Transportation Density and Opportunities for Expediting Recovery to Promote Security

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New York State ranks prominently among other states in the nation in the size and scope of its transportation system, with most of the usage of that system concentrated in and around New York City. Areas of infrastructure density and bottlenecks pose security challenges. Moreover, transportation is highly dependent on other infrastructure. Research addressing the reduction of security threats is proposed in terms of transportation operations and expediting recovery. Existing research is presented on transit recovery in the New York area after September 11, 2001 as a guide for future research into prevention of, and recovery from, disruptions to transit.

KEYWORDS Transportation, transit, security, terrorism, infrastructure interdependencies

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INTRODUCTION

New York State (NYS) ranks among the top few states in the United States in terms of the extent, capacity, and use of its transportation infrastructure. Much of this usage is a consequence of the size of the population. In this article New York City (NYC) and its region are used to illustrate the resiliency of transportation, focusing on transit, and the factors that have and can contribute to this resiliency, with a particular emphasis on the system’s recovery following the World Trade Center (WTC) attacks of September 11, 2001 (9/11). Resiliency in this context is measured primarily in terms of the ability to sustain and recover ridership.

NYS transit is an important area of study for the security of transportation in general in NYS for a number of reasons. Transit usage nationwide is very concentrated in NYS, with the state accounting for 40% of U.S. transit ridership. Within NYS, much of the concentration of transit occurs within NYC and its region, and in 1999, the NYC transit system ranked about third among transit systems in the world in terms of annual subway ridership (Zimmerman 2005, 22). According to the Metropolitan Transportation Authority (MTA), which manages much of the transit in NYC and its region, “MTA subways, buses, and railroads provide 2.4 billion trips each year to New Yorkers—the equivalent of about one in every three users of mass transit in the United States and two-thirds of the nation’s rail riders” (Metropolitan Transportation Authority 2008).

Although other transportation infrastructure systems, such as roads and bridges, are important security concerns, they have not exhibited the same level of threats and incidents from terrorism that transit has experienced, though the potential is always present. Studies of terrorist incidents in transit systems outside of the United States reveal many hundreds of such occurrences within the past century as documented by the Mineta Transportation Institute; several notable attacks occurred after the WTC attacks in London and Madrid, and a 2004 survey of transit systems within the United States found that 28 agencies had experienced incidents and 16 reported receiving threats (Taylor, Fink, and Liggett 2006, 6).

DESCRIPTION OF TRANSIT SYSTEMS IN NYC AND ITS REGION

NYC is served by a number of different transit systems. The transit systems that operate within NYC and in the region bringing commuters to and from the city account for the largest transit ridership in the nation. The MTA, a New York State authority, consists of several units, the main ones being NYC Transit (operating the NYC bus and subway system), the Long Island Railroad (LIRR), and Metro-North Railroad. Two other systems that provide service between NYC and New Jersey are the Port Authority Trans Hudson
(PATH) system owned and operated by the Port Authority of NY and NJ (PANYNJ) and NJ Transit.

POST 9/11 RECOVERY OF NYC-AREA TRANSIT

Ridership is an important and commonly used measure of system usage, and is used here as the basis to assess recovery of the NYC area’s transit systems. After initial dramatic drops in ridership, ridership recovery occurred in most NYC-area transit systems in the weeks following the 9/11 attacks, and transit ridership continued to increase. The NYC Comptroller (2007) summarized an annual incremental change in ridership on the NYS portion of the system about five years after the attacks consistent with other accounts of the rebounding of the system: between April 2006 and 2007, subway ridership increased 3.8%, LIRR ridership increased 5.1%, and Metro-North ridership increased 4.3%.

Rail Transit

SYSTEM CAPACITY

Table 1 summarizes selected system characteristics and the capacity of the MTA Network, including the NYC subway system, the LIRR and Metro-North, and the other rail transit systems serving the city and the region—the PATH and NJ Transit. The MTA system in its entirety is estimated at 2.4 billion trips per year (MTA 2008). NYC Transit is the largest of the systems. According to the MTA the average weekday passengers on the subway system (NYC Transit) for 2007 is estimated at almost 7.3 million people, and on an annual basis this comprises 1.5 billion subway rides, making New York City subway ridership the third largest in the world in 2006 (moving up from a rank of fifth largest in 2004). The facilities for passenger access and transport (not including maintenance facilities) consist of 468 stations and 660 miles of passenger track (not including rail yards).

