Making Infrastructure Competitive in an Urban World

By RAE ZIMMERMAN

The infrastructure of the future provides the opportunity for new innovations to meet the constantly changing and diversified needs of cities. Some of the relatively more recent needs are using renewable resources, protecting infrastructure and its users against natural hazards, reducing environmental threats including global warming, enhancing safety and security, and providing an overall high-performing service for infrastructure users. Given that resources to support these additional financial needs and services are limited, this article will examine ways in which cities can address the demands of these new emerging areas synergistically as well as through more traditional investments. In particular, traditional investment areas for upgrading urban infrastructure to meet "state-of-good-repair" benchmarks are presented for energy, transportation, and water as a foundation for conceptualizing how these new demands might alter, yet dovetail with, traditional investment.

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confronts these issues directly, sector-specific approaches to infrastructure and its investment will continue to dominate and increase overall costs.

Understanding the tradition for public and private investment in infrastructure in the United States provides an important context for these five key issues; these patterns of spending are examined briefly in the following sections.

Public spending patterns

Public spending for infrastructure at the national level has followed patterns that frame the resources available to localities to meet their infrastructure needs. Some of these patterns for two major publicly funded sectors, transportation and water, are as follows:

- The largest share of federal infrastructure expenditures goes to highways, with various forms of public transit aggregated together ranking second (U.S. Congressional Budget Office [CBO] 2007).
- Infrastructure spending as a share of total federal spending declined between the mid-1980s and 2004 in spite of the increase in federal spending on infrastructure between 1956 and 2006 (U.S. CBO 2007).
- Between 1956 and 2004, the percentage that both total and capital infrastructure expenditures are of GDP shows a negative trend over time, and in later years—for example, between 1983 and 2004—the trend flattens out (U.S. CBO 2007; also see Uchitelle 2008).
- The percentage of federal spending increased at a lower rate than the increase in state and local spending for infrastructure between the mid-1980s and 2004 (U.S. CBO 2007), requiring states and localities to draw on many of their own resources to support infrastructure.
- While patterns of capital and operation expenditures have been paralleling one another over time since 1980, expenditures on operations have consistently exceeded capital expenditures (U.S. CBO 2007).

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Many of these patterns and trends in public spending for infrastructure have been dramatically altered by the federal stimulus initiative, the American Recovery and Reinvestment Act of 2009, which is discussed in greater detail below.

Private funding initiatives

Shifts from public to private financing arise when public funds become threatened and cost estimates for infrastructure escalate. In 2008, New York State set up a panel to explore public-private partnerships for infrastructure investment (Hakim 2008). Private financing tends to emphasize sector-specific and project-specific needs and has occurred primarily in urban areas and/or their surrounding regions. Some recent notable examples from the Chicago area (Anderson 2008) include the proposed private financing for Midway Airport, in a deal that ultimately failed (Mihalopoulos and Oneal 2009); the Chicago Skyway, which received private funds of $1.83 billion in 2004 from two companies (Associated Press 2004); and the Indiana Toll Road, part of I-90, which received private funds in the amount of $3.8 billion in 2006 in exchange for the rights to own, operate, and collect the road’s revenues (Kim 2008; Indiana Toll Road 2007). The privatization of airports has met with limited success, as Negroni (2009) has explained, in part because of federal government limits on the extent of such privatization. Profit concerns have also played a role. Negroni notes that Stewart Airforce Base in Newburgh, New York, was ultimately sold to the Port Authority of New York and New Jersey in 2007 after the National Express Group in the United Kingdom, which purchased the airport in 2000, did not find it profitable.

With these patterns of investment in mind, the remainder of this article focuses on key factors that influence public investment strategies for urban infrastructure but that are often overlooked or not directly addressed in urban infrastructure finance. It also presents common technologies and approaches to service provision and usage, which are applicable to these factors simultaneously, with the aim of arriving at solutions to economize on resource investments.

Factors Influencing Infrastructure Investment

The factors that shape infrastructure investment have changed dramatically. Although some of these factors and their precursors have been recognized for a long time, attention has focused on separate infrastructure sectors and, within each sector, separate functions or areas of responsibility. What is new is the convergence in time and space of these seemingly competing interests, especially as they play out in urban areas.

