1. Introduction

TRANSPORT, ENVIRONMENT AND SECURITY: COMMON OBJECTIVES AND SHARED STRATEGIES

The traditional purpose of transportation is to enable people to have access to goods and services and social support. Transportation, like other public services, is often taken for granted. It is assumed to be available when needed and effortless with the main purpose of overcoming distance. Yet, relationships between transportation and the values and needs encompassed by the environment and security influence how transportation infrastructure and its services are configured. The environment is multidimensional, including both physical and social dimensions, encompassing for example, climate, air and water quality, land resources and social equity. Security acknowledges the growing incidents worldwide, and vulnerabilities, consequences and concerns regarding terrorism. Accidents and natural hazards bring their own set of environmental and security problems. The rationale for combining transport, environment and security is that they share much in common, such as common outcomes. As such, these phenomena can often be managed in ways that are synergistic or at least consistent.

Synergies often arise as co-benefits. Precedents exist for co-benefits for transportation, environment, and security. Air quality and climate change goals, both of which relate to transportation, have co-benefits when pursued simultaneously (ApSimon et al. 2009). Social benefits arise from improved health by reducing air pollutants and greenhouse gases. For example, the US Environmental Protection Agency (EPA) program for common strategies to integrate climate change, air quality, health and the economy implies co-benefits (US EPA 2009). Holland (2008, p.3) identified co-benefits between air quality and health, estimating reductions in lives lost, hospital admissions and other health factors from reductions in fine particulates, sulfur oxides and nitrogen oxides (components of some transportation emissions) and greenhouse gases (GHG). Co-benefits of air quality and GHG reduction were also analysed in Asia by Huizenga and Ajero (2005) using transportation as a key component, and Bollen et al. (2009) examined similar co-benefits in the Netherlands.
Co-benefits emerge in areas not directly involving transportation but the strategies are nevertheless applicable to the environment – transport synergies, for example, by Elbakidze and McCarl (2004, 2007) and Pattanayak et al. (2005) who evaluate co-benefits of GHG mitigation and water quality improvements.

Thus, combining objectives is not new, but the combination of transport, environment and security is less well-studied or studied in more limited ways. For example, while transport has commonly been considered with air quality issues, another dimension for integrating transport and the environment is ecological or wildlife corridors which are a popular means of achieving environmental and transport objectives simultaneously. Chapter 5 addresses this.

Climate. Health. Sprawl. Disasters. Security. Economy. Environment. Transport has been the field in which these competing interests have played out for well over a century, and longer, when humans first relied on wheels to move faster. It is over a hundred years since major transportation technologies emerged to meet the needs of an enlarging and often decentralizing population.

When decision choices are framed separately, they often compete, leading to expanding budgetary demands. Recognition of the interconnectedness of the many demands that are made on transport is crucial for meeting competing goals. The environment, including climate change, and security are posing new challenges especially where several of these objectives have to be met simultaneously. While these multiple needs have been around a long time it is their combination that presents new challenges. Even if synergies are not possible, compatibility or co-existence is an important option.

Transport and the choices people make about it involve a design that is often unseen and ad hoc but is reflected in networks. Networks are an organizing principle that can combine often disparate needs into a common set of goals. Transport has been extensively explored as a network, and incorporating environment and security builds on that concept.

Networks connect transportation to disasters, environmental protection, renewable resources, and security, recognizing interdependencies and co-benefits. A network approach provides the interconnections to explore multiple priorities and policies.

There is a sense of urgency in addressing these areas together. There are some wake-up calls that disasters have called attention to, where transportation behavior plays a key part in survival. People who perish in natural disasters often do so in their cars. Accessibility to the means of egress during disasters is often socially, culturally, and politically determined.
Disadvantaged people in hazard-prone areas have less access to the means of travel whether it is car ownership or accessibility to public transit (Bullard 2007).

The connections between environmental benefits and transportation provided by renewable energy, for example, often arise unexpectedly. Solar energy for vehicles provides environmental benefits, addresses climate change, and can provide backup power in emergencies where solar panels are used directly on emergency vehicles (CH2MHiHill 2009, p.7). Electric vehicles equipped with batteries were used to enter devastated areas following the Japan earthquake in March 2011; they were able to use backup power, they could be charged using ordinary outlets or fast charging stations, they did not rely on gas stations which were out of service, and could move easily over debris given their lightweight construction and tire structure (Belson 2011). According to Belson’s account, they were used for a wide range of services including transporting supplies, serving doctors, and supporting inspections. Moreover, steel-encased batteries in electric vehicles (the Nissan Leaf) were able to withstand the destructive force of the tsunami though the cars suffered damages (Bunkley 2011). Countless disasters have spawned new disasters with escalating consequences because essential services were disrupted. Important co-benefits are realized if strategies such as renewable energy can fill the gap for transport and other services, even if just in the short term.

TRANSPORT AS A NETWORK

Transport as a network is a valuable approach for understanding the linkages among transport, environment and security and the consistency of transport and production of co-benefits with the environment and security. The network concept is briefly introduced, borrowing from network science – what it is and how it shapes choices and institutions. Then network concepts are applied to the forces that connect, disconnect and reconnect transport services. Major drivers of these forces are presented primarily in terms of population – its size, density, distribution, and rate of change – that often frame transportation choices and the means to integrate transport, environment, and security. The utility of the network concept is that transport, environment, and security follow similar network principles, which enables a common language to be created among them that allows comparisons and an understanding of their interactions.
Network Theory in Brief

Networks are in their simplest construction nodes (often called vertices) connected by links (also called edges) (Newman 2010, p.1), and the concept is well-developed throughout the literature in multiple disciplines (Barabasi 2002). Activity flows and transfers occur across networks and physical contexts influence their form or structure and behavior. Although the behavior of networks is highly contextual a few principles have become apparent. These are meant to be examples rather than exhaustive. The degree to which they have been tested and agreed upon varies considerably. Emphasis is placed on what aspects of a network provide strength or make it vulnerable in the face of internal and external influences.

