors will prepare a paper summarizing their work.

Here, we summarize one of the four scenarios, and it was deliberately chosen because it illustrates how the rail corridor and plume models can be used together. The chlorine leak we illustrate starts near a chlorine manufacturing facility and the plume follows the train carrying the chlorine south and west. It covers Newark Penn Station, the PATH station in Harrison, and then part of the New Jersey Turnpike and interstate-78, touching the edge of Newark Liberty International Airport and approaching the city of Elizabeth 90 minutes later. We recognize that the scenario is very low probability, given leak detection systems, however it is plausible. It most certainly is not the worst chlorine incident that we could have modeled. Table 11 describes the range of impacts from chemical, radiological, and biological events.

A chlorine event would clearly have public health impacts. The one we simulated could injure or kill the rail crew, hurt and kill people especially at the Newark Penn Station and the PATH station, spread out and impact other workers along the route, and injure people outdoors and perhaps some who live or work near the rail line.

Economic damage would be associated with deaths and injuries. Some might die, and others might be severely injured. The plume would temporarily disrupt rail service and the surrounding communities. Even after the event concluded and evacuees return to their homes and jobs, there likely would be some level of economic stigma for at least a short time. A 90-minute event that could precipitate an evacuation for several days is unlikely to disrupt social capital, so this is not a focus. Indeed, it might build social capital in the impacted communities.

Table 11. Health, environmental, economic, and social impacts of potential major chemical event
<table>
<thead>
<tr>
<th>Public Health</th>
<th>Economic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate death</td>
<td>Severe damage of structures</td>
</tr>
<tr>
<td>Life-shortening exposures</td>
<td>Severe devaluation of property</td>
</tr>
<tr>
<td>Acute illness</td>
<td>Reduced appreciation of property values</td>
</tr>
<tr>
<td>Severe disability</td>
<td>Cost of cleanup and other maintenance activities</td>
</tr>
<tr>
<td>Chronic illness</td>
<td></td>
</tr>
<tr>
<td>Minor and temporary illness</td>
<td></td>
</tr>
<tr>
<td>Emotional illness and stress</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disruption of existing communities</td>
</tr>
<tr>
<td>Distributional effects falling primarily on disadvantaged people, and on specific types of communities</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ecological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecosystem elimination</td>
</tr>
<tr>
<td>Elimination of species</td>
</tr>
<tr>
<td>Reduction of diversity</td>
</tr>
<tr>
<td>Reduction of species</td>
</tr>
<tr>
<td>Reduction of biomass</td>
</tr>
<tr>
<td>Loss of water source</td>
</tr>
</tbody>
</table>

*Adapted from Greenberg and Anderson 1984.

In order to portray some of the health and physical damage, we mapped all 194 frames that showed the distribution of the plume on top of the census areas below. The census data is from the year 2010. We gathered resident population, population that is African American and Latino, persons employed in the units, housing units and their value, individuals in trains and on train platforms covered by the plume. We also determined the number of schools and hospitals in the area.

Several important caveats are in order. The plume is a creation of the model, as are the concentrations in the plume. As noted above, the concentrations are based on emptying a single tank at 10 kilograms per second. The numbers must not be taken at face value. Location in the red zone is not a death sentence. The risk is higher at the beginning of the event and as the train and plume head southwest, the concentration of chlorine in red zone decreases as does the
likelihood of a chlorine-caused fatality. Being indoors with closed windows will help, and immediately alerting people not to run outside would reduce the risk.

For purposes of the analysis we focused on those in the red zone. We counted the number of people who live in the red zone and everyone who was as Newark Penn Station, the Harrison PATH station, Grove Street, Broad Street. This number is 13,000 at the train stations as the event evolves and another 36,000 in the surrounding residential areas. Notably, 75% of the residents are African-American and Latino compared 31% in the State of New Jersey as a whole.

In order to understand the health impacts of the event, we spoke with three public health colleagues at our universities (two physicians and an epidemiologist); all have experience with these chemical events. We also spoke with researchers from the US Army Corps of Engineers and US Department of Homeland Security who have experience with chlorine and have worked on chlorine risk assessments.