Some of the key factors that influence public investment in infrastructure and are likely to continue to do so in the future are as follows:

- Multiple goals for which infrastructure is designed and managed.
- Flexibility or the ability of technologies and service delivery to adapt to threats in a way that preserves public services.
Interdependencies, which reflect the interconnectedness of different infrastructures spatially and functionally and which often magnify the vulnerability of infrastructure.

Management interventions that can occur in any one of a number of ways, which rely on a comprehensive understanding of an infrastructure system to prevent its demise in the face of threats. Different points of intervention in the management of infrastructure exist, and intervening at any one point can avoid or reduce the consequences of infrastructure disruptions and the cost of recovery systemwide.

Regulatory levels that reflect the stringency with which infrastructure is controlled, whether by government or the private sector; such regulatory levels reflect values and expectations, particularly related to public values and priorities tied to the visibility of infrastructure to the public.

Multiple goals

Infrastructure services within urban areas have had to meet a very diverse set of needs. These include protection from multiple threats such as resource insufficiency, natural hazards, environmental risks including climate change, security, safety, and financial shortfalls in connection with maintaining service performance and enhancement to provide services that are convenient, comfortable, and economically and socially acceptable. In some cases, these multiple threats occur simultaneously, reinforcing one another and magnifying their overall effect. Many of these threats appear to be increasing in frequency, particularly in urban areas, with extreme events becoming more commonplace. The costs of reducing exposure and the consequences of these events, as well as of achieving other goals, can far exceed available financial resources unless the means to prevent exposure are directly confronted and internalized in cost estimates. Urban areas present a particular challenge given their size and population density.

First, resource sufficiency is critical to the viability of infrastructure. Constraints on the sufficiency of resources that infrastructure services depend on have been common throughout history, requiring that these services reach well beyond the boundaries of the cities and regions they serve to meet population expansion and increasing population needs. For example, limited water resources within urban area boundaries have often forced these areas to draw water from farther and farther away. New York City developed its water supply system by drawing water from 125 miles away at its farthest point. Los Angeles draws its supplies from several hundred miles away. There is reason to believe that similar trends have occurred and are continuing to occur in other areas. This condition has key land use implications for how and where development occurs relative to resource location. Another example is access to materials, supplies, and labor needed to support infrastructure services. The time and cost of infrastructure construction, for example, has often been limited by interruptions in the supply of concrete and steel and scarcity of the vehicles and labor to transport these, especially as distances to secure these increase.

Second, natural hazards routinely compromise energy, transportation, communication, water, and sanitation services, resulting in infrastructure deficiencies that can be the direct cause of deaths. Hurricane Katrina’s damage cost of $81 billion
was the highest of any hurricane occurring through 2006 and more than three times that of the second-highest-ranking hurricane, Andrew (Blake, Rappaport, and Landsea 2007, Table 3a). During Hurricane Katrina, deaths in nursing homes in New Orleans were in part attributed to the loss of power for life support systems and for cooling in temperatures of more than 100 degrees. Transportation and communication system failures denied residents access to the means to escape. The occurrence of these hazards and their costs are increasing. Overall, eight of the top ten hurricanes in terms of damage cost ($5 billion or more) occurred after 2000 (Blake, Rappaport, and Landsea 2007, Table 3a). Federally declared major U.S. disasters have been increasing (Simonoff et al. 2008, 382), and weather-related electric power outages in the United States have been increasing since the early 1990s (Simonoff, Restrepo, and Zimmerman 2007).

