5.3 Transportation and Communication Lifeline Disruption

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S. L. Cutter, D. B. Richardson and T. Wilbanks (eds.) *The Geographic Dimensions of Terrorism,* in press.

One of the many lessons from 9/11 is that terrorism is not just about terror. Terrorism is also an attempt to disrupt the daily lives of non-combatants to achieve political objectives. Physical or virtual networks that are vital to health, safety, comfort, and economic activity are called *lifelines* (Platt 1995). The complete or partial failure of even a limited number of lifelines can have a major impact on economic productivity as well as making peoples' daily lives more difficult and in some cases nearly impossible. This is not just a matter of convenience. There are members of society with limited resources or other economic, social and demographic constraints, whose very livelihoods depend on reliable functioning of such lifelines. The population explosion of the past two centuries combined with high rates of urbanization means that effective public transit and road networks are indispensable. Increased mobility on a daily or weekly basis or over the course of a lifespan results in an enhanced reliance on communications networks (physical and virtual) in order to conduct daily activities and maintain relations in business, social and family settings. The negative impacts of lifeline disruptions on economies, personal finances, and lives can be so invasive that the terrorists' political ends often are achieved as effectively as through the direct use of force.

Transportation and communication lifelines are among the critical networks required for moving material, people and information among locations distributed in geographic space (Platt 1995). The criticality refers to their role as an essential foundation for the relatively plentiful and stable supply of food, consumer goods, and information. To disrupt them produces ripple effects not only in the region where it occurred, but extends outward to the nation and the world. The best example of this was the halting of all commercial air traffic in the U.S. in the few days after 9/11 and its worldwide impact in terms of travel disruptions and economic losses.

Since lifelines are so central to the functioning of modern society and yet are so fragile, it is important to understand their vulnerability to planned and unplanned disruptions. Lifeline vulnerability refers to the susceptibility of a system to incidents that cause considerable loss of service (Berdica 2000). Understanding lifeline vulnerability can lead to 1) better protection strategies by identifying particularly vulnerable components of the network (and the benefits and costs of reinforcing those components); 2) improved strategies for recovery from disruptions (by identifying consequences and magnitudes, and effective mitigation strategies); and 3) enhanced support for long-term design and planning and related land-use systems that are less vulnerable.

Indicators of Lifeline Vulnerability

Many approaches have been used to measure lifeline vulnerability but most can be grouped into two major categories: performance based indicators (network reliability and network performance) and user based indicators (accessibility). These are briefly described below.

Network Reliability and Network Performance

Network vulnerability is the susceptibility to disruptions that can cause considerable reductions in network service or the ability to use a particular network link or route at a given time (Berdica 2000). An important aspect of service is the ability to use a lifeline at a certain place and time. Another aspect of network reliability involves the consequences of disruption, that is, reductions in service. Networks that cannot quickly recover from a disruption with minimal reduction in service are deemed more vulnerable than those whose recovery is faster and with less overall disruption. For example, a transportation network that concentrates flow through a small number of links (such as the bridges and tunnels connecting Manhattan to the rest of the New York metropolitan area) is more vulnerable than a more fully connected network since there are fewer choices for re-routing traffic if one or more of these "bottleneck" links fail.

Most analyses of network vulnerability use the related concept of reliability or adequate serviceability at a given time. Network reliability theory treats network arcs and nodes as having a random probability of failure. Network reliability also depends on flow and congestion within the network. Since urban transportation networks are increasingly saturated, localized disturbances (such as a traffic accident) can propagate widely through the network causing system-wide delays. There are several ways to estimate reliability, including the probability that an origin-destination pair remains connected by a route after component failures, or that the time required for traveling between the origin-destination pair does not exceed a maximum limit.

Network performance approaches monitor or simulate network flows and evaluate their behavior in response to real or simulated disturbances. They are being used more often now than in the past due to the deployment of intelligent transportation systems for monitoring flows, and the availability of dynamic methods for simulating variable time flows. Network performance measure includes travel time, travel rate (travel time divided by segment length) and delay rate (actual travel rate minus desired travel rate) (Pratt and Lomax 1996).

