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The Four Pillars of Sustainable Urban Transportation

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ABSTRACT *The unsustainable nature of current urban transportation and land use is well recognized. What is less clear is the prescription for how to move towards a more sustainable future, especially given the many interest groups involved, the complexity of urban systems and the fragmented nature of decision-making in most urban regions. It is argued that the process of achieving more sustainable transportation requires suitable establishment of four pillars: effective governance of land use and transportation; fair, efficient, stable funding; strategic infrastructure investments; and attention to neighbourhood design. A review of each pillar identifies key issues. The characteristics of an ideal body for governance of land use and transportation are considered. Trade-offs are identified with: spatial representation; organizational structure; democracy; and market philosophy. Effective financing and pricing of urban transportation may be distorted because responsibility for infrastructure is separated from service provision. Financing mechanisms are categorized depending on vehicle use and location. Investment in infrastructure for alternative fuel vehicles and intermediate semi-rapid transit may be required in many cities. Major investment in public transit infrastructure will likely not suffice if macro land use and micro neighbourhood designs are not supportive of these investments.*

Introduction

The necessity of addressing serious environmental challenges makes the already complex business of transportation planning extremely difficult. Designing corridors, streets and thoroughfares to provide safe movement and access to people and goods, by cost-effective means, involves application of management and technology to resolve many social, economic and political forces. Add to this delicate balance a number of pressing environmental concerns, such as impacts of air pollution on human health, global climate change and destruction of land ecosystems, poses a challenge that stretches human ingenuity and organizational capability (Homer Dixon, 2001).

The pressures to develop sustainable transportation systems are particularly acute in urban areas. The World Bank (2002) estimates that 0.5 million people in

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developing countries die each year from transport-related air emissions, with a similar death toll from traffic accidents. The urban population in the developing world is close to 50% and growing rapidly. In the developed world, which already has a 75% urban population, designing sustainable transportation systems is considered one of the most pressing issues faced by modern cities (Hall, 1998). Of particular issue is the rapid growth of sprawling, low-density suburbs where commuters, especially those travelling across town, rely largely on automobile use. Vehicle emissions, congestion and auto dependency conspire to reduce quality of life in many cities.

There is debate about what types of urban form, defined by land use and transportation systems, are more sustainable. This issue has been discussed at length in the literature (e.g. Gordon and Richardson, 1989; Newman and Kenworthy, 1989; Anderson *et al.*, 1996). There can be little doubt that certain urban forms are more 'efficient' in terms of the level of automobile usage (often measured in terms of vehicle-km travelled, VKT), energy use, atmospheric emissions, travel cost and use of land. Studies of Toronto, for example, have consistently found that per-household VKT, emissions and annualized travel costs all increase as residential locations suburbanize (Miller and Ibrahim, 1998; Miller *et al.*, 2004). Conversely, there is little to no evidence worldwide that current patterns of urban growth (characterized by low-density suburban 'sprawl' and increasing auto dependency) are sustainable in the long run. Indeed, the most likely prognosis for the future under a 'business as usual' scenario is increasingly dysfunctional cities, involving ever-increasing congestion, loss of quality of life, and, most likely as a result, decreasing economic productivity and competitiveness (for an early discussion of the 'pathology' of large, auto-dependent cities, see Mumford, 1961).

Thus, it is argued that a clear *diagnosis* of the ills of the modern city is available. What is far less clear, however, is the *prescription* for how to move from current unsustainable trends in urban form and transportation towards a more sustainable future, especially given the many interest groups involved, the complexity of urban systems and the fragmented nature of decision-making in most urban regions.

To make progress on this matter first requires the establishment of performance measures that can then be used to define sustainability objectives. Many groups have contributed to this by establishing sustainable transportation indicators (Alberti, 1996; US Environmental Protection Agency (EPA), 1999; European Environment Agency, 2001; Kenworthy and Laube, 2001; Kennedy, 2002). Ideally, such indicators are established with community participation (since communities are ultimately part of the solution). Lists of such sustainability performance measures should be expected to vary between regions reflecting differences in scale, geography and culture. Table 1 attempts to capture the central attributes of these performance measures. In broad terms, movement to sustainable urban transportation involves the provision of accessibility and the generation of wealth

Table 1. Central attributes of sustainable transportation performance measures

- Accessibility
- Health and safety
- Cost effectiveness
- Impacts on competitiveness and generation of wealth
- Consumption of natural capital
- Production of pollutants (local and global)

by cost-effective and equitable means, while safeguarding health and minimizing the consumption of natural capital and emissions of pollutants.

But even if targets can be set and the blueprints for more sustainable cities drawn, the challenge of implementing the plans is another matter. Many barriers to the implementation of urban sustainability persist, e.g. attitudes towards vehicle ownership, risks in developing brown-field sites, inappropriate pricing and/or funding of transportation (Bannister, 1998). Establishing sustainable transportation practices may require significant social change. But even within a single organization, change processes are notoriously difficult to implement (Beer and Nohria, 2000).

The present paper is concerned with the *process* of moving towards sustainable urban transportation. It reviews the critical literature on four essential components, specifically: (1) the establishment of effective bodies for integrated land-use transportation planning; (2) the creation of fair, efficient and stable funding mechanisms; (3) strategic investments in major infrastructure; and (4) the support of investments through local design. Around each of these essential 'pillars' of sustainable urban transportation, many tough and crucial questions remain unanswered. A particular objective of the paper, therefore, is to formulate these key questions and identify areas for future research.

The first pillar is a matter of governance. The urban planner or transportation official understanding the need for sustainable transportation and wishing to do something about it may likely be unable to do so. In most cases, such authorities probably do not have the mandate, responsibility, power or support to make decisions that are consistent with sustainable development. Perhaps the most common problem is the division in responsibly between transportation authorities and land-use planners. This paper reiterates the need for integrated land-use transportation planning. The key question is raised about what are the characteristics of an ideal governing body for integrated land-use transportation planning.

As it is argued, for the third pillar, that major infrastructure investments are required, then a prerequisite step is the creation of a stable funding mechanism. Several different means of financing capital investments and long-term maintenance are reviewed.

Given how unsustainable are current transportation systems, it is inevitable that major infrastructure investments must be made to correct this. Several authors have argued that it is expedient to make more effective use of current infrastructure rather than building anew (Gillen, 1996; Rietveld and Bruinsma, 1998). This is a reasonable position if continuation of the status quo is the objective. But the continuation of current conditions whereby in many urban regions 75% of trips, or more, are made by gasoline-fuelled automobiles is inconsistent with global sustainability. Whether the solution is greater use of less environmentally damaging modes of transport or a change in automobile technology either way involves significant long-term infrastructure investments.

Investing in major infrastructure alone, however, is likely to be ineffective unless accompanied by actions at the local scale. There are many local policies and small-scale investments that might improve the attractiveness of walking, cycling and transit use. Although there is contention in the literature, these local actions may potentially boost ridership on more environmentally sustainable transportation modes, ensuring that major investments are cost effective. This attention to detail at the community scale, while concurrently planning major transportation corridors, lies at the heart of successful integrated land-use transportation planning.

