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## Managing urban development through innovative infrastructure and environmental systems planning

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# **Managing Urban Development Through Innovative Infrastructure and Environmental Systems Planning**

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## **Abstract**

A resurgence in interest in problems of urban and suburban conglomerates has occurred, revisiting growth management issues of the 1970s. Rates of per capita developed land and vehicle usage increase in spite of the introduction of sustainability concepts into planning. Today's concerns still focus on the incapacity of infrastructure systems, the ambient environment, and land resources to support growth and even maintain the existing level of development. Issues of the equitable distribution of infrastructure systems and their impacts have complicated these issues still further.

Managing new and existing infrastructure facilities and services as a common system aligns development with its spatial context. Various theoretical approaches address this problem ranging from sustainability concepts to life-cycle engineering. This paper first identifies the incongruence or difference in structures between existing and new infrastructure systems and the manifestation of these differences in developed and adjacent developing areas. Second, some relationships between existing and new systems are evaluated for key infrastructure services for water supply, water resources management and wastewater treatment. This evaluation is based on observations and original research on public service management and planning within major U.S. metropolitan areas and some European cities. The evaluation treats a central set of decisions or events applicable to existing and developing facilities as a single system. Finally, the paper addresses how technological innovations can link developed and developing areas so they can become mutually supportive, avoiding spatial and capacity constraints.

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Key words: urban development, sustainability, infrastructure.

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## INTRODUCTION

Imbalances in the resources of core cities and their nearby regions, a subject that had been popular some thirty years earlier, has been revived as a critical planning issue of the 1990s. Infrastructure support systems are part of this issue, since they provide both physical and service linkages between the urban core and adjacent regions. When infrastructure systems are seen as an inherent part of the urban and regional fabric, a more coherent picture of the urban/region phenomenon is likely to emerge. The relationship between infrastructure and its urban and regional context is an obvious one and one that has often been studied. These studies, however, typically don't make the relationships explicit and moreover, don't directly address the differences in infrastructure needs and the suitability of different infrastructure technologies for urban core versus regional areas.

At the present time, development and the infrastructure systems that support and often direct it are typically unassociated. Infrastructure and environmental support systems are usually added in an uncoordinated manner to support development, and this can have adverse social, economic and environmental impacts. The nature and extent of the ramifications of the lack of integration of development and its infrastructure and resource base depends on the structure of the particular urban region, although some generalizations are apparent.

Girardet (1995) points out that cities currently occupy 2% of the land area worldwide, yet consume 75% of the world's resources. London, he estimates, with 12% of the country's population, consumes 125 times its area in terms of the land required for food, timber, and vegetation to absorb carbon dioxide emissions from the city. U.S. cities show a similar pattern and trend. The New York region, with the greatest population in the country and compact relative to other urban regions, has a per capita land consumption growth rate that exceeds the population growth rate, and this trend has persisted since the middle of the century (Yaro and Hiss 1996). The rate of land consumption for development continues to rise: "... from 1962 to

1990 the amount of land devoted to business and residences shot up by 60%,” (equivalent to 1 million acres); this rate was only 13% in the 30 years prior to 1962. Land devoted to open space dropped from 81% 30 years ago to 70% today,” they point out, whereas “a generation ago, only 19% of the region’s 12,000-plus square miles were covered by roads, offices, and houses. The current total for open space is 30%. If we do not start growing smarter, it will be 45% by 2020.”<sup>1</sup>

Not only is the existence of this phenomenon notable, but the rate at which it is occurring is unusual. Population growth rates and the rate of growth of urban settlements are the indicators most often used. Girardet (1991) captures this phenomenon by noting that “New York took 150 years to reach eight million people whereas Mexico City and Sao Paulo are taking only 15 year to increase their populations *by* eight million.”<sup>2</sup> Cohen (1995) provides a very comprehensive set of rates of population growth worldwide along with their implication for the sustainability of the world’s resources. Thus, the bottom line is that urban regions typically do exceed and have historically exceeded the resource base within their borders, whether these are natural resources or resources that have been provided through infrastructure. The rate at which this phenomenon is occurring appears to be increasing.

Yet, little is known about the manner in which infrastructure supports or directs this development including the effect that the length of time the design-build-operate process takes to be completed has on the mutual adaptability of infrastructure and development to one another. Explicitly confronting these needs is particularly critical, since new growth typically uses more energy, water, and other utilities and generates more vehicle miles of travel than older development. An understanding is needed of at least how these differential infrastructure usage rates are compatible with adjacent areas.