Accessibility

Accessibility is a fundamental concept in human geography. Accessibility measures the ability of individuals to participate in activities in space and time, and the use of transportation and communication technologies to achieve this participation. Accessibility is a much broader concept than serviceability and views vulnerability as susceptibility to substantial reductions in *space-time autonomy*, or the freedom to participate in events distributed in space and time. The concept recognizes that transportation and communication are derived demands and exist not for their own sake but to help people accomplish other activities in space and time. Loss of accessibility greatly impacts abilities to earn a living, access health care, conduct parenting activities, or maintain social relations. For example, survey evidence suggests that time spent driving reduces community involvement and volunteerism (Putnam 2000). Network-centric performance-based measures do not capture these potentially widespread and devastating effects of lifeline disruption since they view the network as detached from the context of human activities.

Measuring the Human Dimensions of Lifeline Disruptions

Time geography is a powerful and sensitive framework for analyzing accessibility in space and time. Two fundamental concepts are the space-time path and the space-time prism (Hägerstrand 1970). The space-time path traces an individual's movement in geographic space and world time over any time scale (from hours to years). The prism demarcates possible locations for the space-time path during a travel episode given a time "budget" for travel and the maximum travel velocity allowed by the transportation system. Figure 1 illustrates a space-time path (top half) and a simple space-time prism (bottom half) where the origin and destination are coincident and with stationary activity time not considered (e.g., time spent at a doctor's office). The prism geometry is more complex with non-coincident anchoring locations and with stationary activity time. A related concept from activity theory is a space-time pattern. This is an allocation of a limited time budget (e.g., minutes of a day, hours of a week) for certain activities in space and time (such as grocery shopping, travel to work, Internet surfing). Space-time paths, prisms and patterns can be used in two ways to assess lifeline vulnerability: direct losses of space-time autonomy and induced changes in space-time patterns.

Loss of space-time autonomy

The prism can assess directly, the convergence between space and time as a function of transportation network configuration, travel velocities, scheduling constraints, and network congestion. Existing techniques are available for analyzing prisms based on travel in continuous space or within specific transportation networks (Burns 1979; Forer 1998; Miller 1991, 1999; Wu and Miller 2001). These techniques can be extended to lifeline vulnerability analysis by examining changes in the prism before and after a simulated transportation or disruption.

Changes in space-time patterns

By definition, a lifeline failure requires fundamental changes in peoples' lives. Another strategy for analyzing lifeline vulnerability is measuring changes in the spatial and temporal distribution of activities induced by network disruption. This strategy would analyze changes in space-time paths and patterns at an individual level in response to real or simulated failures. This method would require tracking and recording of the space-time paths before, during and after a planned disruption.

The disruption events that drive this type of empirical analysis could be large-scale transportation construction projects such as the "Big Dig" in Boston or the I-15 reconstruction in the Salt Lake Valley. These large-scale transportation projects produce impacts that approach the scale of major terrorist attacks (see the box on "Network Disruption, Time and Lives: The I-15 Reconstruction in the Salt Lake Valley.") Since simulation systems require individual space-time diary data as inputs to infer representative activity paths and patterns, it is important to develop location-aware technologies or intelligent transportation data collection systems to acquire them. There is a wide range of emerging dynamic flow and simulation approaches to linking space-time activity paths and patterns to network performance in order to understand how people will respond and adjust to disruptions (see Weiss 1999). Activity theory also provides guidance on how these adjustments occur (see Golledge and Stimson 1997).

Time Geography and Information Technology

Accessibility is a concept that is traditionally based on movement in physical space. However, activities are increasingly disconnected from geographic space as a result of the increased use of information technologies (IT) (Couclelis and Getis 2000). Time geography can be extended to encompass IT-based virtual interaction as well as physical movement (Adams 2000). Unlike most accessibility measures, time geography is sensitive to emerging perspectives that view time as the scarce commodity of the information economy and accelerated modern lifestyles (see Gleick 1999; Goldhaber 1997).

Embedding space-time vulnerability measures within a decision or policy process requires methods for supporting the exploration and comparison of vulnerability scenarios. A spatial decision support system allows analysts, decision-makers and stakeholders to develop, execute and assess vulnerability scenarios. This requires integrating a space-time prism or activity modeling system with solution exploration and comparison techniques. Geographic Information Systems (GIS) software supports such spatial database management, in addition to spatial-temporal query functions, and geographic visualization tools (see Armstrong et al. 1986; Jankowski 1995).