Important properties of networks are relevant to the study of transport networks. These include centrality and the related concepts that define centrality – degree, betweenness, and closeness (Newman 2010; Wasserman and Faust 2009). Bohannon (2009, p.409) summarizes these concepts for terrorism (citing Krebs 2001): Degree measures the extent of activity, betweenness is control over network flows, and closeness is the accessibility of a given node to others in the network. Taking a closer look at the concepts, centrality as the overarching concept is a measure of the importance of a node and in the social network theory literature it is equated with its visibility or prominence (Wasserman and Faust 2009, p.172) and can occur at various scales in a network – the node, link or sub-groupings of the network (Wasserman and Faust 2009, p.170). Newman (2010, p.169) defines the degree centrality of a node as the extent to which the nodes have edges attached, which is the same as the definition of degree (Newman 2010, p.133). Betweenness is related to centrality and Newman (2010, p.185) defines betweenness centrality as whether a particular node or vertex is between other vertices along a path and can be a measure of its influence (Newman 2010, p.186). Closeness centrality is a measure of distances among vertices (Newman 2010, p.181). These concepts very much depend on the network structure, for example, whether the structure is star-shaped, circular or linear (Wasserman and Faust 2009, p.171).

Network flows can have direction or not, and be weighted or not. Summarizing these concepts again (adapted, for example, from Newman 2010):

- Centrality signifies importance
  - Degree is the number of links connected to a node (control);
  - Betweenness is the extent to which a node lies between other nodes along a path (influence);
  - Closeness is the proximity of nodes to other nodes (accessibility).
Network-related concepts other than those related to centrality are also important for transport, environment and security linkages:

- Concentration pertains to spatial and functional distributions;
- Remoteness refers to outliers or nodes connected to a single node or link in only one direction, potentially indicative of isolation;
- Flexibility and adaptability refer to the ability to serve more than one function or support activity in more than one direction. Redundancy can provide flexibility but not always.

Certain specific principles arise from the literature on network theory and its applications to transport that are relevant to how transport systems relate to the environment and security. Network structure has been related to vulnerability (Taylor and D’Este 2007). Holme et al. (2002) and Grubesic and Murray (2006), for example, observe that network structure changes as important nodes and edges are removed, and how they are removed affects vulnerability.

Some key principles are common themes throughout the book, presented below in terms of how network properties influence transport.

1) Network structure, number of connections, flows and network vulnerability:
- More complex and diverse networks are more susceptible to intrusion than simple networks. Stefanini and Masera (2008, p.35) point out that those infrastructure networks that are more networked and highly distributed need to consider more diverse threats than simpler or single systems.
- Networks can be multidimensional with interconnections defined as occurring among the dimensions. Some have characterized this as “metanetworks” (Bohannon 2009).
- The greater the number of links, nodes and interconnections among them, the more vulnerable the system becomes to intrusion, since potential flows can increase and the degree of control can decrease (Aderinlewo and Attoh-Okine 2009).
- Measures of importance related to centrality are distance (among nodes), or how long it takes to move from one node to another, as well as clustering or tightness (Newman 2010, p.10).
- Motter and Lai (2002) argue that where loads or activity flows can occur freely in a network, cascading effects can occur, and the disruption of a single node where it has a large load can have dramatic effects.
The size of a node or link can reflect how concentrated the flows are.

Network boundaries can be dynamic and unstable where the number and location of nodes and links are expandable (Wasserman and Faust 2009, pp.30–33).

Network structures may not be uniform in influence. In fact certain levels may contribute to the stability of the entire network. That is, the placement of certain features of a network can be critical. Deutsch (1966, pp.154–5) theorized that the “middle level of command” in government and other organizational structures enables a network to keep in touch with its parts especially when resources are scarce. He defined the “strategic middle level” as being close to both the rank and file and higher echelons defined in terms of the vertical structure of an organization (Deutsch 1966, p.154).

(2) Network adaptability:

Networks can adapt if loads can shift from one node or link to another. This implies heterogeneous and dynamic structures. The ability to reconfigure is key to adaptation. Motter and Lai (2002), however, argue that when networks can shift their loads around among different nodes, instabilities can occur that contribute to cascading effects and can ultimately destroy the network. Their concept involves the size of nodes, and they argue that where small nodes are removed the effect may not be as great as if larger ones are removed. Moreover, they argue that homogeneous networks are more stable than heterogeneous ones.

The capacity of networks to isolate portions of their structure is one aspect of adaptability.

Networks are more adaptable where subgroupings or subnetworks exist, enabling the network to fall back to relatively stable units after an intrusion or disruption. The Herbert Simon (1966, pp.90–92) parable of the watchmakers illustrates that clearly; where the watchmaker that built in subunits into the watches would not have to start from scratch every time there was an interruption.

Networks and Transport, Environment and Security

Transportation systems consist of nodes, links and user activity that constitute flows. A number of studies use networks as a foundation for describing and analysing the behavior of transport systems (Rodrigue et
al. 2006, 2009; Nagurney and Qiang 2009; Levinson and Krizek 2008) and specifically to address behavior in the context of disruptions, vulnerability and security (Murray-Tuite 2008; Murray-Tuite and Fei 2010).