DAMAGE FROM THE WTC ATTACK

Direct damage occurred to portions of the MTA and PANYNJ systems on 9/11, and this history is well-known (Lower Manhattan Development Corporation (LMCD) 2003, 6). Immediately during and following the WTC attacks, damage to roughly 1,800 feet of track in the immediate vicinity occurred, as did damage to numerous stations of the MTA system. The WTC PATH station was demolished along with the towers. According to an account by the U.S. DOT Volpe National Transportation Systems Center (2003), operators of MTA subways and PATH trains initiated emergency procedures within minutes of
Transportation Density and Expediting Recovery

### TABLE 1
Selected system characteristics for rail transit, New York region, 2007

<table>
<thead>
<tr>
<th>Transit System</th>
<th>Average Daily (weekday)</th>
<th>Annual</th>
<th>Stations Number</th>
<th>Track Miles</th>
<th>Area Served</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYC Transit (MTA)</td>
<td>7,262,760</td>
<td>1.5 billion</td>
<td>468</td>
<td>660 (passengers); 840 (total)</td>
<td>5 counties</td>
</tr>
<tr>
<td>Metro-North (MTA)</td>
<td>265,949</td>
<td>&gt;80 million</td>
<td>120</td>
<td>775</td>
<td>7 counties</td>
</tr>
<tr>
<td>LIRR (MTA)</td>
<td>289,586</td>
<td>82 million</td>
<td>124</td>
<td>594</td>
<td>5 counties</td>
</tr>
<tr>
<td>PATH (PANYNJ)</td>
<td>227,000</td>
<td>66.9 million</td>
<td>13</td>
<td>43.1</td>
<td>3 counties</td>
</tr>
<tr>
<td>NJ Transit (NJTransit)</td>
<td>833,950</td>
<td>241.1 million</td>
<td>217 (rail and light rail)</td>
<td>643 (track miles maintained)</td>
<td>5,325 sq. mi.</td>
</tr>
</tbody>
</table>


LIRR track mileage and annual ridership: About LIRR: http://www.mta.info/lirr/pubs/aboutlirr.htm

the first plane crash and shut down all systems for at least a few hours because of the uncertainty of the situation. In addition to the destruction of the PATH station at the WTC, the tunnels to New Jersey were in serious danger of being flooded as well.

As discussed in what follows, ridership on buses and subways dropped precipitously for a day or two. Weekday subway ridership returned to normal levels two weeks later with some residual day-to-day instability; bus ridership followed a similar pattern but generally recovered more rapidly than subways. LIRR ridership dropped slightly in the months after the attacks, while the regional rail systems NJ Transit and PATH sustained larger, and longer-lasting, estimated impacts on ridership (Zimmerman, Simonoff, & Arnett, 2006). The ability to restore service immediately following 9/11 relied on the ability to reroute trains and buses. Restoration of the physical system took longer, but has resulted in innovative approaches to delivering transit, including the redesign of lower Manhattan rail complexes underway at Fulton Street and the WTC site.

**SYSTEM RESPONSE**

A statistical analysis using ridership figures was undertaken to assess the effects of the WTC attacks on MTA, LIRR, NJ Transit, and PATH ridership.
The data available are very limited and in some cases highly aggregated, preventing a more detailed and extensive analysis, but the general modeling strategy, transferable to other situations with similar data, is as follows. The basic model is a three-way analysis of variance model without interaction effects (Hocking, 1996, Section 14.2)

\[ r_{ijkl} = \alpha_i + \beta_j + \gamma_k + \varepsilon_{ijkl}, \]

where \( r_{ijkl} \) is the number of riders on the \( l \)th day \( k \) (where \( k \) corresponds to Monday, Tuesday, and so on) of month \( j \) (where \( j \) corresponds to January, February, and so on) in year \( i \) (where \( i \) corresponds to years 2000, 2001, or 2002). The model includes ridership effects for year (\( \alpha \)), month (\( \beta \)), and day of the week (\( \gamma \)), and allows for day-to-day variability through the error term \( \varepsilon \). These parameters are estimated omitting the time period affected by the 9/11 attacks, and then expected ridership on each day during the affected time period is estimated. The observed ridership can then be compared to these expected numbers to see what the effects were. The idea of omitting observations and refitting the model without them to see how unusual the observed responses are relative to the general pattern is standard in the analysis of unusual observations in regression; see, for example, Hocking (1996, Section 9.3). Because daily figures are not available for the systems, analyses are performed at an aggregated time period level, such as weekday/Saturday/Sunday or month. The systems for which the analysis was conducted are the transit systems serving Manhattan from the east and west (not including Amtrak). The following is a summary of the results by system. For each system, the normal pattern is first described followed by the response following the 9/11 attacks.