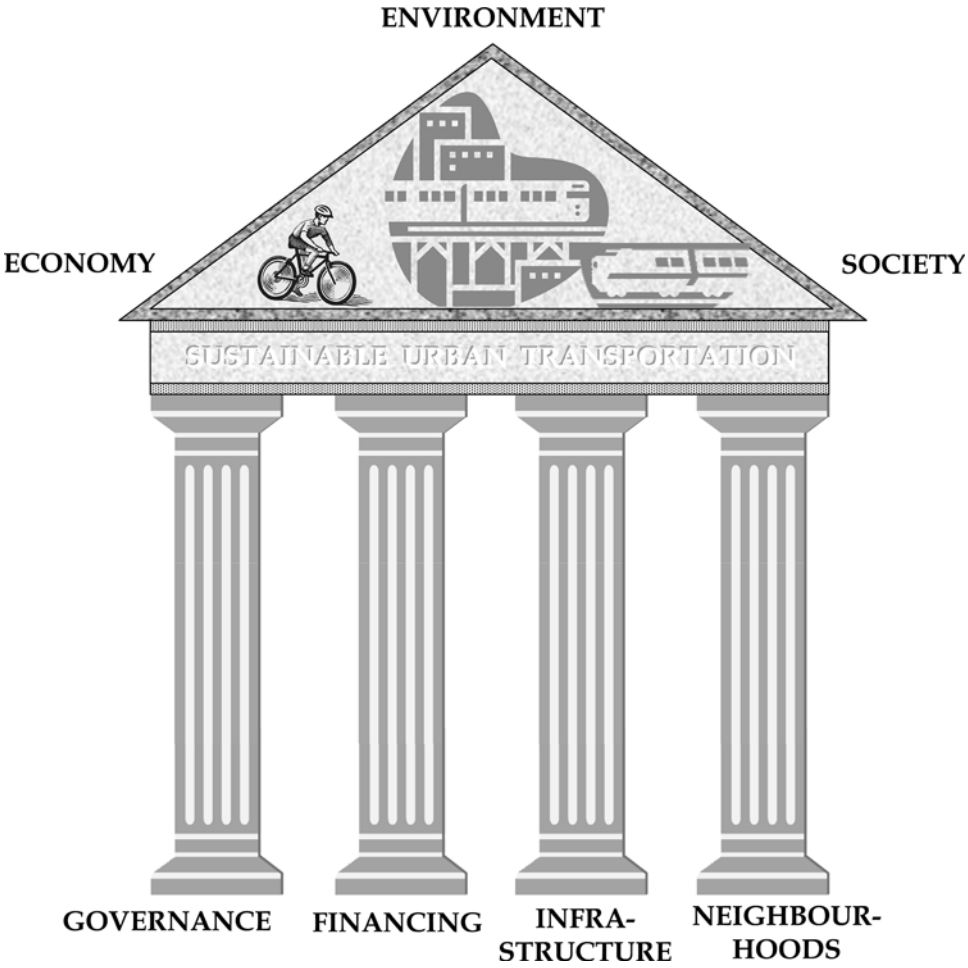

Figure 1. The four pillars of sustainable urban transportation (for further detail, see the text)

Figure 1 illustrates these concepts schematically, with the classic triangle of economic, social and environmental sustainability being supported by the four 'pillars' of sustainable urban development. These pillars are discussed below.

Establish an Effective Body for Integrated Land-use Transportation Planning

The city is an enormously complex system for which changes in one part can affect others in unanticipated ways (Bourne, 1982). As discussed by Miller *et al.* (1998) (among others), it is only through a comprehensive, integrated approach to transportation and land-use planning that one can hope to understand the complex interactions within cities and to address with any confidence the range of policies and their likely outcomes. Unfortunately, for a host of reasons (again, see Miller *et al.*, 1998), land-use and transportation often are not dealt with in a sufficiently coordinated way by municipal (and higher level) governments and agencies.

A few cities have been recognized as achieving integrated land-use and transportation planning. Examples include Curitiba, Zurich, Singapore, Tama Garden

City and cities in the Netherlands (World Bank, 2002). The Dutch system of urban governance has been widely praised (Hall, 1994, 1998; OECD, 2002). Central to the Dutch success is a highly regulated hierarchical structure, for which tight land-use controls stem from central government. The Dutch system also involves the development of shared visions and movement towards cooperative management with commitment from government, the public and the private sector (OECD, 2002).

The Netherlands has also been one of the first countries to reform transportation planning to give as much emphasis to accessibility as to mobility (Table 2). The dominating planning model in industrial societies has long been one of maximizing personal mobility. Yet, while mobility enhances productivity, it inevitably leads to congestion and pollution (Camagni *et al.*, 1999). Switching to a paradigm of planning for accessibility is key to developing sustainable cities (Cervero, 2001). Dutch planners use innovative techniques to classify locations within cities based on their accessibility. Locations with high accessibility are achieved using public transport systems, mixed-use developments and connections to neighbourhoods by pedestrian and bicycle networks.

Although a few examples of good integrated land-use planning exist, most urban regions have generally struggled to establish suitable governance to achieve this goal. Dijst and Schenkel (2002, p. 3) note that "urban transportation is a public domain in which policy has not been very effective" and that "this often derives from a bad distribution of the responsibilities between the many parties involved". In a broader context, Hall (1998, p. 655) surmises "There is a certain terrible permanence in our failure to run our cities". Overall, few urban regions have suitable governance to manage growth and plan transportation systems effectively.

Table 2. Examples of mobility planning and accessibility planning (adapted from Cervero, 2001)

Mobility planning	Accessibility planning
Road construction and expansion	Land-use management and initiatives
Motorways, freeways, beltways, interchanges, rotaries	Compact development
	Mixed uses
Arterial expansion	Pedestrian-oriented design
	Transit villages
ITS, smart highways and smart cars	Telecommunication advances
On-board navigational systems	Telecommuting/teleworking
Vehicle positioning systems	Telecommunities
Real-time informational systems	Teleshopping
Transportation system management	Transportation demand management
One-way streets	Ridesharing
Rechannelizing intersections	Preferential parking for high occupancy vehicles
Removing curbside parking	Parking management and pricing
Ramp metering	Guaranteed ride home programmes
Large-scale public and private transport	Community-scale public and non-motorized transport
Heavy rail transit and commuter rail	
Regional busways	Light rail transit and trams
Private tollways	Community-based paratransit or jitneys
	Bicycle and pedestrian paths

So what are the characteristics of an ideal body for effective land-use transportation planning? There is no simple answer to this question; it depends on cultural, geographical and political factors. But if a higher-level government is looking to establish effective governance for regional transportation, what are the main considerations? Determining the form of the governing body would likely require balance with respect to several attributes: spatial representation; structure; democracy; and market philosophy (Figure 2).

Spatial Representation

Achieving a balanced representation of local community interests and the interests of the urban region as a whole is a proverbial planning issue. There are certainly cases where community neighbourhoods have suffered due to the pursuit of regional transportation goals (Jacobs, 1961). However, in other cases, the self-interests of smaller local governments might be detrimental to the sustainable growth of a region. Small municipalities on the edge of a growing metropolis can be a catalyst for irresponsible land development. The lure of additional revenues from development charges or from an expanding population can drive the local government's agendum. Without suitable regional controls, the competition between the many such local governments around the edge of cities can result in a 'race to the bottom' with rampant development in the areas that offer the lowest development charges or other incentives. Some degree of regional representation is clearly necessary.