As indicated earlier, the advantage of viewing transport as a network is to combine it with other conditions such as the environment and security. Networks also allow transport structure and behavior to be related to the economy and Newman (2010, p.32) traces this to the early work of Kansky (1963).

The applicability of network concepts and theories to transportation systems goes back many decades at least to the mid-twentieth century. Gorman (2005, p.31) reviews historical studies on land use and transportation relationships from a network perspective. Lynch (1960) writing on the principles of places, uses transportation networks as a major underpinning for alternative views of a city: links appear in the form of paths and edges and nodes appear in the form of districts, nodes and landmarks.

Under ordinary circumstances system transfers are a key part of transportation networks. Hadas and Ceder (2010, p.2) formulate three types of transfer points: those that are nonadjacent, adjacent or shared. These can occur in multiple dimensions or layers (Hadas and Ceder 2010, p.4).

The Sen et al. (2003) study of rail transit in India introduced by Newman (2010, pp.32–3) makes a distinction between those links that provide through traffic between two nodes and those that allow stops at nodes along the links. Newman (2010, p.33) suggests a way of representing such a network in terms of a “bipartite network” in which the two kinds of nodes can be distinguished.

According to Ceder and Teh (2010), connectivity improves public transport (PT) systems. Ceder and Teh (2010) identify and compare PT connectivity in central business districts of three New Zealand cities using measures based on factors influencing individual choice of PT as a travel mode. They conclude that more paths between origin and destination are best. Moreover, centrally locating a PT terminal helps to improve connectivity (by increasing the number of paths). Such a solution may not be optimal for security unless extreme precautions are used to protect the single terminal or node.

In disasters, networks are routinely broken and reconstructed. When passageways are needed to reconnect washed out roads and collapsed bridges, engineers have relied on unique approaches. Some noteworthy examples are bridges that can be floated in very quickly to replace a disabled unit. Rapid bridge replacement has been described by Bai and Kim (2007). Floating bridges described by Zoli and Englot (2008) temporarily route traffic to safer locations.
The ability of traffic flows to be redirected in emergencies has gained momentum (Cho et al. 2001). Contraflow enables road traffic to be redirected away from hazardous conditions toward temporary shelters (Urbina and Wolshon 2003). For example, according to the Disaster Center web page, during Hurricane Rita traffic was directed north and west along many major roadways. Trains can reverse direction also, rerouted for the same reason as roads, and this ability saved major exposure to disaster.

Transportation networks have been commonly used to analyse node disruption either by natural hazards, accidents or terrorism. Cho et al. (2001) use transport networks to calculate the economic effects of a disruption of transportation systems in an earthquake.

Concentration

Concentration is one aspect of transportation networks particularly critical for both environmental compatibility and security. There is no single measure to describe it and definitions vary according to context.

For transport, concentration is necessary for users to access many different areas efficiently and with fewer environmental impacts, for economic viability (economies of scale), or to tap concentrated resources. Perrow (2007) has presented examples of drawbacks of concentration. Parfomak (2008) raises the issue of concentration in the context of critical infrastructures. Simonoff et al. (2011) analyse the impact of infrastructure concentration on resource allocation. Concentration becomes particularly critical where infrastructures are interdependent either spatially or functionally (Rinaldi et al. 2001; Zimmerman 2006; Zimmerman and Restrepo 2006).

The “upstream” resources for transport, or those used as inputs for transport services, are particularly noted for their concentration. A few examples illustrate how the vulnerability of supplies for transport is affected by concentration. For example, the convergence point of nine interstate pipelines and four intrastate lines is called the Henry Hub, located near Erath, Louisiana (Budzik c2000). The area is in the major striking zone of hurricanes; however, it has not sustained much damage from hurricanes (DisasterCenter.com web page). On September 13, 2008, the owner of the Henry Hub shut it down due to the threat from Hurricane Ike (Reuters 2008). Another example of a threat to concentrated transport-related resources is an account by Coker (2010) of a Japanese tanker traveling through the Strait of Hormuz that was damaged and allegedly attacked, and an estimated 20 percent of global oil shipments travel that route daily. Thus, the potential of a similar attack on oil supplies could be significant. In the wake of threats by Iran to affect transport through the Strait of Hormuz (Sanger and Lowrey 2011), alternative routes have been
Introduction

9

put forth to convey oil, for example, the construction of a pipeline by Abu Dhabi (Hamdan 2012).

Concentration as a network attribute is highly compatible with environment and security objectives. Concentration of critical infrastructure and population can occur within urban settlements in ways that support environmental needs as well as focusing resources for security, though the threat might be greater in concentrated areas. Savitch (2008, pp.148–53) argues against the “dystopia” or arguments for “defensive dispersal” following the September 11, 2001 attacks indicating that such views ignore the resilience of cities. For environmental compatibility, renewable resources, for example, can be dispersed within dense urban settlements as solar cells on rooftops. Transportation systems adopting matrix structures with numerous intersections and transfer points promote both dispersion and flexibility within dense urban areas. Thus, if concentration increases vulnerability, it is countered by the resilience that concentration and its unique features create.

CONNECTING

The Land Use, Population and Transportation Connection: One More Time

Land use and population characteristics have a fundamental and historically prominent role in defining transportation (Ewing and Cervero 2010) and the relationship between transportation and other goals such as the environment and security. Three areas are discussed as they shape these relationships – the amount of land consumed by transportation, land use and GHG relationships, and characteristics of rapidly growing urban areas.