This paper identifies and compares some generic characteristics of the infrastructure that supports dense urban cores and suburban their regions for different urban region structures. The specific focus is on how new and innovative technologies are adaptable to the needs of different kinds of regions and parts of the same region.

## A Framework: Models of the Form of Urban Regions

Urban regions, as used in this paper, mean regions of development and activity surrounding or otherwise in proximity to urban cores. Many models and concepts exist that portray the structure of such regions usually expressed in terms of various degrees of decentralization of activities from the core. These subdivisions include discrete, self-contained centers near yet independent of urban cores (Cervero 1995). These are often referred to, for example, as new towns and “polycentricity” or subcentering. Alternatively, they are identified as less self-contained areas such as rings, wedges or corridors, rural-urban fringes<sup>3</sup> or other sectors that are functionally dependent upon the core.<sup>4</sup> These models usually define differences in spatial form in terms of the location and movement of employment and/or travel patterns and densities, activity patterns, and the evolution of social patterns over time.

## Portrayal of Infrastructure for Urban Region Models

Components of these models are typically isolated from or simplified with respect to the infrastructure systems that indirectly create and support development. The components are usually cast in terms of very broadly defined activity patterns or goals and not the specifics of what makes infrastructure function effectively as a support system. This applies both to how existing operational levels of infrastructure are maintained and how new technology is applied to expand capacity and improve quality.

The exception to the absence of explicit attention to infrastructure is some of the empirical and conceptual work that has tried to relate at least population density (not the form of population settlements) to various kinds of infrastructure technology. For example, in transportation it is often pointed out that mass transit metro or subway systems require the greatest population density to be supported, followed by other forms of light rail and finally bus and automobile. Although public preferences distort the pattern, these relationships are often cited for sustainability of the infrastructure systems both economically and environmentally. Similarly for water and wastewater systems, wells and septic systems support sparse densities whereas large

water supply and wastewater treatment plant systems with extensive distribution systems are required as densities increase.

What needs to be recognized here, however, is that the economics and engineering technology associated with these infrastructure systems usually implies a relationship of density and population size to type of infrastructure that looks more like a step function than a smooth curve. That is, there are abrupt changes or thresholds rather than continuous relationships. These can produce discontinuities between infrastructure in developed core areas (often requiring infrastructure renewal technologies) and developing regions around the cores (where different technologies often operate).

Extreme events created by natural hazards or even slow acting but persistent adverse environmental conditions can seriously undermine the integrity of infrastructure systems and hence the viability and growth of urban regions. These threats to infrastructure have been explored conceptually in connection with global warming (Zimmerman 1996) and are commonly addressed in the literature on natural hazards management and planning.

The manner in which infrastructure problems or needs have arisen in core and outlying areas is described below along with the differences in the technologies that have been used to address these needs.

## TRANSPORTATION INFRASTRUCTURE AND THE VITALITY OF CITIES

### Technological Reach: Innovations in Bridge Construction and Renewal Technology

Urban densities, unique geographic configurations (especially where water is in close proximity to the land areas), and the need to link city to suburb and cities to cities have tested the limits of many technologies. In the Spring of 1998, the world's longest suspension bridge, the Akashi Kaikyo Bridge, opened. According to Kashima and Kitagawa (1998), it linked two Japanese

islands, but was part of a plan to link four islands, the smallest of which had a population of 4 million. The entire span is 3,910 meters, its central section stretches 1,990 meters, its towers are 283 meters above the water, and the cables carry tensile forces of 120,000 metric tons (Kashima and Kitagawa 1998). Other record-setting bridges are opening. In June 1998, Denmark opened its 4.2 mile long Storebaelt Bridge, the longest suspension bridge in Europe (NYT, “Within Denmark, a Link for East and West,” June 15, 1998). Thus, newer infrastructure is expanding the capacity for intercity, city to suburb, and intersuburban travel.

Meanwhile, the older bridges in urban areas that are very much a part of regional transportation systems face very different problems and use technology differently. The problem is not so much expanded capacity with the construction of new links, but rather the rehabilitation of existing links to maintain the existing function and capacity of the urban cores that are a vital part of the urban regional structure. One such problem is the removal of lead-based paint from bridge cables and supports. This is a problem that tens of thousands of bridges throughout the country will face as they age, since lead-based paint was used as a common protective coating. Addressing such a problem in dense urban areas where people are in close proximity to the bridges requires a very broad based approach in which community and environmental factors are taken into account upfront in the selection of alternative removal technologies.