Structure

Drawing upon organizational theory, the structure of a body for regional land-use development and transportation planning could lie between a strong hierarchical form and a loosely coupled structure. One argument in favour of hierarchical structures is that a higher degree of control over processes and personnel is possible due to clear communication channels and fixed responsibilities (Kerzner, 2003). It

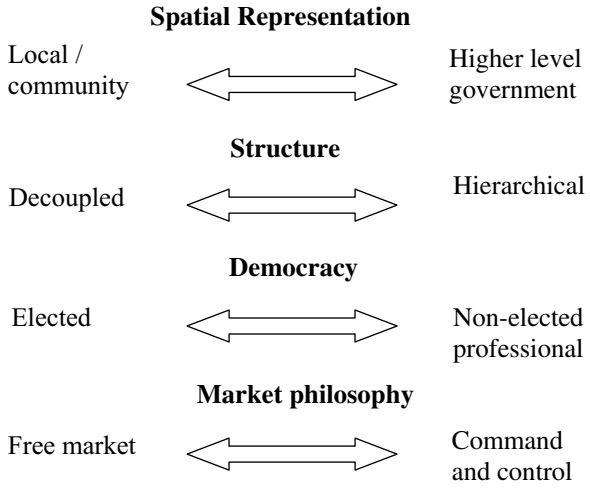

Figure 2. Trade-offs in the establishment of effective regional governance for regional land-use and transportation planning.

might be argued that for sustainable development to become a reality, a hierarchy is the ideal structure to implement a strong top-down policy focus in government. In such a case, a large vertically integrated structure controls all decisions under one umbrella, resulting in greater control over land use.

A weakness of most hierarchical organizations, however, is horizontal integration. Although the lines of communication are effective within functional groups in the vertical direction, communicating between different functional groups may be inefficient (Kerzner, 2003). This problem is compounded in the case of transportation planning and policy, which involves many diverse actors, all with various interests in the process. These actors include public actors from various functional groups within the regional hierarchy (e.g. departments responsible for transportation, land-use planning, environment, housing) as well as communities and the private sector. The hierarchical structure is not designed to handle the negotiation that is necessary between all the actors. To deal with this problem, informal communication and negotiation channels develop between the actors to improve the decision-making process. These interactions form a new organizational structure within the existing hierarchy that ignores the existing vertical channels in favour of more efficient horizontal relationships. The emergence of informal relationships and coalitions, often referred to as policy networks, involving several different actors is quite common in many different fields within public policy.

Dijst and Schenkel (2002) suggest that urban governance might become more effective through such policy networks, whereby hierarchical authority is replaced with a constellation of loosely connected political, economic and social actors. They argue that urban policies often cannot influence urban performance directly, but only become effective through understanding the relations between processes in urban society, the behaviour of actors and the development of urban form. Networking and negotiation between actors in urban development may complement or substitute the regulatory process.

Nevertheless, the arguments against such decoupled structure are also strong. In many cities, responsibility for land development and transportation planning may already be far too loosely coupled. The best examples of integrated land-use transportation planning are recognized to come from the Netherlands, which has strict hierarchical control over land use. Moreover, in a loosely coupled governance system, no one takes responsibility for pollution or congestion externalities. A further consideration is that leaving policy networks to form by chance is a risky way to deal with important public issues.

Democracy

A difficult consideration in regional transportation planning is the extent to which decision-making should be subject to political processes. In simple terms, the issue is establishing an appropriate balance in authority between professional managers and elected officials. It could be argued that professionals might take a longer time perspective on planning. It could also be argued that professionals may be out of touch with public needs. Both arguments are of course unfounded generalities. An important consideration, however, is that the interactions between urban development, transportation systems and urban economies are complex, so whatever the make-up of a regional transportation body, it has to be sophisticated.

One possible model that could be emulated in regional transportation planning is that of the independent central bank. Over the past two decades an increasing number of central banks have been granted independence from their national finance ministries, and have performed better with respect to overall policy outcomes (Cecchetti, 2000). Controlling the monetary policy of a country requires a high level of skill and experience, which is perhaps best done at arms' length from government, although not without some checks. Similar arguments could also be made for the development of transportation and land-use planning in large urban regions. Skilled professionals are required and too much political interference can be detrimental.

Public participation, however, is also important for developing sustainable cities. Any serious and inclusive move towards sustainability will require a significant shift in the attitudes, perceptions and lifestyles of the community in general. Moreover, an effective planning approach will also be built on the recognition that there is considerable knowledge and experience with transportation in those who use the system. Blending this knowledge and expertise with that provided by government actors and by transportation providers is central to building sustainability and monitoring progress toward that goal. There are challenges to the process of public participation, such as achieving equal representation and the speed of decision-making (Rydin and Pennington, 2000; Bickerstaff and Walker, 2001). Yet, public participation legitimizes policy decisions, strengthens relationships between stakeholders and promotes sharing of knowledge.

Market Philosophy

Regardless of the structure and composition of a regional planning body, it could take widely differing approaches to the role of markets in delivering transportation services and controlling land use. The spatial interdependencies between different aspects of transportation systems mean that some components may be more suitable for the free market than others. Depending on its market philosophy, a regional transportation body could be anything from a large public organization controlling and operating transportation systems to a smaller regulatory body that contracts services to the private sector.

There are differing views on the role for, and relative success of, free market participation in transportation services. Nijkamp and Ursem (1998) argue that there are market solutions for sustainable cities, e.g. free market enterprises running circulating mini-buses or jitneys, as per the developing world, could be a partial solution to sustainable suburban transport. Mees (2000), however, argues that the most successful urban transit systems are generally run by strong public bodies. He argues that the privatization of bus companies in Australia and in the UK has largely been a failure, leading to a lower quality service and decreasing ridership. Competing private operators have failed to provide comprehensive, integrated service with 'near effortless connections' which has been central to successful transit planning in countries such as Germany and Switzerland. Moreover, Mees argues that by understanding and exploiting network effects cities such as Paris and Zurich have been able to provide high-quality service to medium-density areas with dispersed travel patterns. He surmises it is institutional weakness, lack of knowledge and politics that hinders provision of effective public transportation.

Operating transportation systems based on free market principles is also problematic with respect to responsibility for pollution. For example, some of the worst transportation emissions in developing countries are associated with free market enterprises running vehicles with two-stroke engines. If markets are to be used to deliver transportation services, then strong regulation and control are necessary. As McNeill (2000) notes, there does not seem to be a single case throughout human history where an industry effectively self-regulated itself with respect to pollution and other adverse 'externalities'. Moreover, clear, well-administered regulation may not have to result in significant 'inefficiencies' in the market's operation. More importantly, the social welfare gain achieved by internalizing the 'externalities' into the market is always worthwhile if done appropriately; further, new industries almost inevitably spring up in response to this internalization process. Pollution control devices are one example. Thus, strong regulation of transportation appears to be necessary for sustainable urban development.

Responsibilities of a Regional Planning Body

In addition to the trade-offs identified in Figure 2, further complexity in the establishment of regional land-use transportation planning bodies may derive from the powers and responsibilities that such bodies require. In general terms, the responsibilities might include capital investment, pricing/taxation, regulation and education/information. Key specific responsibilities might include the following:

- Development of region-wide strategic transportation plans.
- Control over zoning, planning and urban design.
- Long-term infrastructure management.
- Authority to generate and control funds.
- Ensure appropriate scheduling and pricing.
- Some responsibility for local economic development.
- Support logistics of urban freight movements.
- Obligation to monitor and reduce vehicle emissions.