Land consumption by transportation

In connecting people with places, transport consumes a significant amount of land. Although there is little systematic information on land consumption and measures that do exist are not consistent, that is, measure different kinds of spaces, some estimates exist. Forman (2000, p.31) estimates that 1 percent of the US area is covered by roads and roadsides, and the ecological effects of roads extend over 22 percent of the continental US, which enlarges the actual area that roads impact (Forman 2000, p.34). Evink (2002, p.16) cites a similar figure of 1 percent but does not include parking areas. Cambridge Systematics, Inc. (2005, p.5 citing Lawrence Berkeley National Laboratories) showed that in four large urban areas,
Sacramento, Chicago, Salt Lake City, and Houston, 33–59 percent of the pavement area was devoted to streets, and very little, 16 percent or less, was devoted to sidewalks (Cambridge Systematics, Inc. 2005, p.6 citing other studies). Rodrigue et al. (2009) give an estimate of 155,000 square kilometers as the land devoted to car use in the US. Estimates per car, per roadway section, and per household or per capita also exist. Brown (2001) provides some unit figures per car – that in the US 0.07 hectares or 0.18 acres is required per car in the form of roads and parking areas. In total, he indicates 6.3 million kilometers (3.9 million miles) or 16 million hectares (61,000 square miles). He argues that food shortages could result from the competition for land between growing food and transportation. An earlier estimate of the rate of land consumption by roadways is 80 acres of land for an intersection and 24 acres of land per mile for a freeway (Detwyler 1971, p.419). Litman (2011, p.38) estimates about 3,600 square feet of paved road per household based on assumed average dimensions of residential lots and roads. The US Department of Transportation (October 2010) compares road density and road extent per capita for eight countries, and the US with about 21 kilometers per 1,000 persons ranks second behind Canada in per capita road mileage. These estimates point to significant transport-related paved areas with their potential for adverse environmental impacts without suitable design or material changes.

**Land use patterns, transport, and GHG emissions**

One of the more intense debates about transportation and land use connections centers around the contribution of land uses to GHG emissions. Automobile usage is often the focus of the transportation and GHG relationship in terms of vehicle miles of travel (VMT), fuel efficiency, and type of fuel addressed in Chapter 3 in connection with transportation and climate change. In particular, the argument focuses on whether density in the form of compact development holds the answer to GHG emission reduction by reducing automobile usage. Burchell et al. (2005) have shown that suburbanization is more costly in terms of the amount of energy consumed, GHG emissions, and oil dependency created by increased automobile dependency. A National Research Council (NRC), TRB (2009) study addresses compactness and vehicle miles of travel (VMT) created by automobile dependency (NRC, TRB 2009 p.1), though other aspects of compactness are presented also.

Specifically, the NRC TRB (2009) study cites literature that indicates compact development can reduce VMT by 5 to 12 percent and possibly by 25 percent, but only if accompanied by mass transit improvements and proximity to employment (NRC, TRB 2009 p.4). According to the NRC,
compactness in turn can also reduce direct and indirect energy use and CO$_2$ emissions but these reductions are modest at first increasing over time (NRC, TRB 2009 pp.5–6) (cited by Zimmerman 2011, Lecture 1).

Calthorpe Associates (2010), however, critiques the NRC TRB findings, arguing that more detailed modeling shows that land use is of greater importance in reducing VMT and CO$_2$ emissions. They also argue that (cited by Zimmerman 2011, Lecture 1) VMT reductions reported by NRC TRB are even low based on existing literature, assumptions about the VMT of non-compact development against which their scenarios are compared are too low, and the study underestimates the behavioral and demographic changes that will occur on the part of travelers toward favoring compact growth, biking and walking (Calthorpe Associates 2010, pp.2–3). Cervero and Murakami (2010) found an inverse relationship between urban density and VMT tempered somewhat by road density characteristics but the relationship still held.

Population size, rate of growth and density are seen as a foundation for shaping land use patterns and trends. The Brookings Institution (2010, p.40) review of metropolitan area growth trends finds that the Far West and Southeast have the higher growth rates in the 1990–2009 time period overall, and during that period, a couple of Texas cities emerge in the higher group (cited by Zimmerman 2011, Lecture 2). In that group, Las Vegas leads with the highest growth rate of 84 percent from 1990–2000. The Northeast or Midwest is where cities with slowest or declining rates of growth are located, though New Orleans has the highest declining growth rate in the latter part of the two decade period (Brookings 2010, p.40 and cited in Zimmerman 2011, Lecture 2). The American Association of State Highway and Transportation Officials (AASHTO) (2010) reports similar findings with Far West and Southeast cities leading the growth rate.

Beatley (2000) argues that density produces transportation savings and economic benefits (Beatley 2000, p.31). Transportation by car versus transit is influenced by the density of cities, and a higher transit usage occurs in the denser European cities than in American cities (Beatley 2000, p.30). Beatley further argues that compact cities are supported by spatial forms that promote green spaces, emphasize city center activity and mixed use, infill, reuse of land, pedestrian access, connectivity, and other sustainability strategies.

Burchell et al. (2005, pp.59–60) point to the strong relationship between population density and road mileage density, arguing that one is a surrogate for the other, and use this as a basis for modeling the impact of development scenarios on road expansion, construction and hence cost.
Rapidly growing urban areas
An in-depth look at the US Census Bureau’s 2010 results sheds light on what Brookings (2010), AASHTO (2010), Beatley (2000), Burchell et al. (2005) and others have emphasized. A key outcome of the overall trends significant for the transportation, environment and security linkage is that the fastest growing areas are not the most populous areas. Romero-Lankao and Dodman (2011, p.114) identify as one of the key processes of change worldwide for urban areas that the small urban areas are undergoing rapid growth as well as changes in their form with half of the urban population in areas under a half million people.