**NYC Transit.** Bus and subway ridership is normally fairly stable from month to month, other than a weekday dip during the summer months. Ridership is roughly 45% lower on Saturdays than on weekdays, and roughly 30% lower on Sundays than on Saturdays. There was an immediate precipitous drop in subway ridership in the aftermath of the 9/11 attacks for a day or two. This was followed by a jump in ridership, and then a steady increase in weekday ridership until it reached a normal level roughly two weeks later. Even 16 days later, however, levels were unstable enough to drop more than 15% from one day to the next because of rider concerns. Weekend ridership, which presumably includes many more discretionary riders than on weekdays, was slower to recover, and was still below its expected levels three weeks later. Bus ridership followed a similar pattern, except that ridership recovery took noticeably less time, reaching roughly normal levels on most days one week after the attacks (although instability in ridership level was still apparent).
LIRR. Ridership normally slowly increases from January to May, then jumps in June and July (presumably reflecting traffic to Fire Island, the Hamptons, and Montauk), and then is moderate the rest of the year. Ridership decreased steadily from 2000 to 2002. During the immediate period following 9/11, the ridership figures in the next three consecutive months were all roughly one standard deviation below the expected levels, suggesting a weak effect on ridership lasting a few months.

NJ Transit. Ridership is normally low in January, then stays reasonably consistent until June, when there is a jump, followed by a dip in July and August. It then increases again in the autumn months. Ridership annually increased steadily from 1998 to 2001, but then dropped in 2002. In September 2001, ridership for the month dropped 4% from expected levels, but then rose in October while still being below expected levels. It is possible that NJ Transit picked up traffic lost from the PATH system, although ridership levels were still lower than expected in the last three months of 2001.

PATH. Prior to 9/11 PATH ridership was relatively stable from month to month, although it was somewhat higher in the first half of the year than in the second half. The PATH system has two alternative routes into New Jersey from Manhattan. One originates from 32nd Street (called the 33rd Street Station) traveling over several stations to Christopher St. and then proceeds to several stations in New Jersey. The other originated from the WTC station to Exchange Place in New Jersey, and that line was eliminated by the WTC attacks. The first route ended up absorbing a lot of the traffic from the original route, but the estimated ridership for September through December 2001 still underwent a massive drop roughly 7 to 12 standard deviations below the expected values, which was then sustained through 2002.

The observed ridership patterns related to the buses, subways, LIRR, and NJ Transit are consistent with research on the psychological status of the general population of the New York City metropolitan area after the 9/11 attacks (the PATH situation is fundamentally different, because one of the routes into Manhattan was completely closed). Schlenger et al. (2002) reported an 11.2% prevalence of probable post-traumatic stress disorder (PTSD) among residents of the New York City metropolitan area one month after the attacks. Galea et al. (2003) reported the results of surveys of NYC residents 1–2 months, 4–5 months, and 6–9 months, respectively, after the attacks. They found that while there was a 7.5% prevalence rate of probable PTSD and 17.4% prevalence rate of subsyndromal PTSD one month after the attacks among residents of Manhattan below 110th Street, by four months after the attack the rates had dropped dramatically to 1.7% and 4.0%, respectively. Because avoidance of situations that remind the sufferer of the initial trauma
is one of the symptoms of PTSD (American Psychiatric Association 2000), it is unsurprising that MTA riders would prefer buses to subways in the weeks immediately after 9/11, and the ridership patterns on the LIRR and NJ Transit are consistent with an easing of such symptoms after 3–4 months.

System Restoration

In the short term, within a few days of the WTC attack, PATH service from the WTC station was picked up by stations to the north, drawing on the entire uptown branch. Subway service was rerouted around the WTC stops, and various trains were converted to shuttle service. The ability to adjust mass transit in this way was enabled by the dense network of transit lines within Manhattan, and the fact that the WTC had been at the end of a single line.