Conclusion

Transportation and communication disruptions immediately following the 9/11 attacks clearly illustrate the dependence of our society on transportation and communication lifelines. Lifelines provide convenient opportunities for terrorists to seriously affect economies and lifestyles from the local to the global. In this way, they rank among the nation's most important infrastructure. Analyzing and understanding vulnerability to disruptions in lifelines leads to improved protection, mitigation, and recovery strategies. Among the techniques used for analyzing lifeline vulnerability, accessibility and time geographic approaches recognize the nature of transportation and communication as derived demands within a broader human activity context. This can allow more sensitive analyses of lifeline disruption on daily lives than methods that examine impacts only on the networks. Spatial decision support and GIS software, as well as digital geo-spatial and human activity data, can make this mode of analysis feasible as well as understandable to policy analysts and decision makers.

9/11 exposed not only our vulnerability to lifeline disruption, but also our lack of knowledge about the relationships between these networks and human activities. There is little fine-grained, scientific knowledge and how critical transportation and communication networks affect daily lives, and the urban dynamics that emerge from the interplay of individual activities in space and time. Gaps in scientific knowledge about the interrelationships between human activities and transportation/communication networks are disturbing since these are also at the heart of transportation science and urban theory. The relationship between individual activities and connectivity in space and time is also central to policy questions surrounding urban livability and sustainability policy (National Research Council 2002).

There are several research and development frontiers where progress will not only advance our understanding of lifeline vulnerability but also help create more livable and sustainable communities that are responsive to peoples' daily lives. Required are new data collection protocols and methods that exploit advances in information technologies and position-aware technologies such as the global positioning system, intelligent transportation systems and location-based services. Also needed are theories and models that have detailed, individual-level linkages between transportation/communication lifelines, the organization of activities in space and time, and the interplay of these activities in creating lifeline demands and urban dynamics. Also required are enhanced versions of the space-time path, prism and other time geographic constructs that can be disconnected from geographic space and referenced within cyberspace (the information space created by networked information technologies). Finally, researchers and developers need to create user-friendly GIS and spatial decision support tools to help emergency managers, transportation planners and other officials to use these advanced, individual-level theories and models in real-world applications. The discipline of geography, with its established and emerging traditions of time geography and geographic information science, is well suited to make major contributions to these essential research frontiers.

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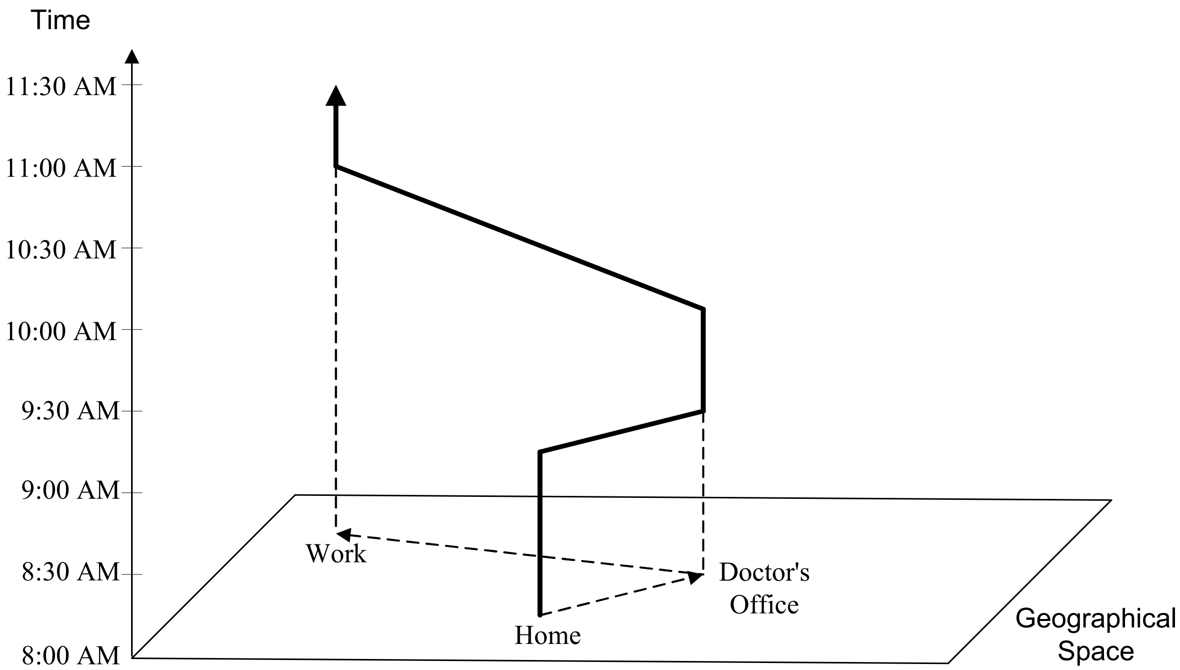
Issue Box