The US Census Bureau (2011, p.6) identified ten areas as the fastest growing metropolitan statistical areas (MSAs). A number of insights about the relationship between rate of growth and transportation-related characteristics are apparent in these fast-growing areas and some computations using the data are presented below.

- As Romero-Lankao and Dodman (2011) indicate, the fastest growing areas are not the most populous MSAs. In fact, there is no overlap between the Census’ fastest growing urban area list and the Census’ top ten most populous MSAs, and this MSA pattern is also true of the Census’ listing of populous and fast-growing counties and incorporated places (US Census Bureau 2011, p.9; 11).

- These fastest growing MSAs are growing faster than the states in which they are located. The ratio of the rate of change in the MSA compared to the state it is in is always above one.
  - Palm Coast, Florida has 5.2 times the growth rate of Florida, followed by Bend, Oregon which is growing at 3.1 times the rate of Oregon.
  - Half of the top ten fastest growing are growing about twice the rate of the states they are in. These are St. George, Utah; Raleigh–Cary, North Carolina; Cape Coral–Fort Myers, Florida; Greeley, Colorado; and Myrtle Beach, South Carolina.
  - Three areas, Las Vegas–Paradise, Nevada, Provo–Orem, Utah and Austin–Round Rock–San Marcos, Texas are growing between about 1–2 times the states they are in.

- Four of the top ten fastest growing MSAs are in states that rank high in terms of VMT based on US Department of Transportation (DOT) Federal Highway Administration (FHWA) VMT data (2011, Table VM-2 dated January 2012): the two Florida MSAs, Palm Coast and Cape Coral–Fort Myers; the Austin area in Texas, and the Raleigh area in North Carolina. The other MSAs rank low, which may imply a radical change in how they accommodate
vehicular traffic. A closer but still broad estimate of transportation sufficiency is VMT per lane mile based on US DOT, FHWA (2011, Tables HM-20 dated December 2011 and VM-2 dated January 2012) data. According to the FHWA data, the states in the US ranged from 95,000 to over 2 million VMT per lane mile in 2010. Two of the fast growing MSAs are located in states towards the high end of that range – Palm Coast and Cape Coral–Fort Myers, both in Florida. The other MSAs are in states with lower VMT.

INRIX, Inc. (2011) identified roadway bottlenecks within some of these areas. Finally, transit availability is sparse in these fast growing areas. Heavy rail systems tend to be more common in the highly populous cities rather than those that are growing fast. None serve these faster growing MSAs but heavy rail exists in other parts of the states in which they are located, such as in Portland, Oregon, Pompano Beach, Florida, and Dallas–Fort Worth, Texas. This is also the case for light rail, where light rail exists in the state in which a fast growing MSA is located: Portland, Oregon, Dallas and Houston, Texas, Charlotte, North Carolina, and Tampa, Florida, but not in the fast growing MSAs themselves. Commuter rail is not located in the rapidly growing MSAs but in other cities in their states: Dallas–Fort Worth, Texas, Portland, Oregon, and Pompano Beach, Florida. Thus, growth in newer areas tends to be in areas that are auto dependent, which increases the potential for GHG emissions and other environmental effects.

DISCONNECTING

The reach of transportation often follows, as well as shapes, human settlements. It disconnects as well as connects. A few forces of disconnection are described briefly below: equity issues, sprawl, disasters, and the deconstruction of roads.

Equity and Transport Networks

Social injustice arises as a force disconnecting areas within cities, with transportation playing a major role. In its broadest construction, environment encompasses social justice, and in fact the environmental justice movement historically combined those two issues with transportation often at the center. The creation of nodes in a transport system is often driven by some social need. The need for station access in disadvantaged areas has achieved in many places the status of a social movement in and
Transport, the environment and security

The US EPA (2010), for example, used access to light rail transit to combine the need for social equity and environmental compatibility. In 2010, the US EPA awarded St. Paul, Minnesota an achievement award for the partnership it created to build three light rail stations to provide access to communities that depend on transit to connect them to their livelihoods. The US EPA announcement noted that “Construction of the three light rail transit stations will directly benefit the 8,331 people who live within a quarter mile of the stations (81% minority; average median household income for homes near the three stations is $32,000)”, and will connect downtown St. Paul with downtown Minneapolis (US EPA 2010).

The 2010 American Community Survey data (US Census Bureau 2010) reveals differences in how workers in various levels of poverty travel to work, as shown in Table 1.1 (for example, based on a one-year estimate, of those who take public transportation to commute to work 11.2 percent were below 100 percent of the poverty level, whereas only half of that, or 5.8 percent, of those who drove alone were in that poverty category).

<table>
<thead>
<tr>
<th>Total*</th>
<th>Drove alone**</th>
<th>Car-pooled**</th>
<th>Public transportation***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 100% of the poverty level</td>
<td>6.9</td>
<td>5.8</td>
<td>10.0</td>
</tr>
<tr>
<td>100–149% of the poverty level</td>
<td>6.7</td>
<td>6.0</td>
<td>9.6</td>
</tr>
<tr>
<td>At or &gt; 150% of the poverty level</td>
<td>86.3</td>
<td>88.3</td>
<td>80.5</td>
</tr>
</tbody>
</table>

Notes:
* Based on 135,861,000 workers 16 years and over for whom poverty status was known.
** In cars, trucks or vans.
*** Excludes taxis.