These threats also vary across cities. Using the example of hurricanes alone, the following examples compiled from Blake, Rappaport, and Landsea (2007, 21, Table 12) illustrate the geographic diversity among cities and variations in the costs of damage over time. According to the information provided by Blake, Rappaport and Landsea, between 1990 and 2005, more than two dozen cities were hit by major hurricanes of Category 3 or higher. Florida led in the number of cities affected, accounting for twelve of the twenty-six cities, followed by Louisiana with four cities during that period. The cities affected by each hurricane in descending order of total dollar amount of the overall damage (not necessarily confined to each of the cities listed) are as follows:

- Four cities—New Orleans, Louisiana; and Bay St. Louis, Biloxi, and Pascagoula, Mississippi—suffered the catastrophic effects of Hurricane Katrina in 2005, with a total of $81 billion in damages (for all areas affected).
- Two cities—Morgan City and Houma, Louisiana—were hit by Hurricane Andrew, which entered Louisiana August 26, 1992, with a total of $26.5 billion in damages (for all areas affected). In addition, other studies have shown that numerous cities in South Florida sustained extensive damage when the storm hit on August 24, 1992, documented by aerial surveillance and ground surveys (Marshall 1992).
- Two cities—Key West and Naples, Florida—were hit by Hurricane Wilma in 2005, with a total of $20.6 billion in damages (for all areas affected).
- One city—Fort Myers, Florida—was hit by Hurricane Charley in 2004, with a total of $15 billion in damages (for all areas affected).
- Two cities—Mobile and Gulf Shores, Alabama—were hit by Ivan in 2004, with a total of $14.2 billion in damages (for all areas affected).
- Two cities—Cameron, Louisiana; and Beaumont, Texas—were hit by Hurricane Rita in 2005, with a total of $11.3 billion in damages (for all areas affected).

In many of these cases, evacuation was of paramount concern, and the transportation infrastructure needed to play a key role was seriously disabled in the hours and days following the hurricanes. Urbina and Wolshon (2003, 268) inventoried contraflow practices for evacuation routes, which enable roadways to reverse direction. Although they list contraflow measures for twenty-one routes in ten states, none of those listed appear to serve the urban areas identified above as having experienced the worst damages during the hurricane seasons of 1990 through 2005.
The utility impacts after Hurricanes Katrina and Rita and other hurricanes provide a picture of how hurricanes can affect water, power, and communications. Water resource facilities were also severely affected. In Louisiana, by September 30, 2005, the U.S. Environmental Protection Agency (EPA; 2005, “EPA Response Activity—October 1 Drinking Water Assessment”) summarized the status of 1,591 drinking water facilities serving approximately 5 million people as follows in their October 1, 2005, latest update of the “Drinking Water Assessment”: “378 of these facilities are operational, 80 are operating on a boil water notice, 32 are not operating, and further information is being gathered on 1,101 (most of these facilities are in unaffected areas).” In Mississippi, the EPA (2005) summarized the status of 1,368 drinking water facilities serving about 3.2 million people as follows: “1,253 of these facilities are operational, 79 are operating on a boil water notice and 36 are inoperable.” Similarly, for wastewater facilities, out of a total of 173 public-owned treatment works (POTW) in Louisiana, the EPA (2005, “EPA Response Activity—October 1 Wastewater”) summarized their status by September 29, 2005, as follows: “140 of these facilities are operational and 33 facilities are either not operating or their status is unknown.” In the area affected in Mississippi, out of 118 POTW, the EPA (2005) summarized their status by September 29, 2005, as follows: “114 of these facilities are operational and 4 facilities are either not operating or their status is unknown.” In Alabama, “7 facilities are operating and 1 is not operating.” A survey by Stein et al. (2009) of residents of Harris County, Texas (where Houston is located), after Hurricane Ike in 2008, revealed noteworthy similarities and differences in the impacts of the hurricane on the utilities. Close to a third of the respondents indicated that they had both cable/Internet and power losses for more than ten days, and another quarter of the respondents indicated that the outages lasted five to ten days. About a fifth of the respondents indicated that telephone service was out for five to ten days, and another fifth indicated outages over ten days. In contrast, two-thirds of the respondents indicated that they never experienced water loss.