Lead-based paint removal in New York City illustrates some of the issues in this area. In NYC alone, 500 of the 770 bridges that the City owns are estimated to require corrosion protection that can involve lead-based paint removal.<sup>5</sup> The Williamsburg Bridge which links Brooklyn and Manhattan in NYC is an extreme case of a narrow, single-purpose solution to maintenance involving lead-based paint removal that ultimately aggravated an already sensitive community, resulting in a court-mandated solution. The decision to rehabilitate the bridge was made in 1988 underscoring its still vital purpose as a major transit and traffic link within the City of NY. Once the decision was made to rehabilitate the bridge, conventional means of removing lead-based paint as a part of its restoration followed. The use of sandblasting without protective cover resulted in community outrage at the actual and potential dispersal of airborne lead particles that ultimately led to a court-mandated procedure. The City was required to produce an

environmental impact assessment of the activity and provide for public review throughout the process. These requirements were restricted to sandblasting, and did not cover other means of lead-based paint removal (i.e., water blasting and chemical removal) which continued through the environmental review process.<sup>6</sup> The DEIS contains an estimated scenario of 5.7 million square feet as the total paintable surface area of the bridge with an estimated total lead release of 19,555 pounds if no cleanup were undertaken.<sup>7</sup>

The newer bridges such as the Akashi Kaikyo Bridge can adopt newer technologies to avoid these problems at the outset. The designers of the Japanese bridge adopted a design that allowed cables to be lighter yet have a higher tensile strength to support the longer roadway (Kashima and Kitagawa 1998). Apparently other means of eliminating moisture from the cables were used instead of lead-based paint. Although older bridges are less flexible in this regard, the adoption of new technologies is a definite possibility. For example, new ways of encapsulating lead-based paint rather than removing it have been developed. Encasement of the blasting area using negative air pressure is another innovation.

The construction associated with both new structures and the renewal of existing ones presents its own set of options that can make or break public acceptability of the construction activities, and very much influence the nature of development. Recently, unobtrusive methods for construction have been adopted in limited areas to minimize the burden on local residents and infrastructure users. For example, bridge reconstruction or construction can be the source of considerable disruption especially when it is done in connection with existing infrastructure rather than new facilities. One approach to minimize disruption is to simply speed up the process. This has been termed “fast-track construction” or “invisible construction”<sup>8</sup>. Anderson, Schwartz and Zollinger (1998) examined the conditions under which reconstruction of urban intersections could be undertaken in 60-72 hours. In South Africa, an overpass was swung into place over ten lanes of traffic (Addis 1998), and in the U.S. a portion of the NYS Thruway was put in place overnight. Similarly, in the area of rail line reconstruction, the reconstruction of the NYC subway line that runs over the Queens viaduct was staged in a way that enabled the line to continue in service during reconstruction.



## Transportation: Vehicle Design

Vehicle design in both transit and automobile travel has been oriented toward greater capacity or service and speed while reducing adverse environmental effects from the operation of the vehicles. Several areas of integration are needed. First, the consumer and user of vehicles have to be in line with the goals. Although fuel economy and clean fuels have sought to reduce fuel emissions, vehicle miles of travel (VMT), an indicator of the extent of automobile travel, has been increasing nationwide at least since the 1960s. Some regard this kind of human behavior as negating the advantage of fuel technology, although admittedly the situation would be worse without such technological changes. Second, is a more basic concern that new technologies be viewed from a systems perspective which incorporates all of the elements from production to consumption. Third, the underlying infrastructure needed to support these systems, such as roadways, rail, and the deployment of maintenance stations, and, critical to extreme events, an understanding of some of the smallest structural components, need to be integrated into the conceptualization and design of these vehicles. These points are illustrated by two major technological innovations – the electric car and hi-speed rail.

The Electric Car. The electric car has long been touted as the solution to vehicle emissions from combustion engines. It is considered the only Zero Emission Vehicle (ZEV). States have already mandated that a certain percentage of the vehicle fleet be ZEVs. The function of the electric car in the urban region setting, in particular, the infrastructure needed to support it, is less well understood. Two of the key limitations of the vehicle – the fact that it can only travel a limited distance between rechargings and recharging takes a considerable amount of time, makes its utility almost limited to very short trips in areas (usually only suburbs) that have easy access to electrical recharging stations. A new advance, the Hybrid Electric Vehicle (HEV), builds in more flexibility by allowing the vehicle to run on both fossil fuels and electricity (Wouk 1997).