Source: Compiled from the US Census Bureau, American Community Survey 2010, Table B08122.

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Nationwide, the American Community Survey (ACS) shows that 4.4 percent of all commuters had no vehicle available, but for those using public transportation, 36.5 percent had no vehicle available (US Census Bureau 2010, Table B08141).

Bullard (2007) links land use to equity in terms of the lack of access to public transit and private vehicles and funding for transportation (Bullard...
2007, pp.36–7). He notes the absence of rail transit in Detroit, considered heavily racially segregated (Bullard 2007, p.40).

Wachs (2010) argues persuasively that mobility is key to reducing poverty throughout the world, and the manner in which this connectivity occurs and can promote sustainability differs depending on the nature of each place.

A number of different aspects of social justice pertain to transport. One is environmental justice, which initially arose in the context of protecting people from the environmental effects of waste processing and disposal, and later expanded to transportation. The initial US federal action was Executive Order 12898 and subsequent guidance and plans to implement US EPA policy (US EPA 2011).

Another is access to transport services in outlying areas. Some unique case studies identify the disconnectedness of outlying areas usually housing lower income residents from urban centers, and transportation plays a key part in this (Shannon and Wells 2007). The coverage of transport networks has often been the target of claims regarding equity, where lines may pass through low income areas but have no access points there.

Nine cities were reported by Kneebone (2011; also cited by Tavernise 2011) similar to earlier work (Kneebone and Garr 2010a, 2010b) with more than 50 percent of their poor populations in suburbs in 2010. When the ratio of the share of poor populations living in metropolitan areas is computed from the Kneebone data (2011) for 2010 versus 2000, the results show 33 cities with ratios exceeding 1.0, that is, the percentage of their populations that were poor increased between 2000 and 2010. Table 1.2 shows an illustrative group of 11 whose ratios exceed 1.20. Only two to four of these areas are served by rail systems and those that are account for a relatively low share of nationwide rail trips. The Chicago–Naperville–Joliet is the one exception which has 6 percent of US heavy rail passenger trips and 15.5 percent of US commuter rail system trips (computed from the National Transit Database). This suggests that the suburban poor tend to be disconnected from public transportation in these cases though further research is needed to evaluate specific access.

Sprawl as Disconnecting Core and Region

The spatial demands of sprawl illustrate unconnected development. Though in a sense sprawl developments are connected to urban cores and the infrastructure to support them is inevitably connected to some centralized area, they are unconnected in the sense that they produce discontinuities at least in the way transportation is provided to connect them to urban centers. It is analogous to habitat fragmentation in ecology.
Transport, the environment and security

Burchell et al. (2005, p.3) refer to this as “leapfrog” developments where land uses become separated spatially, requiring longer utility lines and increased automobile dependency (Burchell et al. 2005, p.14). Now the imperative of climate change and energy resource needs are proposing to reshape the way transportation is done to achieve greater connectivity.

AASHTO has made a similar point about discontinuities between urban and rural areas from a different perspective. AASHTO (2010) argues that the decline in or lack of connectivity between rural and urban areas is associated with the lack of roadway capacity. Their argument is that while population and roadway dependent users have increased in relatively distant areas of the country, reflected in increasing VMT, roadway mileage

Table 1.2 Comparisons between changes in shares of poor populations in suburbs from 2000 and 2010 and prevalence of rail transit in 2009 for selected US cities

<table>
<thead>
<tr>
<th>Metropolitan area</th>
<th>Ratio of 2010 versus 2000 share of poor populations (&gt;1.20)*</th>
<th>Prevalence of rail transit % share of trips**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provo, UT</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>Milwaukee, WI</td>
<td>1.34</td>
<td></td>
</tr>
<tr>
<td>Jacksonville, FL</td>
<td>1.31</td>
<td></td>
</tr>
<tr>
<td>Chicago–Naperville–Joliet IL–IN–WI</td>
<td>1.30</td>
<td>5.8</td>
</tr>
<tr>
<td>Detroit–Warren, MI</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>Austin–Round Rock, TX</td>
<td>1.26</td>
<td></td>
</tr>
<tr>
<td>Cleveland, OH</td>
<td>1.24</td>
<td>0.1</td>
</tr>
<tr>
<td>Houston, TX</td>
<td>1.23</td>
<td>0.5</td>
</tr>
<tr>
<td>Minneapolis–St. Paul, MN–WI</td>
<td>1.22</td>
<td>0.0</td>
</tr>
<tr>
<td>New Orleans, LA</td>
<td>1.21</td>
<td>1.2</td>
</tr>
<tr>
<td>Dallas–Fort Worth–Arlington, TX</td>
<td>1.21</td>
<td>0.2–0.3</td>
</tr>
</tbody>
</table>

Note: HR = heavy rail, CR = commuter rail, and LR = light rail.
These urban areas are those that had a change in the percent share of their population that was poor in suburbs of greater than 1.20 from 2000 to 2010, computed from Kneebone (2011) data. Tavernise (2011) using Kneebone work has discussed the movement of the poor to some suburbs.

Sources:
* Computed from Kneebone (2011). Data provided courtesy of E. Kneebone. Metropolitan areas are arranged in descending order of the ratio of the percentages in 2000 versus 2010. For earlier work see Kneebone and Garr (2010b).
** Computations from the US DOT, National Transit database 2009.