Third, climate change poses another threat to infrastructure. Recent estimates for climate-related sea level rise and the frequency and severity of storms reveal that existing infrastructure facilities, especially in coastal areas, lie at or below sea level, potentially endangered by flooding. Transportation facilities, for example, are vulnerable since many ventilation shafts and entry and exit points are in these low-lying areas. These vulnerabilities have been specifically identified for transportation nationwide (Transportation Research Board 2008), particularly for the New York region (U.S. Army Corps of Engineers et al. 1995; Zimmerman and Cusker 2001; Zimmerman 2003a). Population and population density in coastal areas most vulnerable to the impacts of climate change continue to increase, particularly in the urbanized portions. Moreover, cities have distinctive carbon footprints that are showing serious implications for climate change, and these patterns vary geographically and by transportation and energy use (Brown, Southworth, and Sarsynski 2008). It is cities that are leading initiatives for adaptation and mitigation in connection with climate change throughout the United States and the world.
Fourth, security is an increasing concern in the infrastructure sector, and critical infrastructure protection has been a key focus of security policy for more than a decade (Zimmerman 2006). Although few terrorist attacks have attacked infrastructure within the United States, these attacks are frequent and increasing in some infrastructure sectors outside the United States, particularly in urban areas or on the infrastructures servicing urban areas (Taylor, Fink, and Liggett 2006; Simonoff, Restrepo, and Zimmerman 2005). That urban area transit is a target is illustrated by the attacks in Madrid and London and the hundreds of smaller attacks recorded by the Mineta Institute in urban areas throughout the world (Jenkins and Gersten 2001). Linear networks are typically the component targeted in infrastructure systems, as the hundreds of attacks on rail and pipelines worldwide illustrate. In the electric power sector, outside of the United States, attacks on transmission systems account for about two-thirds of the attacks (Zimmerman et al. 2005).

Several federal funding programs particularly address security threats within cities, such as the Urban Area Security Initiative (UASI), and others aimed at infrastructure, such as the Infrastructure Protection Program (IPP) and the grants that accompany it (U.S. Department of Homeland Security [DHS] 2008b). In fiscal year 2008, the U.S. DHS allocated UASI funds in sixty municipalities in thirty-one states, the District of Columbia, and Puerto Rico (U.S. DHS 2008a). Studies of resource allocation for security at the state level reveal that population is a strong determinant of the allocations (Greenberg and Zimmerman 2008), though other criteria are also used. For cities, a similar basis for resource allocation emphasizing population is apparent. In fiscal year 2008, New York City led other urban areas with a UASI allocation of $144.189 million, followed by the Los Angeles/Long Beach area with $70.403 million, the District of Columbia with $59.801 million, and Chicago with $45.862 million (U.S. DHS 2008a). When infrastructure is added into resource allocation schemes, the ranking of cities with respect to resource needs can change (Bier et al. 2008).

Safety is reflected in accident statistics. The annual number and duration of electricity outages from equipment-related failures as well as weather have been increasing since the early 1990s (Simonoff, Restrepo, and Zimmerman 2007); this has ramifications for health and safety. The U.S. Department of Transportation’s Office of Pipeline Safety tracks the causes and consequences of oil and natural gas pipelines ruptures. Although incidents have declined for some substances carried via pipeline, property losses for oil (hazardous petroleum products) have increased (Simonoff et al. 2008; Restrepo, Simonoff, and Zimmerman 2009). Accidents in the transportation sector (excluding airplane accidents) are investigated by the National Transportation Safety Board (NTSB), primarily when deaths occur.

Finally, infrastructure investment has traditionally been oriented to maintaining a “state of good repair” or normal performance of infrastructure. The cost for this in the United States was estimated at more than $1 trillion in 2005 by the American Society of Civil Engineers (ASCE), and the estimate increased to $2.2 trillion by 2009 (ASCE 2009). Although the ASCE does not give urban area
breakdowns, many of the infrastructures rated either are in cities or serve cities. Bridges are an important example, with trends showing that the condition of bridges in urban areas does not appear as positive as in rural areas. Nationwide, between 1998 and 2007, the number of urban bridges rose by 17.8 percent, while the number of rural bridges declined slightly by 1.3 percent. While the number of urban bridges has increased, bringing new bridges into the urban area inventory at a greater rate relative to bridges in rural areas and thus improving overall condition, improvement rates for the condition of urban bridges are relatively not as good as improvements in rural bridges between 1998 and 2007. Bridge condition is measured in terms of structural deficiency and functional obsolescence. The total number of structurally deficient rural bridges declined overall by 24.6 percent, as compared to only an 8 percent decline in structurally deficient urban bridges. Thus, in terms of structural deficiency, the inventory of bridges in rural areas appears to be improving faster than those in urban areas. The picture with respect to functional obsolescence was even worse for urban bridges relative to rural bridges. The number of functionally obsolescent bridges rose by 20.1 percent in urban areas, whereas the number of bridges in such condition declined by 10.1 percent in rural areas (computed from U.S. Department of Transportation [DOT] 2008, Table 2-1-9, 38).