Determining which of these powers are appropriate for a regional planning body will depend upon local conditions, existing government structures and the specific goals/objectives of the proposed agency. In general, however, it is likely that part of the commitment to such a body by existing governments and agencies must include a willingness to cede power and authority to the planning body where this is necessary for it to achieve its mission.

Create a Fair, Efficient and Stable Funding Mechanism

Development of efficient, long-term financing for transportation systems is essential for the well being of cities, either for investment in new infrastructure or for the long-term operation and maintenance of existing systems. The financing of transportation infrastructure in many cities has been challenged in recent decades by the shrinking role of central governments. Having re-evaluated the governance of transportation and land use, cities may benefit from examining alternative funding mechanisms for sustainable, long-term financing of transportation. This section briefly reviews the various mechanisms that have been considered and identifies points of contention.

The World Bank (2002) notes three significant complications that typically distort effective financing and pricing of urban transportation:

- Responsibility for infrastructure is separated from service provision.
- Responsibility for interacting modes of transport is dispersed.
- Infrastructure financing is separated from infrastructure pricing.

The ability to develop successfully efficient and stable funding for transportation relies much on the establishment of an appropriate governance structure, as discussed above. To overcome the above three disparities, urban regions would need regional transportation and land-use planning bodies with responsibility for financing infrastructure and for the financial stability of operations for all transportation modes.

There are several further criteria that regional transportation bodies might typically consider when developing long-term funding mechanisms: adequacy, efficiency, fairness, stability, flexibility, potential for evasion, administrative costs, ease of implementation and political acceptability (Reno and Stowers, 1995; Nakagawa and Matsunaka, 1997; Jones, 1998; Clary *et al.*, 2001).

Broadly speaking, two perspectives on alternative transportation funding are apparent in the literature. There is a long-standing economic literature on road pricing and traffic congestion that has typically evaluated other funding mechanisms for transport, and is increasingly motivated by concerns over environmental emissions as well as congestion (Hau, 1992; US Department of Transportation, 1992; Button and Verhoef, 1998; Link *et al.*, 1999; McDonald *et al.*, 1999). The second perspective is that of the transportation managers and financiers within government or the private sector. The US Transportation Research Board (TRB) has several pertinent publications, such as funding strategies for public transportation (TRB, 1998a) and surface transportation (Reno and Stowers, 1995), and proceedings of conferences on transportation finance (TRB, 2001). The content of these publications extends beyond consideration of urban systems and typically gives less consideration to environmental emissions.

Funding Mechanisms

A summary of funding mechanisms for urban transportation systems is given in Table 3. The mechanisms listed predominantly involve the generation of revenues

Table 3. Potential sources of funding for urban transportation systems

	Non-vehicle related	Vehicle-related
Non-location-related	General tax base Local transportation levy	Fuel taxes Vehicle license fees New vehicle or vehicle parts sales taxes Vehicle use fees Emissions fees
Location-related	Development fees Transit impact fees Right of way fees Leverage real-estate assets	Road tolls Congestion pricing Parking fees Transit user fees

from road users. Nevertheless, the funding mechanisms may be seen as ways of financing both road transport and transit.

A first category of funding mechanisms includes those that are unrelated to vehicle use and location. Funding of transportation infrastructure from the general tax base is practised in several developed countries including Canada, France and the UK (Nakagawa and Matsunaka, 1997). The benefit of this approach is presumably the flexibility it provides to high-level governments to implement national policies, e.g. reduce greenhouse gas emissions, or control government spending. But this flexibility perhaps also allows governments room to avoid making strategic long-term investments in infrastructure to meet shorter-term goals. An alternative mechanism with greater focus on urban regions is the charging of transit levies to local businesses or employees; such local taxes are applied in some parts of France and Brazil (World Bank, 2002).

The predominant current means of funding transportation systems is through fuel taxes. Several countries including Germany, Japan and the USA specifically tie gasoline taxes to the funding of transportation infrastructure (Nakagawa and Matsunaka, 1997). There are differences, however, in the flexibility of the spending: revenues from gasoline taxes in many jurisdictions within the USA are specifically reserved for road infrastructure, while in Germany such revenues can also be used for non-road infrastructure. Several Canadian cities including Vancouver, Montreal and Calgary receive a dedicated percentage of provincial gasoline revenues to fund urban infrastructure. Gasoline taxes are unsuitable as a long-term source of infrastructure funding, first because establishment of sustainable transportation requires substantial reductions in gasoline use; and second, because the future of oil supplies is uncertain. Nevertheless, dedication of gasoline taxes to funding of transit infrastructure is perhaps a viable short-term measure consistent with sustainable development.

Several other vehicle-related, but location-independent funding mechanisms have been used or proposed as alternatives to fuel taxes; many have potential environmental benefits. Modest vehicle license fees are common, but raising licenses to substantial levels as in Hong Kong, Malta and formerly Singapore can both generate revenues and keep auto-ridership in check (Button, 1998). A similar strategy that might also reduce auto travel in the long run is to impose higher sales taxes on new vehicle sales or on auto parts. Other related funding mechanisms that are more sensitive to actual vehicle use or road wear, in the case of trucks, include fees based on distance travelled, weight, vehicle value, emissions or some combination thereof.

Fees that are both vehicle- and location-related are desirable in the respect that they reflect the value that users place on transportation services. Of these mechanisms, three are common: toll roads, parking fees and transit user fees; the fourth approach, congestion pricing (or value pricing), is rare but increasingly viable with technology changes. Parking fees are commonly used to generate revenues but are insufficient in magnitude and may be difficult to control where private off-street parking facilities are common (Button, 1998). Tolls are familiar on bridges and tunnels worldwide, and on major highways in France, Japan and the USA. The use of electronic tagging makes the implementation of tolls on urban highways easier: the 407 toll highway in Toronto is one example. Transit user fees are rarely sufficient to cover operational costs, and few systems can fund ongoing capital costs from the fare box. There are creative ways to add to or enhance

Table 4. Example methods of extra revenue generation by transit agencies (cases are discussed in TRB, 1998a, Vol. 2)

Capital expenditures:
● Turnkey procurement
● Advance construction authority
● Cross-border leasing
● Progress payments
● Public–private partnerships
Fare revenue enhancement:
● Cashless fare payment
● Eco pass programme
● Partnerships with the community
Creative use of transit assets:
● Station concessions
● Advertising
● Leasing right-of-way
● Joint development

fare revenues, including cross-border leasing of vehicles, eco-pass programmes and station concessions; several further examples are listed in Table 4.

Congestion pricing has long been advocated by transportation economists and is perhaps receiving greater attention due to its recent implementation in London. Small and Gomez-Ibanez (1998) review 13 cases where congestion pricing has been implemented or studied, starting with Singapore in 1975. This review does not include discussion of failed attempts in Kuala Lumpur, Bangkok and an early scheme for Hong Kong in the 1980s (World Bank, 2002). Perhaps the greatest barriers to congestion pricing schemes are implementation costs and social/political acceptance. But even with relatively old video technology, London expected to recover its capital investment within 2 years and social acceptance of the London scheme appears to be holding so far.