Network Disruption, Time and Lives: The I-15 Reconstruction in the Salt Lake Valley

Many cities and regions in the United States are experiencing transportation network disruptions caused by major construction projects. These construction projects can have serious impacts on people lives and livelihoods. During 1997 - 2001, 16.5 miles of Interstate 15 in the Salt Lake Valley, Utah was expanded from six lanes to ten. Additional congestion caused by the project generated an average of 15 minutes delay per trip. This means that a regular commuter on I-15 lost more than 500 hours during the four-year project. While commuters are expected to enjoy time savings in the post-construction era, they will not "break-even" until 2010, eight years after project completion (McCann et al 1999). The I-15 construction corridor also experienced a substantial rise in traffic accidents and fatalities due to the shift of traffic from the highway to surface streets. Accidents on some streets increased as much as 300 to 500 percent. In unincorporated Salt Lake County alone, the number of traffic fatalities increased from 202 in 1996 to 315 in 1997 (Horiuchi 1997).

Figure captions

Figure 1: Space-time paths and prisms; Top half – a space-time path (based on Wu and Miller 2001); Bottom half - space-time prism.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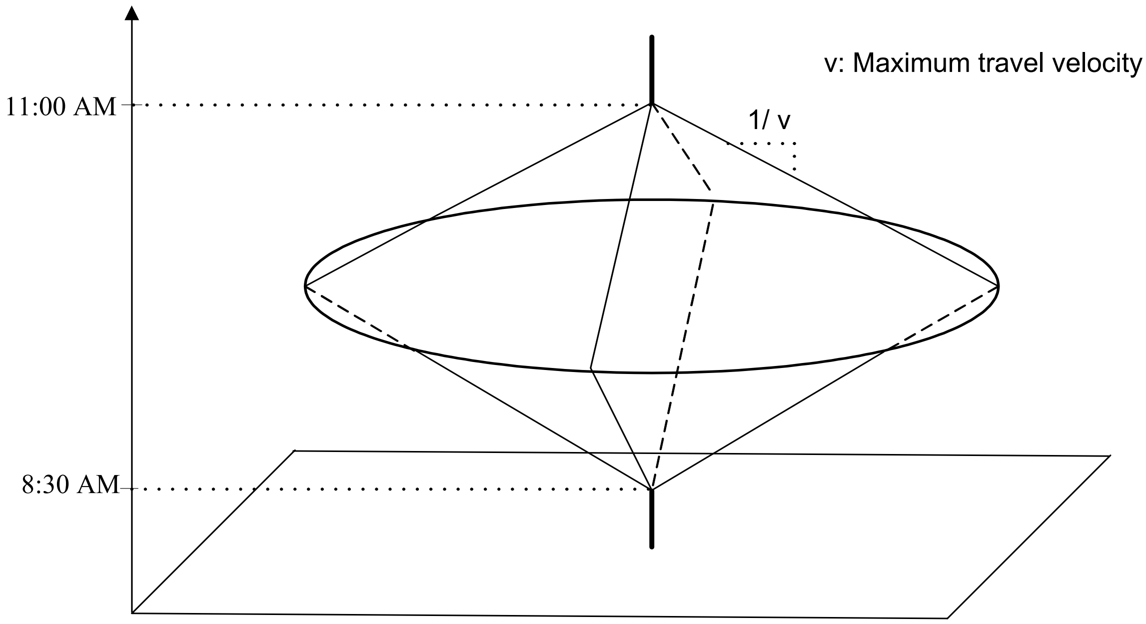
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