Transit is another infrastructure area in which performance has suffered. Funding for transit has primarily been from local sources, which accounted for two-thirds of the sources in 2004 (computed from the ASCE 2009 transit report card). The new federal funding initiatives under the American Recovery and Reinvestment Act of 2009 that became law on February 17, 2009, allocated $38,155,308,399 nationwide for infrastructure and transportation (encompassing the categories of highways and bridges, transit capital, fixed-guideway modernization, and clean water state revolving funds) (U.S. House 2009) with additional funds allocated separately for energy infrastructure. Only approximately $7.5 billion has been allocated for transit (transit capital and fixed-guideway modernization), or $8.4 billion (if oversight, tribal transit, discretionary energy funding and new starts are included). In contrast, $26.8 billion has been allocated to highways and bridges (U.S. House 2009). In analyzing these expenditures, Edward Glaeser (2009) has observed a disparity in per capita funding between the states with the highest population density and those with the lowest population density, with the latter group of states receiving twice the per capita transportation funding as the former.

New York City provides an instructive example of the evolution of infrastructure, as individual goals changed over time yet coexisted. In the late nineteenth century and early twentieth century, New York City expanded its water, electric power, and transportation systems to meet a growing population. The water supply system is a noteworthy illustration. In the late nineteenth century, the city reached north and west to upstate watersheds for more water to meet a growing population. These supplies were also needed to meet public health concerns for a clean water supply to combat the threats posed by cholera and typhoid fever.
The massive third water tunnel when completed will ensure the security of the system and will allow the two aqueducts that service the city to be refurbished. Through the twentieth century, federal and state public water supply standards increased in stringency and number. The number of federal water supply standards meant to protect the quality of water resources increased from only half a dozen in the mid-twentieth century to a couple of hundred by the end of that century. As climate change has emerged as a key public issue, New York City has evaluated alternative water practices for the adaptation of the water supply (New York City 2008). After the World Trade Center (WTC) attacks on September 11, 2001, when water supply lines within and around the WTC site were impaired and firefighters struggled with the severe water shortage, the importance of the water supply to security took on a new meaning. Finally, with respect to general performance, breakages continue to occur at the rate of about five hundred per year—some minor, some relatively severe that require attention to ensure safety and bring the entire system to a “state of good repair.” The multiple goals New York City’s infrastructure faces are not unlike the multiple goals other cities experience.

Thus, given the very high costs to infrastructure from all these threats, the key issue is what synergistic solutions can simultaneously address this wide range of problems.

**Flexibility**

Infrastructure needs to have the flexibility to provide services in more than one way. For electricity, this is backup power generation; for transportation, alternative modes and routes; for water, alternative routes and product substitution. Conservation and usage reduction applies to all of these areas. In a world of steel and concrete, it is difficult to make the components of infrastructure physically flexible, but flexible rerouting and service use are possible. Innovations in adapting services in emergencies have been noteworthy. After the attacks on the WTC, about thirty miles of electricity cables were installed over the streets to connect to a different substation. Communication and electricity generation relied on portable cell towers and diesel generators imported from all over the country, and transit was able to shuttle trains over alternative routes to restore service (Zimmerman 2003b; O’Rourke, Nozick, and Lembo 2003). Given the relative flexibility of rail transit that existed before September 11, rail transit services returned later that day and readjusted within about two weeks, though overall service levels remained somewhat reduced over time (Zimmerman and Simonoff 2009). Elsewhere, following massive bridge collapses, innovative temporary bridges have been constructed rapidly to supply service. Although incorporating flexibility might initially imply more costly services, when total costs are accounted for including damages and costs to users, the cost of flexible services might not be larger. Accounting systems are obviously needed to evaluate this.
Interdependencies