Based on these discussions and our own research, we constructed two scenarios. The first, called less impact, assumes that 1%, or 500 people would die as a result of the exposure and another 10% would be injured (5000). Of those injured, half would return to work in three days (2500), 25% in two weeks (1250), and 25% would suffer permanent injury and not be able to return to work (1250). The relatively low number of people who die and are injured is based on the assumption that the vast majority of people are inside buildings and cars. The second scenario, more impact version, assumes that 5% would die (2500), and that 20% would be injured (10,000). Of those injured 25% would return to work in three days (2500), another 50% would return to work in two weeks (5000), and 25% would be permanently disabled (2500). In reality, both scenarios probably underestimate what would happen. A major issue in this scenario is that a large number of people would be outdoors on platforms and while people often evacuate in an orderly fashion, the nature of this event is such that orderly evacuation will be a challenge.
because of the limited number of exits from the platforms and the likelihood that some individuals will panic causing the entrances to block and further injuries. Furthermore, access to individuals who have been injured in the street will be difficult, but will be much more difficult for those at the train station. These are crowded (this event assumes that we begin during rush hour) and it would be extremely difficult for rescue personnel to gain access to all of the people that have been exposed and will have a sufficient amount of equipment to prevent the injuries, even if they do have access. Also, while we would expect people to stay inside, many might not. In short, our two scenarios may understate the consequences. We believe from the literature and those individuals we spoke with that this is the first attempt at a risk analysis where the chemical event for chlorine is moving rather than emanating from a single fixed source.

St. James Hospital is with 0.6 miles of Newark Penn Station, and there are 15 schools. In order to avoid double-counting children and school employees, we have not counted any of them in the red zone calculations. Nor have we included the people who do not live in the area who would be in buses or automobiles passing through. We have not included employees, and assumed that there are no recreational events at the Prudential Arena in Newark, the soccer stadium in Harrison, and the PAC Theater that lies a short distance from the Newark Penn Station. By starting the event at 7:30 a.m. and trying to avoid any double-counting, the 50,000 estimated to be in the red zone is likely an underestimate.

Table 12. Demographic Characteristics of Most Exposed People (Red Zone)

<table>
<thead>
<tr>
<th>Group &amp; attributes</th>
<th>Red (high) exposure zone (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total resident population, 2010</td>
<td>36,079</td>
</tr>
<tr>
<td>African-American resident population, 2010</td>
<td>13,991 (38.8%)</td>
</tr>
<tr>
<td>Hispanic resident population, 2010</td>
<td>13,602 (37.7%)</td>
</tr>
<tr>
<td>Commuters on trains and at stations, during first 30 minutes of the event, Newark Penn Station, PATH, Broad Street, Grove Street, Harrison (estimated by</td>
<td>13,123</td>
</tr>
</tbody>
</table>
**Table 13. Data to Estimate Direct, Indirect and Induced Economic Consequences of Chlorine Event**

<p>| | |</p>
<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospitals</td>
<td>0</td>
</tr>
<tr>
<td>Schools</td>
<td>15</td>
</tr>
<tr>
<td>Total included in red zone exposed calculations</td>
<td>49,202</td>
</tr>
</tbody>
</table>

*Assumption is that security personnel stop access to the stations at 30 minutes, so that exposure of rail passengers does not continue for 90 minutes.

Being in the orange and yellow zones implies less exposure, it does not mean that some exposed individuals would not experience health effects, ranging from overstimulation of their cardiovascular system to mild irritation. Furthermore, there might be indirect health impacts caused by auto accidents, exhaustion on the part of medical teams and other health-related consequences. Consequently, while we estimate the number of people in each of the three zones, this must not be interpreted as a direct measure of mortality or morbidity. There simply are too many confounding factors, and we have tried to be conservative and not grossly overestimate the risk.

We assume that even under the worst conditions that require evacuation, people will be able to return to their homes in two days. The question is will there be an economic stigma? And more important, how much and for how long? While our focus has been on the red zone, we present some aggregate data for the orange and yellow zones.