A debate occurred in 1995 in which numerous scientists and engineers participated, which largely addressed the need for a broader context in which to view the benefits and costs of such a

vehicle (Lave, Hendrickson and McMichael 1995). The focus of the debate was that an analysis of the environmental benefits of electric cars had to encompass all of the material cycles associated with the raw materials making up the vehicle and the processes by which those materials were produced. This also had to be considered for analogous processes for combustion engine vehicles. A key focal point for electric cars was the impact of the use, production and disposal of lead-acid batteries. This argument has been somewhat minimized with the introduction of new Nickel metal hydride batteries, which avoid the pollution problems of lead and extend the range of the vehicle.

Hi-speed Rail. High-speed rail is considered to be the key to interurban travel, and the support of much of the urban forms dependent upon such travel, namely subcenter structure. The emphasis is on vehicle speed. The attention to hi-speed rail is notable in light of the fact that in the U.S. interurban and commuter rail accounts for only 2% of passenger miles per year, and this lack of consumer interest will have to overcome if hi-speed rail is to be a viable technology in the U.S.<sup>9</sup> The following are some of the advances in this area, primarily in Europe (Eastham 1995). The type of technology known as “Steel wheel on steel rail” trains travel at speeds as high as 300 km/hr. The Japan Super Train (STAR 21) being developed for higher speeds (the prototype achieved 425 km/hr) and the Japan Shinkansen (bullet train) travel at very high speeds. In France, the Train a Grande Vitesse (TGV) is the hi-speed rail equivalent, and the TGV Atlantique currently operates at a maximum speed of 300 km/hr. In Germany, the InterCity Express (ICE) has a speed of 250 km/hr. In Sweden – the X2000 has a top speed of 220 km/hr (the passenger compartment is tilted relative to the wheeled undercarriage for passenger comfort around curves at higher speeds). Italy has the ETR-450 tilt body train. Eurostar will link cities in England and the continent through the Chunnel. Finally, the very hi-speed rail is represented by Maglev. Maglev is being developed for speeds from 400-500 km/hr.

All of these trains, especially Maglev, are limited by the supporting infrastructure. Eastham points out that unlike hi-speed rail which utilizes existing rail lines, Maglev requires new rail infrastructure. The major obstacle to reaching higher speeds greater than 500 km/hr is aerodynamics, according to Eastham (1995), which can be overcome by having the lines move in

a tube from which air has been evacuated. For other kinds of hi-speed rail systems, the supporting rail infrastructure has been given serious attention. Raoul (1997), for example, points out that conventional roadside signaling systems must be substituted by computerized signals, given the speed of the trains, and the motion and vibration of the cars on the tracks also becomes a critical infrastructure consideration.

While the big things are being targeted for technological innovation, it is usually the small things that can lead to massive disruptions at the extremes that go unnoticed and are in many ways too simple to draw the attention of the experts. The examples in transportation are numerous and occur everywhere in transportation and in other areas of infrastructure as well. For example, the collapse of a section of the Mianus Bridge was due to a crack in a pin supporting the section, resulting in the death of several people. The failure of No. 8 bolts occurred with sufficient frequency that Congress produced a hearing report, entitled “Is America Losing Its Grip?” A major shutdown of Metro North occurred one winter due to the failure of a small shoe to clear snow that could have been replaced by a known, more efficient device. The German ICE train crashed on June 3, 1998, killing over a hundred people. Although the cause has not been determined, one idea that has been put forth is that it had to do with the rolling gear (Cowell June 5, 1998). These components of the infrastructure are widely dispersed in the economy, fall within the domain of many institutions, and are large subject to discretionary decision-making making them particularly difficult to manage.

To summarize, new technologies for both rail and automobile travel are emerging and in some cases are very well developed. In the case of both hi-speed rail and electric vehicles, the infrastructure is sorely needed to support the technologies. This need probably exists at different levels in different parts of urban regions. Moreover, existing infrastructure has shown itself to be vulnerable to very small defects in mechanical parts as well as human error. Ultimately, new technologies will suffer as well from these kinds of problems, and the recent collision of the German hi-speed train suggests this. Thus, linkages to both related supporting infrastructure and the human and mechanical systems associated with them are critical to the effective implementation of these technologies.

## WATER RESOURCES AND ASSOCIATED INFRASTRUCTURE

### Water for the Cities

Although historically water was a critical factor in the location of cities for navigation and industrial use, water supply has been made accessible at greater and greater distances from urban areas allowing other factors to determine urban location. Thus, distance of the supply rarely influences the location and probably the form of cities. Nevertheless, as cities expand, distribution systems in older areas vs. those in newer ones present interesting constraints and opportunities.

Dozens of cities in the United States now draw water from very long distances, which is a practice dating from the 19th century. For example, New York City draws its water from over 100 miles away, Los Angeles from over 200 miles away, and Tempe, AZ from over 300 miles away. Availability is not the only determinant of where supplies are tapped. For example, the City of Newark at the turn of the century had to move its water supply from the nearby Passaic River to the more distant Pequannock River watershed when the Passaic became too contaminated for a potable water supply.