Infrastructures are increasingly dependent on one another to sustain routine performance. These interdependencies occur in many different forms, generally categorized as functional, structural, and geographic (Rinaldi, Peerenboom, and Kelly 2001). Electricity is a critical point of dependency for other infrastructures, and infrastructures are increasingly dependent on information technologies and computers for command and control. Thus, an information technology outage from weather, a cyber attack, or an accident can seriously compromise a broad range of infrastructures in a series of cascading failures. Zimmerman and Restrepo (2006) showed that after the blackout of 2003, it took sometimes double or triple the time for dependent services in cities, such as water in Cleveland and Detroit, to return after electricity was restored. In the case of terrorism, after the WTC attacks, electric power and telecommunication outages due to the loss of two substations created effects extending far beyond the immediate site. The loss of Internet routing under the WTC affected Internet service as far away as South Africa, illustrative of the extensive geographic interdependencies in the telecommunications sector (Zimmerman 2003b). Interdependencies very likely increase the cost of an infrastructure disruption if they are not taken into account in disaster planning, from prevention through mitigation and recovery.

Management interventions

The history of infrastructure failures shows that numerous factors and conditions contribute to such failures, rather than just one. This not only applies to day-to-day infrastructure performance but also affects the resiliency of infrastructure in the face of other threats, such as extreme weather conditions (Zimmerman 2008). Therefore, any given failure could have been averted at any of a number of points of intervention. Some of the catastrophic bridge failures illustrate this point. Since the NTSB was established in the mid-1960s, it has investigated more than two dozen such bridge failures. (Although flooding or other natural causes contributed to the demise of hundreds of bridges, these have occurred primarily in rural areas, usually with little loss of life. The NTSB usually investigates collapses that cause a loss of life, which have occurred primarily in, near, or providing vital links between urban areas.)

The collapse of the Mianus River Bridge over Interstate 95 in Connecticut illustrates the number of factors that can contribute to a bridge’s demise and makes clear the fact that interventions could have occurred at numerous points to prevent the collapse (NTSB 1984; Zimmerman 1999). A diagnostic framework was needed to identify and exercise such management options, especially in catastrophic situations. First, the bridge had a nonredundant structure that was a common design when it was constructed: the failure of single elements could cause the collapse of the entire structure. Second, the failure of a single one of the “pins” in the pin-and-hanger structure could result in a collapse. The pin that failed was weakened by rust. Inspections did not focus on the buildup of rust, or at least did not consider it
significant enough to act on. Third, the rusting was caused by several conditions simultaneously, including inadequate maintenance, such as painting or preventing the pins from being exposed to water. The pins were exposed to water after the drainage ditches on the sides of the bridge had been covered during a repaving operation, causing water to spill over the side of the bridge. The direct cost of the bridge repairs is estimated at $20 million (Brownlee 2006), not including the costs of the loss of three lives, traffic delays, and the retrofitting of a massive number of bridges to avoid the problem on similar bridges nationwide.

More recently, the collapse of the Interstate 35W highway bridge over the Mississippi River in Minneapolis, Minnesota, on August 1, 2007, showed more than one point of failure where intervention could have occurred. Like the Mianus River Bridge, it was designed using a prevailing nonredundant bridge design. A second area, the structural strength of the plates, was also identified as a weakness. Finally, a third factor may have been construction work on the bridge at the time of the collapse that was performed in a manner that did not account for the bridge’s structural vulnerability (NTSB 2008).

Multiple interventions could have occurred to simultaneously address and prevent the problems associated with infrastructure accidents, terrorist attacks on infrastructure, and threats from natural hazards.

Regulatory levels

The quality of infrastructure services depends heavily on a wide range of standards, guidelines, and professional practices that are constantly evolving. It is at this juncture that values, preferences, engineering tolerances, and economic concerns converge. Standards reflect public values and preferences. Perceptions and attitudes of users are fundamental to defining the value and visibility of infrastructure to the public. These often vary by population sector, are unstable over time, and are contextual. Over the years, standards have increased in number and stringency as incomes have risen and public expectations and preferences for infrastructure services have been voiced. The increasing number of emergencies and disasters has resulted in routine suspension of standards and other regulations, since provisions exist for the formal suspension of regulations in emergencies. While these exemptions are critical for rapid response, they may have long-term unforeseen effects.