Even assuming that no one from the orange or yellow zones needed hospitalization, the challenge to risk managers is formidable. At a minimum some people would evacuate, which would lead to injuries and fatalities. Table 13 shows the large number of people, dwelling units, daytime population in the larger zones that include the orange and yellow plumes. This does not include the value of industrial facilities, infrastructure, and other invested non-residential capital assets.
<table>
<thead>
<tr>
<th>Group &amp; attributes</th>
<th>Red (high) exposure zone</th>
<th>Orange, yellow, and rest of municipality in yellow zone (not including red zone)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total resident population, 2010</td>
<td>36,079</td>
<td>1,014,171</td>
</tr>
<tr>
<td>African-American resident population, 2010</td>
<td>13,991 (38.8%)</td>
<td>374,546 (36.9%)</td>
</tr>
<tr>
<td>Hispanic resident population, 2010</td>
<td>13,602 (37.7%)</td>
<td>269,819 (26.6%)</td>
</tr>
<tr>
<td>Number of owner occupied housing units, 2010</td>
<td>2,300</td>
<td>169,056</td>
</tr>
<tr>
<td>Total value of owner occupied housing $2010</td>
<td>$728 million</td>
<td>$75.180 billion</td>
</tr>
<tr>
<td>Number of rental units, 2010</td>
<td>10,973</td>
<td>171,991</td>
</tr>
<tr>
<td>Number of schools</td>
<td>15</td>
<td>534</td>
</tr>
<tr>
<td>Number of hospitals</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Daytime population, 2010</td>
<td>NA</td>
<td>1,153,956</td>
</tr>
</tbody>
</table>

*Not available

At this time, we do not have sufficiently detailed data to estimate the economic consequences of this event on this large region. It would be imperative that we disentangle the daytime population who work in the area from the resident population to avoid double counting or even triple counting in the case of those who took the light rail, deboarded at the train station, and worked in a local building. We would want to know how many people were employed in the local hospitals, the colleges and universities, and schools in the area. It is imperative that we hear from officials and measure their capacity to triage people. And we need feedback from officials to estimate the costs of preventing the event and adding resilience to the system.

Modeling the consequences outside of the red zone necessitates considerably more data and interaction with officials than has been possible to date. We would also need to add equations in the model that allow us to measure feedbacks between these events and property values, sales, loss of taxes and other relationships. All of this is feasible, but not available at this time. To simulate further for the orange and yellow zones was too speculative without better information.
We made an initial effort to estimate the economic costs associated with the injuries and deaths reported above (Table 14). We assumed that the event would occur in 2012 and the unemployment rate would not change because the deceased workers would no longer be in the labor force. With those optimistic assumptions in place the results are modest. The lower impact scenario shows almost no impact, and the more severe one shows a modest impact in New Jersey that would not be noticed. However, if we increased the number of permanently injured, increased the unemployment rate, added an impact associated with the loss of key employees who were not so easily replaced, and most important added a stigma effect that caused relocation out of the area, the impact would be more substantial, even in a region as large as New Jersey and the NYMR. For example, Prager et al (2011) studied the impact of the July 2005 London underground subway bombings. Estimated passenger journeys decreased by an average of 8.3% for the four months following the terrorist attacks. Passenger trips returned to predicted levels, but the authors suggest that there may have been a smaller effect for nine more months, that is, for over a year. The London events were caused by a terrorist attacks and our simulated case was not. But it could have been, and created fear and a stigma effect. Indeed, it certainly would be plausible to create a combination of terrorist events involving chemical plume releases, bridge and station attacks that would leave the region with a serious problem. As noted above, we deliberately have chosen not to do that.

Table 14. Economic impact of chlorine leak event on regional economy, only based on 50,000 exposed in the red zone