Once the waters enter urban areas, the provision of water within these areas is beset by numerous water distribution line ruptures, which are factored into the cost of repairing the breaks rather than confronting the origins and effects of such ruptures in a larger context. If one enlarges the picture of such breaks to encompass causes and effects, one finds that many of them are created by other infrastructure systems --transportation (road salting, vibrations from surface and underground vehicles), utilities (electrical currents), and natural hazards. These breakages, in turn, effect those very same systems when they occur.<sup>10</sup>

### Wastewater Technology and Cities

The infrastructure that is the least seen, and when it is, it is an unwelcome site, is wastewater treatment. Yet, it is unquestionably the infrastructure that is critical to the health and environmental sustainability of cities. Although a comprehensive review of the interaction of these systems with the urban environment would be too extensive to present here, one issue puts this area at the forefront of infrastructure support for cities. That issue is the removal of nitrogen from wastewater, which, without controls would produce and in fact, already has produced, dangerous imbalances in the aquatic ecosystems that surround many of the larger cities. The imbalance expresses itself in terms of the partial depletion of oxygen (hypoxia) or complete depletion of oxygen (anoxia).<sup>11</sup> The number of these events and the volume of water and quantity of sediments that are hypoxic have been increasing in many waters surrounding the urbanized areas of the United States.<sup>12</sup> This condition is created by the conversion of ammonia compounds into nitrates. The ammonia originates from decaying vegetation resulting from excessive growth or algal blooms from nutrient inputs. The process is commonly known as eutrophication. One thinks of nitrogen as a problem of agricultural areas, but urbanized areas have many times the discharge of nitrogen that agricultural areas have.<sup>13</sup> The Long Island Sound Study indicates that wastewater treatment plants contribute about half of the nitrogen loadings to Long Island Sound waters (a drainage area of some 16,000 square miles), which is consistent with figures from other estuaries.<sup>14</sup> The many billions invested in wastewater by the federal government and the many more dollars invested by state and local government has not kept paced with the newly emerging needs for water quality protection. As a result, the management process is largely driven by voluntary participation and negotiation.<sup>15</sup>

## CONCLUSIONS

Theories of the growth and configuration of urban regions should explicitly take into account the role of infrastructure in shaping as well as supporting these areas. An important aspect of the relationship between infrastructure and urban region development is that the different parts of the region face different infrastructure issues and hence, use technologies differently to address those issues. The areas within urban regions can accommodate new infrastructure technologies if a more systems perspective is adopted. Thus, hi-speed and energy efficient vehicles currently

thrive in certain parts of the region and not others. Moreover, they require their own supporting infrastructure to work efficiently anywhere. Planners of water system expansions in outlying areas of urban regions need to be cognizant of the history of persistent distribution system ruptures of urban centers that eventually will be experienced in outlying areas also.

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<sup>1</sup> Yaro and Hiss (1996), pp. 7, 14, 66.

<sup>2</sup> Girardet, (1991), p. 64.

<sup>3</sup> Daniels and Lapping (1996), p. 287, define the rural-urban fringe as “the land extending from 10 to 40 miles (and sometimes farther) outside the centers of the nation’s major cities.”

<sup>4</sup> See Gordon and Richardson (1996) for a recent review of empirical work in this area.

<sup>5</sup> NYC DOT, DEIS (June 1998), p. S-9.

<sup>6</sup> Zimmerman, Lead-based paint removal case study, 1996-1998a.

<sup>7</sup> NYC DOT, DEIS (June 1998), p. S-16.

<sup>8</sup> The Institute for Civil Infrastructure Systems at New York University’s Wagner Graduate School of Public Service is planning a workshop on invisible construction, in conjunction with the Sam Schwartz Company, in the Fall of 1998.

<sup>9</sup> Eastham (1995), p. 100.

<sup>10</sup> Zimmerman, Water main break case study, 1996-1998b.

<sup>11</sup> National Research Council (1993), p. 178.

<sup>12</sup> National Research Council (1993), p. 179.

<sup>13</sup> National Research Council (1993), p. 177, quoting S.W. Nixon, et al. (1986) “Nutrients and productivity of estuaries and coastal marine ecosystems,” *J. Limnol. Soc. S. Afr.* 12:43-71.

<sup>14</sup> National Research Council (1993), p. 184.

<sup>15</sup> Zimmerman, et al., Nitrogen Removal case study, 1996-1998.

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