Burchell et al. (2005, p.3) refer to this as “leapfrog” developments where land uses become separated spatially, requiring longer utility lines and increased automobile dependency (Burchell et al. 2005, p.14). Now the imperative of climate change and energy resource needs are proposing to reshape the way transportation is done to achieve greater connectivity.
Introduction

has not increased and access to the interstate is limited. Yet another consideration is that the widening of roadways (reflected in lane miles) has occurred to accommodate some increased capacity. Firestine (February 2011) attributes the decline in connectivity of rural areas to intercity public transportation from 2005 to 2010. Similar arguments have been made for inner city and intercity connectivity in terms of rail transportation, and some attention to increasing rural transit is given in the AASHTO report.

The disconnecting effects of sprawl and some of the constraints on transportation systems it produces can lead to serious gaps in the ability of emergency services to respond in disasters. Characteristics of street connectivity in sprawl areas also affect transportation for emergency services. Trowbridge et al. (2009) focus on the response time of emergency medical services (EMS) and in a nationwide study, correlated the occurrence of motor vehicle crashes, vehicle response time to those crashes, and the degree of sprawl defined at the county level. They found significantly higher delayed response times in counties with a high degree of sprawl, which they explain in terms of the relatively low connectivity of streets and longer driving distances in sprawl areas. Not only was response time correlated with degree of sprawl, but they found that the delay in arrival of ambulances in sprawling counties was double that in non-sprawling areas (Trowbridge et al. 2009, p.430). In addition, streets in sprawl areas were originally designed to be narrower with fewer lanes. As development increased, congestion also increased, especially in and around the small town centers that dominate these sprawled areas. Traffic management in such instances is also a factor, but cannot fully compensate for the street patterns of sprawl communities. Finally, they indicate that the availability of emergency vehicles may be lower in more spread out areas.

Natural Hazards, Terrorism, Accidents and Other Disasters

Transport systems are routinely disrupted due to extreme weather, earthquakes or severe accidents and intentional terrorist attacks, which disrupt how people travel and disconnect communities. Communities are often isolated for long periods of time, and in extreme cases relocated where the transportation infrastructure cannot be restored. The experience of Vermont communities following Hurricane Irene is a case in point. Chapters 6 and 7 go into this in some detail.

Road Deconstruction

Road length has been increasing slightly during the century following the introduction of the automobile, while lane mileage has been increasing
much faster due to roadway widening. In the US there has been a general movement toward not only introducing non-structural approaches but also eliminating structural approaches for the provision of public transportation services, such as eliminating or deconstructing structures to allow for the return of natural processes and promote new transport modes. The deconstruction of roads, addressed in Chapter 4, represents a disconnecting force in transportation networks, though it does not appear to be widespread. Within the US, roads in urban areas have come down in Seattle, Buffalo, Toronto, New Haven, and Milwaukee (Peirce 2008). In New York City, communities have called for the removal of the Sheridan Expressway due to safety and other concerns.

RECONNECTING

Whether disasters or incomplete transport networks disconnect the way people want to travel, innovative ways of reconnecting seem to find their way into the traveler’s portfolio. A revolution has occurred in the ways people travel and are willing and able to travel.

Avoiding Conflicts with Security and Environment While Reconnecting

Sometimes transport modes are consistent with environmental and security needs and other times they are disruptive of those needs, requiring regulatory action to rectify the adverse impacts.

Overland passage where roads and rails do not exist or are not used has generated its own set of vehicles. Here is where the environment and security intersect with transport.

The means of transport that do not involve roads or rail or do not involve them exclusively are either motorized or non-motorized. Non-motorized forms, which are fairly benign relative to motorized transport in non-road areas, include various forms of walking, running and hiking and the use of animals such as horses, camels and alpaca for transport. The attention here is on the motorized forms.

In order to overcome distances where few roads exist or roadway capacity is limited, a number of different forms of motorized transport have arisen for different types of trips. Many of them originated as recreational vehicles but their purposes have expanded. They are distinguished by the fact that they do not use public roads but rather paths, trails or even no defined routes moving freely over land. The names that typically are used are all-terrain vehicles, all purpose vehicles, and off-road vehicles.
The history of one such vehicle – snowmobiles – exemplifies the struggles between transport and the environment as well as issues of equity and social class, and is described in detail in Chapter 5. The snowmobile, invented at about the same time as the automobile, paralleled the history of the automobile in non-road-based environments. To some it connected people with the recreational opportunities of wilderness areas and to others it disconnected people from the natural environment in those areas.

**Unusual Connections and Reuse: Pedestrian and Multi-use Paths**

Cities have an advantage in designing vertically, given their density. Old elevated transport networks that have fallen into disuse often find new uses. Shevory (2011) identified a number of the initiatives to convert rails into pedestrian routes:

- Paris, France: Promenade Plantée;
- Atlanta: BeltLine;
- Chicago: Bloomingdale Trail;
- New York: The High Line;
- Philadelphia: The Reading Viaduct;
- Seattle: Waterfront Seattle; and
- St. Louis: The Iron Horse Trestle.

Although old rail stations have commonly been reused as public buildings, the conversion of rail networks is not as common and is far more extensive when it occurs.