The fourth category of funding mechanisms in Table 3 is not directly related to vehicle use, but is driven by the impacts that new or changing transportation systems have on land values. As the value of land increases due to increased accessibility to the rest of a city, some of the gain in property value might be captured and used to finance the transportation system. There are several different variations on this theme: (1) development fees are applied to new suburban developments in order to finance the major supporting road infrastructure and utilities; (2) owners of properties that increase in value following transit installation can pay an impact fee or perhaps relinquish some of their external gains through increased property taxes; (3) transportation authorities themselves, either alone or in partnership, can rent or sell land in the periphery of transportation corridors and access points; and (4) right of way fees can be charged to utility or telecommunications companies. It is conceivable that with better understanding and control of land use, transportation authorities could better exploit this funding mechanism.

Public–Private Partnerships

A tough issue is the appropriate use of public–private partnerships in funding and operating regional transportation infrastructure. The topic has received

considerable discussion in the recent literature (US Department of Transportation, 1998; Osborne, 2000; Miller, 2002). Yet while models of collaboration may be changing, there is nothing new about public–private partnerships. Hall (1998) discusses how various forms of public and private collaboration were used by Baron Haussmann in 19th-century Paris; in the development of New York and Los Angeles in the early 1900s; and even for development of the model socialist city: Stockholm in the 1950s and 1960s. Most of these partnerships involved both infrastructure and land development, and some are judged more successful than others. The challenge, as Hall puts it, has always been to "gear urban finances so that the public sector triggers private development and in turn is financed by it" (Hall, 1998, p. 614).

Whether or not it is beneficial for a region to finance major transportation infrastructure using a public–private partnership is unclear. The private sector claims to bring several benefits, including the timely completion of projects, access to financing when public funds are unavailable, higher degrees of expertise, cost-effective service delivery, and the development of innovative service delivery options (Giglio, 1998). There are also several disadvantages from relying too heavily on private funding: lending rates will be higher; and user costs may also be higher, especially if private firms increase service charges during the operational phases of projects in order to make a profit. It would be useful for researchers to develop objective and impartial tools for evaluating public–private partnerships. Along these lines, a useful starting point may be the work of Boardman and Vining (1989). Their study of 500 large industrial firms in competitive markets found that mixed public/private firms were generally less efficient and less profitable than private companies, and often performed worse than state-owned firms. Similar studies of public–private partnerships might be conducted in the context of transportation infrastructure.

This summary has only attempted to lay out the potential funding mechanism without asking which are the most preferable. This question is one that local regions should really determine for themselves within their unique environments. From the perspective of economic efficiency, the World Bank (2002) suggests that the price of fuel should be determined by its resource cost, road maintenance and congestion paid for by differential tolls, and emission costs covered by emission charges; but when ease and costs of implementation are considered, fuel taxes remain the most common mechanism. If cities are to adopt new funding mechanisms for transport, then careful studies are required, for the wider implications of the various schemes are unclear. Even if the microeconomic theory is well understood, what are the impacts of these various mechanisms on land prices, land development and the macro-economy? What are the social and environmental impacts of each?

Make Strategic Investments in Major Infrastructure

With suitable governance and funding mechanisms in place, cities would be well positioned to invest in infrastructure that supports sustainable transportation. This will inevitably involve investment in both transit and private vehicle-based infrastructure. The latter is only briefly discussed here as it relies on the development of technology largely beyond the control of regional authorities. Moreover, in focusing on public transportation, less attention is given here to goods movement, but provision and maintenance of supporting infrastructure (ports, food terminals, rail transfer stations, etc.) is clearly essential to the vitality of cities.

There is potential to make more effective use of existing infrastructure. Some success has been achieved through car sharing lanes, car clubs, park-and-ride, intelligent transportation systems, etc. Yet, in the big picture, such measures might at best hold use of gasoline-fuelled vehicles at current levels.

The automobile is such an integral part of modern city life, bringing a myriad of benefits to society, that planning for a new generation of sustainable automobiles is critical for the sustainable development of cities. Through technical innovation and application of concepts of industrial ecology, there are several possible candidates for the sustainable vehicle of the future. A wide range of fuels and propulsion systems are available that could power vehicles over the next two to three decades. Rigorous assessment of the sustainability performance of such systems requires analysis over the entire life cycle of the vehicle and its supporting infrastructure, including all stakeholders throughout the economy (Graedel and Allenby, 1998). In evaluating a large set of alternative fuel/vehicle life-cycle inventory studies, MacLean and Lave (2003) concluded that there is no 'overall winner' with respect to a set of economic/environmental/social evaluation criteria. The 'winner' depends on the goals of the decision-maker. For example, if significantly lowering greenhouse gas emissions and fossil fuel use are the goals, then the two main candidates are liquid biofuels (from lignocellulosic feedstocks) and hydrogen from renewables or fossil fuels with carbon sequestration.

An important point for cities is that adaptation to sustainable automobiles will likely involve developing new infrastructure. Billions of dollars have been invested in the current infrastructure for gasoline/diesel. The infrastructure required for any alternative fuel would demand large-scale investment in fuel production facilities, distribution and refuelling. However, there have been limited studies that have looked comprehensively at infrastructure requirements. Of the 12 evaluated by MacLean and Lave, only that by Ogden *et al.* (1999) focused on infrastructure design and developed capital cost estimates for refuelling infrastructure (specifically for fuel cell vehicles). For a number of the fuels, particularly hydrogen and ethanol, there are multiple production pathways, adding another layer of complexity to determination of infrastructure requirements.

Transit Infrastructure

If the essence of sustainable transportation is to reduce auto dependence without compromising urban mobility and accessibility, it is imperative for sustainable transportation systems to include an extensive and well-integrated public transit system capable of providing adequate capacity and competitive levels of service that can accommodate and attract a large proportion of urban travellers. How transit systems can be designed to attract sufficient ridership in the face of opposite trends is clearly a key question. North American public transportation ridership, for example, has declined since the early 1990s (Kohn, 2000). Virtually no US metropolitan area that built or expanded light rail systems in the 1980s and 1990s achieved an increase in passenger transport's market share (Dunphy, 1995).

Hass-Klaus and Crampton (2002) suggest that the most important factors for a successful (high-usage) light rail system are a high percentage of travellers using travel cards (an indication of an integrated system and successful marketing); a

low monthly fare relative to national Gross Domestic Product/capita; a high pedestrian street length per city population; and a high population density within 300 m of the corridor (there are exceptions to this). Moving beyond these factors, however, there are possibly broader features of overall network structure and mode integration that affect ridership.

With respect to system configuration, the extensive transit systems found in world-class cities such as London and Paris might be considered close to ideal. Such systems are of sufficient extent that direct rapid transit service is not limited to the traditional central business district. High degrees of mobility and accessibility are achieved at high-capacity levels. By comparison, transit systems in North American cities are generally less extensive, typically having CBD-oriented rapid transit with supplementary street transit routes in the city and suburbs.

Expanding the existing rapid transit systems in North American and other similar urban regions is obviously an expensive endeavour, which would only be cost effective at high passenger volumes. This requires the development of high-density land use at nodes and along corridors outside the traditional CBD. Relying on land-use policy instruments alone to develop the required land-use characteristics for expanding rapid transit systems may not be sufficient. Also, the existing surface transit route network outside the CBD has little potential to help develop such desirable land-use characteristics in a reasonable time frame. Therefore, it may be required to bridge the present 'gap' between medium-capacity, low-performance surface transit and high-capacity, high-performance rapid transit through the investment in an intermediate class of modes, specifically semi-rapid transit. (Semi-rapid transit modes include light rail transit (LRT) and bus rapid transit (BRT); for a classification of modes, see Vuchic (1981).)