Innovations to Support Multiple Investment Needs

Innovative technologies for public infrastructure investment

Renewable resources, rapid construction technologies, more resilient materials, and other innovations have gained acceptance and familiarity in the infrastructure realm. As a set of technologies and services applicable to different places and circumstances, they provide the flexibility, diversity, and decentralization that address the problems identified above.
If designed and managed as a set or system of services, they can address different problems simultaneously and reduce the burden that supporting any single technology creates. For example, the introduction of alternative fuels and vehicular design for personal vehicles can address problems fossil fuel poses for climate change and provide a solution to other problems, such as security. Solar-powered vehicles also address the need to decentralize power sources to make them more secure and to reduce carbon emissions that contribute to climate change.

**Special investment needs of innovative infrastructure services**

These innovations have special finance characteristics, which in turn depend on cost assumptions. First, the cost of innovations depends on the stage of technology development at which costs are calculated. The history of technology points to the fact that infrastructure technologies emerge in stages. Some examples are noteworthy. In transportation, the transitions from horse-drawn carriages to motorized personal vehicles and from horse-drawn trolleys to modern mass transit vehicles involved dramatic changes in transportation technology. In electric power, the move from the use of wood to centralized production using fossil fuels also illustrates this point. In water, the transition from wells to community water supply systems is an illustration of another major technological shift that dramatically changed the pricing of services. Costs are generally higher at the inception of a new technology, declining as demand increases. Second, scale dramatically influences cost calculations. Many infrastructure technologies are now sized in a way that requires a high usage rate to function and be economically viable. Wastewater and water supply treatment plants, for example, cannot function with too little water inflow.

In many infrastructure areas, renewable resources are taking center stage. Like traditional infrastructure technologies, renewable resources for transportation, energy, and water initially entered the market at relatively high costs because of their rarity, and the high degree of uncertainty in their performance. Again like their predecessors, there are signs that the price of renewables is dropping in some areas as technologies mature, tap into alternative materials and designs, and gain broader acceptance. An example of technological maturity is the cost of solar technologies for home heating; these initially suffered from problems associated with the purity of an essential material, silicon; reliance on selenium; the size of collection devices; and storage of generated power. An example of the emergence of managerial solutions to support solar technologies, bringing greater acceptance and potentially lower prices, is solar companies providing installation and maintenance services for home owners in exchange for lease or monthly service fee arrangements (Smith 2008).

Although investments in alternative resources have become more common, shocks in the financial markets worldwide in 2007, 2008, and continuing through 2009 threatened investments in these newer technologies. Krauss (2008) and Tarquinio (2008) note that renewable energy inevitably faces competition from oil,
since the viability of renewables is affected by the demand, use, and price of oil. Tarquinio pointed to the fragmentation in the portfolios in renewables, which can potentially lead to competition among renewables rather than mutual reinforcement of diversified energy sources.

Summary and Conclusions

Given the vast threats that infrastructure faces and the limited public resources available to meet all of the needs to reduce the vulnerabilities, a key challenge is how to identify a critical intersecting set of needs that many of these threats hold in common. Then infrastructure solutions that meet multiple needs can be explored, with respect to the design of services, the manner in which the services are used, and the technologies that support them. Likewise, flexibility, interdependencies, the capacity and propensity for managerial interventions at different points, and regulatory restrictions are key determinants of infrastructure investment levels and where these investments should be placed. Until now these factors have been only indirectly considered in cost estimates, if at all, given the emphasis on the direct economic development impacts of infrastructure.

New technologies include the use of renewable resources, but are not limited to them, and cover strategies to rapidly recover services using temporary structures, for example. For these newer, innovative approaches to be introduced, they need to be balanced with other technologies. It should be expected that they will be more costly at first, but as their viability is proved, their cost will diminish over time. Cities offer the opportunity to integrate the multiple needs of infrastructure services, given the density of the infrastructure and its users.

References


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