The High Line in New York City is an example of parkland and walkways which have been combined with new commercial and residential uses on and around an abandoned rail line. With the completion of the second section in 2011, the High Line is 1 mile long and 30 feet above the street, and according to NYC its 29 projects (some completed and some underway) represent an investment of $2 billion (NYC Office of the Mayor 2011). The positive economic impacts of the High Line have been underscored by many (NYC Office of the Mayor 2011), but questioned by others who have businesses beneath the line (Feeney 2011; NYC Office of the Mayor 2011). Planning for a third section began in 2011. Similar initiatives are emerging in other inner city areas (Giles 2010). “Walkway Over the Hudson Historic State Park” uses a former old rail bridge, the Poughkeepsie–Highland Railroad Bridge, which stopped operating in 1974, as a walkway extending 1.28 miles and used by about 600,000 visitors per year (Applebome 2011).
Bridges commonly provide pedestrian walkways, but one unusual example is the suggestion of using an old bridge to be replaced with a new one as a pedestrian walkway – the 3 mile long Tappan Zee Bridge in New York State (Applebome 2011).

Alternative Transport Modes

Non-motorized and motorized transport modes that reduce emissions are environmentally compatible and promote security given their degree of decentralization yet supporting urban density. A few examples provide an introduction to these alternatives, which are revisited in Chapter 4.

Biking

Biking is considered compatible with environmental quality due to the reduced need for energy and its associated emissions, yet the full life cycle and hence environmental costs of biking will need to consider all of its production components. The growth in biking as a means of transport is reconnecting areas within and around cities as well as many other places. Biking overcomes many obstacles of urban transport such as congestion. The growth in bicycle commuting continues to increase in some of the larger US cities. Based on the work of Pucher et al. (2011, p.459; Bruni 2011) rates of commuting in six US cities have increased dramatically between 1990 and 2009, at least doubling and often tripling or more. Pucher et al. (2011, p.459) estimated that in 2009, the rates of commuting using biking for each of the six US cities were: Portland, Oregon 5.8 percent, Minneapolis, Minnesota 3.9 percent, San Francisco, California 3.0 percent, Washington, DC 2.2 percent, Chicago, Illinois 1.2 percent, and New York, NY 0.6 percent.

The percentages probably reflect in part the relative extent of rail and bus transit in these cities. New York, Chicago and Washington, DC, for example, rank lower in the percentage of people commuting by bike yet rank among the highest in rail passenger trips. This growth does not include the many biking trips taken for non-work related purposes. The increasing trend is no doubt supported by bike share facilities and such facilities have in turn probably grown in response to the demand.

Electric vehicles

Electric vehicles have grown in popularity, given that they reduce emissions. Efforts to take into account the full life cycle costing have been underway, in particular, focusing on the origins of the electric power. As cited earlier in this chapter, electric vehicles unexpectedly showed up for disaster recovery following the catastrophic earthquake and tsunami
in Japan on March 11, 2011 (Belson 2011). Chapter 4 addresses electric vehicles and other alternative vehicles, focusing on the importance of infrastructure charging stations and their location, access to rare earths for batteries, and the use of a life cycle approach to assessing the environmental effects that are key to their viability.

**Adaptable Street Networks**

Street networks that have become transformed to accommodate multiple uses – the “complete streets” – are increasing the connectivity between transport and the environment. Chapter 4 explores the many functions streets have assumed and many of their new functions to achieve environment and security goals as well as transport. Streets provide often overlooked environmental management functions of drainage, waste clearance, and sanitation. They are also the front line for security. In supporting transport, streets need to meet existing and new competing demands made by multiple modes of travel that are motorized and non-motorized, operate at different speeds and purposes, and have different storage needs. New innovations are now transforming streets to begin to meet transport and environmental needs, and the next challenge is to meet security requirements.

The adaptability of streets for biking has not only occurred along existing street networks but also along other kinds of conduits. Pucher et al. (2011, p.464) mention three distinct types as bike routes that are on and off streets and are lanes or paths. Thus, biking is partially breaking away from street networks. They argue that more bike networks encourage more biking. For the six US cities they studied, in decreasing order of the percent of the commuting population using biking, the extent (in kilometers) of bike lanes and paths per 100,000 people in 2010 was Portland, Oregon 73, Minneapolis, Minnesota 70, Washington, DC 27, San Francisco, California 15, Chicago, Illinois 9, and New York, NY 8 (Pucher et al. 2011, p.464).

**Bringing in the Outliers**

Transit systems are unique in their ability to change routes and direction and connect many thousands of people through common transfer points. In that sense they are highly connected and interconnected networks. On the other hand, transport systems inevitably end somewhere. At the end of the line serious disconnects can occur – some are intentional and others not. Some make connections to new forms of transport or to limited access environmental corridors. Newman (2008) painted a very
colorful picture of the last stop about places frozen in time, and identified 24 stops in the NYC system where the rail service terminated. In fact, as he points out, the end points are always listed on the train. Some end in cemeteries, neighborhoods that mark a stopping point, or some physical barrier such as one of NYC’s many waterfronts or recreation areas: the parks, stadiums, and play areas. Others exist to serve large concentrations of people such as schools. Shannon and Wells (2007) painted a less poetic picture of the connectivity of outlying areas in New York City. They argue that many of the commutes are longer in the outer parts of the city where neighborhoods are not well-connected to rail transit and bus connections may not always be that reliable. Other forms of transportation, such as vans and automobiles, may provide such connectivity, but at higher cost. End points are analysed in Chapter 2 for heavy rail transit across the US to illustrate how they occur in transit networks.

Connectedness is in part reflected structurally in transit systems in terms of transfer points (Hadas and Ceder 2010). The connectivity of rail systems displays a high degree of variability in terms of travel activity and physical infrastructure. The next chapter begins with an analysis of the structure of transport.

GOING FORWARD

The phenomena of connecting, disconnecting and reconnecting of networks provide a powerful foundation to integrate transport, environment and security. The chapters that follow identify where the vulnerabilities are occurring in transport networks and how these connections can be strengthened.

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