Semi-rapid transit is a logical upgrade from surface transit, requires relatively modest investments, and has shown to attract 'choice' travellers and help intensify urban density. It can serve as a precursor to rapid transit (i.e. subway/metro) in the core city (outside the CBD) or as a stand-alone system in the suburbs of large urban regions or in relatively small regions. BRT has received much attention recently because of its advantages in having short implementation periods, a high ability to branch out (requiring less transfers), and lower investments than LRT with comparable ridership levels (Vuchic, 2002). Example BRT systems include those in Curitiba, Brazil, and in Ottawa, Canada. However, LRT has shown historically to have a strong image and identity, a sense of permanence, a high vehicle performance due to electric traction and an ability to upgrade into rapid transit. Overall, investment in semi-rapid transit systems could be a key part in developing sustainable urban transportation systems.

Support Investments through Local Design

Until a new generation of sustainable personal transportation vehicles has been developed, investment in public transit systems may be the most viable means of making urban transportation more sustainable. But major investment in public transit infrastructure will not suffice, or even work at all, if macro land use and micro neighbourhood designs are not supportive of, or compatible with, these investments. People have to be able to get to and from major transit 'line-haul' facilities; houses, jobs and other activities must be located in a connected, convenient, attractive way with these facilities. The devil is in the details, and the details start with the design of streets and neighbourhoods.

Table 5. Comparative characteristics of conventional and traditional neighbourhoods (adapted from McNally and Kulkarni, 1997)

	Contemporary suburban design	Traditional neighbourhood design
Network	Circuitous, meandering streets	Interconnected, grid-like street patterns
	Hierarchical street pattern (highways, arterials, collectors)	Separate paths (networks) for pedestrians and bicycles
	Limited access points to the neighbourhood	Narrow streets
	Wide streets without street parking	On-street parking
	Predominantly auto based	Green spaces and tree lining
		Access points to the neighbourhoods
		Many modes successful
Land use	Segregated, clustered land uses	Mixed lane uses
	Access to a limited number of 'highly desirable' land uses	Close proximity of land uses
	Low residential densities	High residential densities
	Large home lots	Small home lots
		Access to parks, recreation and distinct neighbourhood 'centres'
Design	Missing sidewalks	Shaded sidewalks
	Less shaded sidewalks	Variation in housing design and size
	Homogeneous housing	Shallow setbacks
	Dominating garages and driveways	Front porches
		Detached garages

Much of the recent literature has focused on the design of neo-traditional neighbourhoods (Boarnet and Crane, 2001). Such designs are an attempt to recreate pre-Second World War development patterns, with high pedestrian access achieved through connected grid street patterns, mixed land use, narrower streets and a mix of other features (Table 5). McNally and Kulkarni (1997) developed a classification scheme for distinguishing traditional, contemporary and mixed designs based on network, land uses and accessibility characteristics. Owens (1993) discusses finer textural details that distinguish traditional neighbourhoods.

There are practical resources to assist in designing sustainable neighbourhoods. Several codes and guidelines for the design of neo-traditional or transit-friendly neighbourhoods have been produced (Institute of Transportation Engineers, 1997; Morris, 1997). The TRB (1998b) also documents strategies used in Europe and the USA to establish transit-friendly streets. Many North American case studies of neo-traditional neighbourhood designs have been presented (e.g. TRB, 1998b; Fletcher and Dalgleish, 2000). Geographical information systems are also being used to assist in analysing pedestrian accessibility (Aultman-Hall *et al.*, 1997; Hsiao *et al.*, 1997).

The critical issue is whether designing pedestrian-friendly neighbourhoods, such as the neo-traditional, actually encourages travel by sustainable modes. Research has found that traditional neighbourhoods are more conducive to walking and cycling (Handy, 1993) and for supporting transit use (Friedman *et al.*, 1994). But some studies in which other travel demand factors have been considered found neighbourhood impacts to be insignificant (McNally and Kukarni, 1997; Crane and Crepeau, 1998). An important study, however, is that by Cervero and Radisch (1996), which after accounting for other factors, found residents of a traditional neighbourhood had significantly greater use of non-auto modes.

Further studies might be undertaken to establish the impacts of neighbourhood design on travel behaviour, but there is also a need to look at the neighbourhoods in the larger context. Studies by Kitamura *et al.* (1997) and Krizek (2003) suggest that residents' attitudes can be more significant than land-use characteristics in explaining mode choice. But it also has to be asked whether major transit infrastructure is in place to which pedestrian-friendly neighbourhoods could feed. Friedman *et al.* (1994) put it aptly when they note that if a neo-traditional neighbourhood is built as an 'island' surrounded by standard suburban subdivisions, then changes in travel behaviour could be limited. Further studies looking at the impacts of neighbourhood design should also consider whether or not the overall region has a well-developed transit system.

The role of local design in developing sustainable urban transportation likely requires more than just creating pedestrian-friendly neighbourhoods where people live, but also where they work, shop and recreate. Pushkarev and Zupan (1975) describe quantitative methods for designing pedestrian space, particularly in city centres. Monheim (1997) discusses the evolution of car-free centres in the German cities of Freiburg and Nuremberg. Strategies for developing urban bicycle networks with several case studies from European cities are presented in Tolley (1997). Jacobs *et al.* (2002) encourage a return to the development of boulevards for promoting street life. Continued research on ways to make urban areas more accessible and attractive for pedestrians and cyclists, while maintaining economic vibrancy, is desirable.

Ways to make neighbourhoods, shopping and business areas more sustainable involve local polices as well as investments. These include incentives for, and removal of, impediments to land-use planning, intensification and mixed land use; and car-restraint measures. Giving transit priority through reserved lanes, turn restrictions, reduced parking and signal pre-emption will further increase its attractiveness to the public (Soberman, 2002).

However, some regional mechanism for ensuring that local decisions conform to regional sustainability targets is essential. Micro neighbourhood design (of street layouts, pedestrian connections to transit, etc.) should be informed by planning of 'macro urban form' (zoning, broad regional design concepts, etc.). Unless neighbourhoods provide attractive access to major transit facilities, ridership will likely be inadequate and investments in the major systems will be financially unsustainable. Thus, the discussion swings back to the first pillar. It is only through the establishment of effective regional governance of land use and transportation that the essential connections between micro neighbourhood design and macro urban form can be made.

Synthesis and Conclusions

In identifying the essential components of sustainable urban transportation systems, the term 'pillar' has been used for good reason. The underlying theory of this paper is that all four pillars are necessary: all have to be well established in order for cities to develop in a sustainable fashion. For example, fixed rail urban transit systems have the potential to make cities more environmentally sustainable, but unless they are supported with effective land-use policy, then transit systems might be financially unsustainable. Conversely, establishing a neo-traditional neighbourhood in a sea of suburban sprawl may do little to promote transport by sustainable modes. The necessary investments in sustainable

infrastructure systems cannot be made without suitable funding mechanisms. Without suitable regional governance, it is hard to see how either integrated land-use planning or sustainable funding mechanisms can be achieved. Sustainable urban transportation arguably requires all four pillars.