<table>
<thead>
<tr>
<th>Region &amp; metric</th>
<th>2010</th>
<th>2012</th>
<th>2020</th>
<th>difference between baseline and impacted, 2010-2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASELINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Jersey</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2022</td>
<td>2023</td>
<td>2024</td>
<td>Change</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
<td>--------</td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3854.1</td>
<td>3923.7</td>
<td>4181.3</td>
<td>---</td>
</tr>
<tr>
<td>Real Gross domestic product</td>
<td>438.7</td>
<td>459.6</td>
<td>560.3</td>
<td>---</td>
</tr>
<tr>
<td>(2005=100,$bill)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York region</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>5169.5</td>
<td>5265.7</td>
<td>5951.7</td>
<td>---</td>
</tr>
<tr>
<td>Real Gross domestic product</td>
<td>778.9</td>
<td>816.8</td>
<td>942.7</td>
<td>---</td>
</tr>
<tr>
<td>(2005=100,$bill)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOWER IMPACT SCENARIO,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(500 deaths, 5000 injured (2500 lose 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>days, 1250 lose 2 weeks, 25% do not</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>return to work)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Jersey</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Non-agricultural employment (000)</td>
<td>3854.1</td>
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<td>4179.9</td>
<td>-1.4</td>
</tr>
<tr>
<td>Real Gross domestic product</td>
<td>438.7</td>
<td>459.6</td>
<td>942.7</td>
<td>-0.0</td>
</tr>
<tr>
<td>(2005=100,$bill)</td>
<td></td>
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<tr>
<td>MORE SEVERE IMPACTS (2500 deaths,</td>
<td></td>
<td></td>
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<tr>
<td>10,000 injured (2500 back in 3 days,</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5000 in 2 weeks, and 2500 don’t</td>
<td></td>
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<tr>
<td>return to work)</td>
<td></td>
<td></td>
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<tr>
<td>New Jersey</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-agricultural employment (000)</td>
<td>3854.1</td>
<td>3923.7</td>
<td>4179.9</td>
<td>-1.4</td>
</tr>
<tr>
<td>Real Gross domestic product</td>
<td>438.7</td>
<td>459.6</td>
<td>942.7</td>
<td>-0.0</td>
</tr>
<tr>
<td>(2005=100,$bill)</td>
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3. **Concluding Chapter**

3.1 **Summary**

We built three simulation models that allow us to replicate the passenger operations of a 60 mile segment of the Northeast Rail Corridor (NEC) between Trenton, New Jersey and New York, Penn Station. We also built a plume model that allows analysts to disperse contaminants over a large geographical region, adjusting for wind direction, terrain, and other variables. Alternative scenarios were simulated, and the report illustrates them with a simulation that
follows the rail corridor south and west exposing a large number of rail passengers and others to concentrations of chlorine. We built to two different economic simulation models. Our econometric model allows time series estimates of routine high probability low consequence events, as well as low probability extremely high consequence ones associated with a bridge failure for one year and a chlorine exposure event. The results are not to be taken at face value, yet they clearly illustrate major vulnerabilities along the NEC. Furthermore, having tested various kinds of resilience in the system, we illustrate that there clearly is a need to consider a range of preventive steps as well as resilience options, some of which may be problematic from the economic perspective.

3.2 Conclusions

We are certain that the combination of the models represent a valuable set of tools that will allow transportation planners to assess a variety of events, likelihoods, consequences, and mitigations. The capacity to test numerous scenarios is invaluable. Every model has limitations and we briefly highlight them. The rail simulation model validations showed remarkable ability to reproduce rail operations. The major limitation is the need to make sure that the data are current. A second major limitation is that while ARENA is a standard industrial systems model, these simulations cannot be done by a novice. The air pollution model we built used a widely applied simulation method, yet its application to a moving freight train is atypical. Further, there are an endless number of chemicals and other agents, numerous wind directions and times of days, and consequently the model is only as good as its users and analysts are in defining the problem with realistic boundary conditions. In order to be an effective tool for risk analysis, the final user of the results has to play an important role in picking the events. In this report, we deliberately picked a relatively common substance and an equally common way of shipping it. The users and analysts have to reach a consensus on the best and most effective use of these air
pollution simulation tools. The econometric model we built has all of the advantages and disadvantages of econometric models, that is, the essence of it is grounded in history. While econometric models equations can be adjusted, it needs to be done in a way that is replicable. Our CGE model has been difficult to build, and we will to continue to improve it. While CGE has become a very prominent tool, it rests on debatable assumptions, especially about elasticity.

3.3 Recommendations

The policy implications of using all three of these models cannot be overstated. Realistically, it is possible to run numerous analyses that capture the essence of risk analysis and combine the skills of decision makers and researchers. The real challenge is to determine the ways of incorporating the rail line model and the economic models into routine planning so that potential users do not view them as distinct from their normal planning functions. The air pollution model offers so many opportunities that a group of decision-makers and analysts will need to carefully select those kinds of simulations that are most valuable.

4. References


http://news.bbc.co.uk/2/hi/south_asia/3650835.stm


Jenkins B, Butterworth B, Clair J-F. 2010. Off the Rails: the 1995 attempted derailing of the French TGV (high-speed train) and a quantitative analysis of 181 rail sabotage attempts. Mineta Transportation Institute, San Jose, CA.