Within a year of the disaster, many of the systems showed significant readjustments made possible within the existing infrastructure. The PATH system is illustrative of the way in which ridership adjusted across transit stations. Ridership readjusted to stations north of the WTC terminal that had been destroyed. Between August 2001 and August 2002, for example, PATH stations in NYC showed the following changes in average weekly ridership:

<table>
<thead>
<tr>
<th>New York Stations:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>9th Street</td>
<td>109.7%</td>
</tr>
<tr>
<td>14th Street</td>
<td>93.2%</td>
</tr>
<tr>
<td>23rd Street</td>
<td>21.2%</td>
</tr>
<tr>
<td>33rd Street</td>
<td>49.9%</td>
</tr>
<tr>
<td>Christopher Street</td>
<td>96.7%</td>
</tr>
<tr>
<td>Uptown Total</td>
<td>60.7%</td>
</tr>
<tr>
<td>WTC Terminal</td>
<td>−100.0%</td>
</tr>
<tr>
<td>New York Total</td>
<td>−34.3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>New Jersey Stations:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Exchange Place</td>
<td>−100.0%</td>
</tr>
<tr>
<td>Grove Street</td>
<td>41.7%</td>
</tr>
<tr>
<td>Harrison</td>
<td>−23.5%</td>
</tr>
<tr>
<td>Hoboken</td>
<td>−31.8%</td>
</tr>
<tr>
<td>Journal Square</td>
<td>−23.5%</td>
</tr>
<tr>
<td>Newark</td>
<td>−39.7%</td>
</tr>
<tr>
<td>Pavonia</td>
<td>3.6%</td>
</tr>
<tr>
<td>New Jersey total</td>
<td>−29.6%</td>
</tr>
<tr>
<td>Grand Total</td>
<td>−31.6%</td>
</tr>
</tbody>
</table>

PATH ridership changes reflect the disabling of the WTC station in New York and Exchange Place in New Jersey noted earlier. The patterns are consistent with riders coming in from New Jersey taking means of transportation other than PATH to enter Manhattan, or entering Manhattan at stations to the north of what had been the WTC terminal (assuming that trips from New Jersey residents to NYC exceed trips by NYC residents to New Jersey, a reasonable assumption).
Over the course of a couple of months following the destruction of the WTC PATH station, planning for a temporary WTC PATH station serving lower Manhattan commenced and the Exchange Place station construction began at the same time. The temporary WTC station opened on November 23, 2003 (PANYNJ, Temporary PATH Station restoration http://www.panynj.gov/). The Exchange Place station opened on June 29, 2003 (PANYNJ, Exchange Place information http://www.panynj.gov/), involving a reconfiguration of the track system at that station (LMDC 2003, 21). The Cortlandt Street station on the NYC Transit system originally scheduled for reopening remained closed due to construction of the Fulton Street station renovation.

Long-term plans started simultaneously with mid-term planning and adjustments. NYC and regional transportation and development agencies took the opportunity to make major changes in the design or functioning of its transit systems. For example, the World Trade Center Transportation Hub and Fulton Street Transit Center encompasses extensive design changes to the Fulton Street station and the reconstruction will address many passenger circulation problems that had existed prior to 9/11. It also includes reconstruction of the PATH WTC station. LMDC (2007) summarized a number of the plans connected in one way or another to Lower Manhattan transportation needs following 9/11 in addition to the redesign and reconstruction of the WTC PATH and Fulton Street stations underway. These include changes to and redesign of transit facilities both local to lower Manhattan as well as connecting the area to the region, such as: the South Ferry subway station, Jamaica/Long Island and JFK Airport Access, and linkages between the LIRR and lower Manhattan.

Buses

The bus transit system experienced a similar pattern of restoration as the rail transit system in terms of ridership. In fact, patterns of bus ridership are highly correlated with subway ridership ($r = 0.99$), although subway ridership is about 70–100% higher than bus ridership. The response during the period preceding and following the WTC attacks is similar to that of the subway system, although (as noted earlier) bus ridership recovered more quickly than for subways.