Examples of cities that have achieved success with all four pillars are seemingly rare. Toronto perhaps came close in the 1950s. In 1954, it opened its first subway line, which was funded exclusively by the city's transit commission following a referendum amongst the citizens and it exhibited one of the best examples of integrated land-use planning (Kearns, 1964; Toronto Transit Commission (TTC) 1975). In the same year, the municipality of Metropolitan Toronto was created with a close to ideal governance structure controlling all infrastructure and land-use development for the expanding region. By the 1970s, however, the city had grown beyond the boundaries of Metro Toronto and creation of further separate regional municipalities put an end to coordinated planning and effective governance of transportation in the area (White, 2003). So even if a city achieves the requirements for sustainable urban transportation, it still has to adapt its governance structure to the growth of the region.

The process that regions should undergo to move towards more sustainable urban transportation is to follow the four pillars in the order presented here: governance, financing, infrastructure and neighbourhoods. As an example, the process can partially be seen in the changes to transportation that occurred in London over the past 5 years. Substantial reorganization of local government with the establishment of the first elected mayor was closely followed by the formation of a new Greater London Transportation authority, which implemented a congestion pricing scheme for the inner city. Assuming that this scheme proves to be sufficient and reliable in the long-run, then London may well have established the funding mechanism it needs to repair and maintain its ageing subway system. Recent land-use initiatives to create automobile-free squares in Central London add to the sustainability of the system. With further attention to local land-use planning in the outer regions, Greater London might provide a good example of the four pillars process.

Specific details of the four pillars model should likely differ between cities; there are different ways of achieving similar goals. There are also a number of challenging research questions that have been identified here. A summary of these is now given:

- More than anything else, the development of sustainable cities is a challenge to human organizational capacity. It is apparent that few cities worldwide have an adequate governance structure to develop sustainable urban transportation systems with an emphasis on accessibility over mobility. Determining what form of urban governance is necessary for successful regional land use and transportation planning is perhaps the hardest question of all. There are trade-offs to be made between community interests and government control; decoupled policy networks and a hierarchical structure; professional leadership and elected officials; and free-market philosophy versus a seamless, integrated, high-quality public transit.
- Financing of urban transportation is complicated by the separation in responsibility for infrastructure investment and the provision of services. Public–private partnerships have long been part of the urban development process,

but objective and impartial methods for assessing the desirability of funding transportation infrastructure through such partnerships are needed.

- Significant investments in transit infrastructure are required to reduce the dependence on gasoline-fuelled automobiles, particularly in parts of urban areas of high population growth and where transit is currently not highly competitive with automobiles. Semi-rapid transit modes may be logical candidates for receiving major investments in such areas (suburbs and non-CBD-oriented corridors). The choice between candidate modes, mainly LRT and BRT, is an important issue that requires careful attention.
- Gaps in the literature on the impacts of neighbourhood form on urban travel behaviour have been listed elsewhere (Krizek, 2003). It is particularly key that further studies on the impacts of neighbourhood form consider whether or not the overall region has a well-developed transit system. Further research on ways to make communities, shopping areas, and business locations accessible and attractive for pedestrians and cyclists, while maintaining economic vibrancy, is essential.

References

Alberti, M. (1996) Measuring urban sustainability, *Environmental Impact Assessment Reviews,* 16, pp. 381–424.

Anderson, W., Kanaroglou, P. and Miller, E. (1996) Urban form, energy and the environment: a review of issues, evidence and policy, *Urban Studies,* 33(1), pp. 7–35.

Aultman-Hall, L., Roorda, M. and Baetz, B. W. (1997) Using GIS for evaluation of neighbourhood pedestrian accessibility, *ASCE Journal of Urban Planning and Development,* 123(1), pp. 10–17.

Bannister, D. (1998) Barriers to the implementation of urban sustainability, *International Journal of Environment and Pollution,* 10(1), pp. 65–83.

Beer, M. and Nohria, N. (2000) Cracking the code of change, *Harvard Business Review,* 78(3), pp. 133–141.

Bickerstaff, K. and Walker, G. (2001) Participatory local governance and transport planning, *Environment and Planning A,* 33(3), pp. 431–451.

Boardman, A. E. and Vining, A. E. (1989) Ownership and performance in competitive environments: a comparison of the performance of private, mixed and state-owned enterprises, *Journal of Law and Economics,* 32(1), pp. 1–34.

Boarnet, M. and Crane, R. (2001) *Travel by Design: The Influence of Urban Form on Travel* (Oxford: Oxford University Press).

Bourne, L. S. (1982) Urban spatial structure: an introductory essay on concepts and criteria, in: L. S. Bourne (Ed.) *Internal Structure of the City,* 2nd edn, pp. 28–45 (New York: Oxford University Press).

Button, K. J. (1998) Road pricing and the alternatives for controlling road traffic congestion, in: K. J. Button and E. T. Verhoef (Eds) *Road Pricing, Traffic Congestion and the Environment: Issues of Efficiency and Social Feasibility,* pp. 113–135. (Cheltenham: Edward Elgar).

Button, K. J. and Verhoef, E. T. (1998) *Road Pricing, Traffic Congestion and the Environment: Issues of Efficiency and Social Feasibility* (Cheltenham: Edward Elgar).

Camagni, R., Capello, R. and Nijkamp, P. (1999) New governance principles for sustainable urban transport, in: R. Camagni, R. Capello and P. Nijkamp (Eds) *New Contributions to Transportation Analysis in Europe,* pp. 213–250 (Brookfield, VT: Ashgate).

Cecchetti, S. (2000) Making monetary policy: objectives and rules, *Oxford Review of Economic Policy,* 16(4), pp. 43–59.

Cervero, R. (2001) Integration of urban transport and urban planning, in: M. Freire and R. Stren (Eds) *The Challenge of Urban Government: Policies and Practices,* pp. 407–427 (Washington, DC: The World Bank Institute).

Cervero, R. and Radisch, C. (1996) Travel choice in pedestrian versus automobile oriented neighborhoods, *Transport Policy,* 3(3), pp. 127–141.

Clary, L., Hand, C., Creamer, R. and Branagan, G. (2001) Alternative transportation revenue sources, in: Transportation Research Board (Ed.) *Report of the Committee for the National Conference on Transportation Finance, Scottsdale, Arizona, August 20–23, 2000* (Washington, DC: National Academy Press).

Crane, R. and Crepeau, R. (1998) Does neighborhood design influence travel? A behavioral analysis of travel diary and GIS data, *Transportation Research, Part D: Transport and Environment,* 3(4), pp. 225–238.

Dijst, M. and Schenkel, W. (2002) Urban performance in perspective, in: M. Dijst, W. Schenkel and I. Thomas (Eds) *Governing Cities on the Move: Functional and Management Perspectives on Transformations of European Urban Infrastructures,* pp. 1–18 (Aldershot: Ashgate).

Dunphy, R. T. (1995) *Review of Recent American Light Rail Experience* (Washington, DC: National Academy Press).

European Environment Agency (2001) *TERM 2001—Indicators Tracking Transport and Environment Integration in the European Union.* Environmental Issue Report No. 23, Catalogue: TH-39-01-295-EN-C (Copenhagen OPOCE).

Fletcher, D. and Dalgleish, D. (2000) *New Approaches to Suburban Land-use Planning that Support Transit Use: Experience and Model Policy Wording.* STRP Report 0-920559-50-6 (16) (Toronto: Canadian Urban Transit Association).