Ferries

It is well known that the ferries immediately filled in, picking up ridership from lower Manhattan to remove people from the area. Between September 2001 and November 2001 ferry ridership increased an estimated 27% (Zimmerman 2003, 256, calculated from Lee 2001). By the Spring of 2002, the LMDC (2003: 78) estimated that the ridership had increased 42%
over pre-9/11 levels, totaling some 107,000 passengers, and one terminal, Pier 11 in the Wall Street, NYC area, increased by about 300 percent. The Coast Guard was the overseer of the use of ferries (U.S. DOT, Volpe Center 2003). The U.S. Government Accountability Office (U.S. GAO) (2008, 14) reported that $100 million was allocated for construction and operation of eight emergency ferry facilities. In the years following, however, while ferry travel has retained that popularity, it has been beset by a number of financial, capacity, and safety issues that have impeded a stronger, continuing role. Whether it is viable as an alternative means of transportation at a level that can sustain large-scale evacuations in an emergency is yet to be determined. The LMDC (2003, 78–83) outlined a series of strategies, including upgrading of terminals, improving ferry vessels to incorporate high speed technology, and expanding routes that would be needed to provide increased capacity. Zupan (2005) has argued that a plan is needed to define and support the role of ferries in the N.Y. region’s transportation system. Ferries will face a number of factors, many unrelated to security, in order to be competitive with alternative modes of travel. Given the close attention being given to environmental factors, for example, ferries may have to rely on advanced technologies to reduce emissions to be competitive in some contexts with highway travel (U.S. Department of Transportation 2003). Issues related to safety and the relative cost of travel have also arisen, and if ferries are to be viable, public policies that confront these issues in a comprehensive way will be needed.

OTHER CONSIDERATIONS

The transportation system does not exist in isolation in order to function. First, it depends on other infrastructure, in particular, electric power and communications. In NYC, transportation system recovery rates after the August 14–15, 2003 blackout, which was a regionwide event, were much slower than the time it took for the restoration of electric power (Zimmerman and Restrepo 2006): transit and electrified rail recovered 1.3 times longer and traffic signals recovered 2.6 times longer than it took electric power to be restored, most likely due to the need to restore signals and switches. Zimmerman (2005, 26–28) describes numerous incidents that illustrate the interconnections between water and electric power outages and transit. Communications are also vital to the security of transit systems. New technologies are continually being tested, yet major impediments remain to effective performance in normal times that does not bode well for disasters. Neuman (2007) provides one recent example:

New York City Transit has spent millions on a computerized system of speakers and electronic signs on the crosstown L line, which runs
Second, transit is vulnerable to natural hazards and accidents. The paralyzing sudden rainstorm of August 8, 2007, demonstrated what happens to a city when another kind of regionwide event affects transit. A combination of conditions contributed to a stoppage of all of the subway lines for several hours. These factors included intense rainfall, an ongoing condition of drainage waters being channeled into the subway system, and debris and lack of adequate drainage capacity preventing what drainage capacity that exists from working adequately. The reaction of rail transit to events such as flooding provides lessons for the potential consequences of an areawide terrorist attack.

Third, global climate change is likely to result in a slowly evolving change in physical conditions that for many coastal cities is predicted to mean permanent inundation of low lying areas and increased frequency and intensity of storms that will further increase the severity of flooding of infrastructure like subways.

CONCLUSIONS

When outages are geographically localized as they were in the 9/11 WTC attacks, the transit system can and in fact did recover relatively rapidly. Although the 9/11 attacks had far-reaching economic and social impacts of a magnitude not previously experienced, only a small part of the subway system was physically destroyed (although important interconnection points to regional systems were damaged). The shutdowns of parts of the transit system outside of the immediately impacted area were largely precautionary. The matrix-like structure of transit systems in NYC, and the fact that some are interchangeable for riders, enabled a relatively rapid recovery to occur. The mechanisms by which such restoration occurred serve as a model for other transit systems, not only in the face of terrorism, but other catastrophes as well. Future research is needed to analyze alternative transit and transportation configurations, and user behavior and their ability to be flexible to respond to catastrophic events of varying levels of severity and impact.

Going forward, these changes to the transit system will need to incorporate improved security and require an infusion of capital to sustain a robust and secure system. The U.S. government has had an ongoing
emphasis on critical infrastructure protection, including transportation, in its programs even prior to 9/11 (Zimmerman 2006). The U.S. GAO reports that since 9/11, the federal government has provided $5 billion for transit, of which $4.7 billion was provided to NYC primarily for reconstructing transit and related infrastructure (U.S. GAO 2008, 13). Additional funds have been allocated for security infrastructure in connection with transit, and according to public officials more attention is likely to be needed to address what they see as shortcomings. The NYS Comptroller (2008), for example, identified delays, costs, and technological problems associated with the transit electronic security system. These are just a few of the many pieces of a more extended and complex picture involving multiple government agencies and private sector entities that will be needed to improve the resiliency of the transit system, not only in the New York area but elsewhere in the nation and the world.

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