Friedman, B., Gordon, S. P. and Peers, J. B. (1994) Effects of neotraditional neighborhood design on travel characteristics, *Transportation Research Record,* 1466, pp. 63–70.

Giglio, J. M. (1998) Financing, in: Proceedings of the Transportation Issues in Large U. S. Cities Conference, Detroit, MI, USA, 28–30 June, pp. 111–125.

Gillen, D. W. (1996) Transportation infrastructure and economic development: a review of recent literature, *Logistics and Transportation Review,* 32(1), pp. 39–62.

Gordon, P. and Richardson, H. W. (1989) Gasoline consumption and cities: a reply, *Journal of the American Planning Association,* 55(3), pp. 342–345.

Graedel, T. E. and Allenby, B. R. (1998) *Industrial Ecology and the Automobile* (Englewood Cliffs, NJ: Prentice-Hall).

Hall, P. (1994) Squaring the circle: can we resolve the Clarkian paradox?, *Environment and Planning B,* 21, pp. s79–s94.

Hall, P. (1998) *Cities in Civilization* (New York: Pantheon).

Handy, S. (1993) Regional versus local accessibility: neo-traditional development and its implications for non-work travel, *Built Environment,* 18(4), pp. 256–267.

Hass-Klaus, C. and Crampton, G. (2002) *Future of Urban Transport: Learning from Success and Weakness: Light Rail* (Brighton: Environmental and Transport Planning).

Hau, T. (1992) *Economic Fundamentals of Road Pricing.* World Bank Policy Research Working Paper Series WPS 1070 (Washington, DC: World Bank).

Homer Dixon, T. F. (2001) *The Ingenuity Gap* (Toronto: Vintage Canada).

Hsiao, S., Lu, J., Sterling, J. and Weatherford, M. (1997) Use of geographical information systems for analysis of transit pedestrian access, *Transportation Research Record,* 1604, pp. 50–59.

Institute of Transportation Engineers (1997) *Traditional Neighborhood Design: Street Design Guidelines* (Washington, DC: ITE).

Jacobs, A. B., MacDonald, E. and Rofé, Y. (2002) *The Boulevard Book: History, Evolution, Design of Multiway Boulevards* (Cambridge, MA: MIT Press).

Jacobs, J. (1961) *The Death and Life of Great American Cities* (New York: Random House).

Jones, P. (1998) Urban road pricing: public acceptability and barriers to implementation, in: K. J. Button and E. T. Verhoef (Eds) *Road Pricing, Traffic Congestion and the Environment: Issues of Efficiency and Social Feasibility,* pp. 263–284. (Cheltenham: Edward Elgar).

Kearns, J. (1964) The economic impact of the Yonge Street subway, in: Proceedings of the American Transit Association, 83rd Annual Meeting.

Kennedy, C. A. (2002) A comparison of the sustainability of public and private transportation systems: study of the Greater Toronto Area, *Transportation,* 29, pp. 459–493.

Kenworthy, J. and Laube, F. (2001) *The Millennium Cities Database for Sustainable Transport* (Brussels: Union Internationale des transports publics (UITP)) [CD-ROM].

Kerzner, H. (2003) *Project Management: A Systems Approach to Planning, Scheduling, and Controlling* (New York: Wiley).

Kitamura, R., Mokhtarian, P. L. and Laidet, L. (1997) A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area, *Transportation,* 24(2), pp. 125–158.

Kohn, H. (2000) Factors affecting urban transit ridership (Ottawa: Statistics Canada). Available at: http://www.statcan.ca/english/IPS/Data/53F0003X1E.htm (accessed 6 June 2000).

Krizek, K. J. (2003) Residential relocation and changes in urban travel: does neighborhood-scale urban form matter?, *Journal of the American Planning Association,* 69(3), pp. 265–281.

Link, H., Dodgson, J. S., Maibach, M. and Herry, M. (1999) *The Costs of Road Infrastructure and Congestion in Europe* (New York: Physica).

MacLean, H. L. and Lave, L. B. (2003) Evaluating automobile fuel/propulsion system technologies, *Progress in Energy and Combustion Science,* 29, pp. 1–69.
McDonald, J. F, d'Ouville, E. L. and Liu, L. N. (1999) *Economics of Urban Highway Congestion and Pricing* (Boston, MA: Kluwer Academic).
McNally, M. G. and Kulkarni, A. (1997) Assessment of influence of land use transportation system on travel behaviour, *Transportation Research Record,* 1607, pp. 105–115.
McNeill, J. R. (2000) *Something New Under the Sun: An Environmental History of the Twentieth-Century World* (New York: W. W. Norton).
Mees, P. (2000) *A Very Public Solution: Transport in the Dispersed City* (Melbourne: Melbourne University Press).
Miller, E. J. and Ibrahim, A. (1998) Urban form and vehicular travel: some empirical findings, *Transportation Research Record,* 1617, pp. 18–27.
Miller, E. J., Kriger, D. S. and Hunt, J. D. (1998) *Integrated Urban Models for Simulation of Transit and Land-Use Policies.* Final Report Transit Cooperative Research Project H-12. Web Document 9 (Washington, DC: Transportation Research Board). Available at http://www4.nas.edu/trb/crp.nsf.
Miller, E. J., Roorda, M. J., Haider, M. and Mohammadian, A. (2004) An empirical analysis of travel and housing costs in the Greater Toronto Area, *Transportation Research Record,* No. 1898 pp. 191–201.
Miller, J. B. (2002) *Case Studies in Infrastructure Delivery* (Boston, MA: Kluwer).
Monheim, R. (1997) The evolution from pedestrian areas to 'car-free' city centres in Germany, in: R. Tolley (Ed.) *The Greening of Urban Transport,* 2nd edn, pp. 253–266 (Chichester: Wiley).
Morris, M. (1997) *Creating Transit Supportive Land-use Regulations* (Chicago, IL: American Planning Association).
Mumford, L. (1961) *The City in History: Its Origins; Its Transformations, and Its Prospects* (New York: Harcourt, Brace).
Nakagawa, D. and Matsunaka, R. (1997) *Funding Transport Systems: A Comparison Among Developed Countries* (New York: Elsevier).
Newman, P. and Kenworthy, J. (1989) Gasoline consumption and cities: a comparison of US. cities with a global survey, *Journal of the American Planning Association,* 55(1), pp. 24–37.
Nijkamp, P. and Ursem, T. (1998) Market solutions for sustainable cities, *International Journal of Environment and Pollution,* 10(1), pp. 46–64.
OECD (2002) *Governance for Sustainable Development: Five OECD Case Studies* (Washington, DC: OECD).
Ogden, J. M., Steinbugler, M. M. and Kreutz, T. G. (1999) A comparison of hydrogen, methanol, and gasoline as fuels for fuel cell vehicles: implications for vehicle design and infrastructure development, *Journal of Power Sources,* 79, pp. 143–168.
Osborne, S. P. (2000) *Public–Private Partnerships: Theory and Practice in International Perspective* (London: Routledge).
Owens, P. M. (1993) Neighborhood form and pedestrian life: taking a closer look, *Landscape and Urban Planning,* 26(1), pp. 115–135.
Pushkarev, B. S. and Zupan, J. M. (1975) *Urban Space for Pedestrians* (Cambridge, MA: MIT Press).
Reno, A. T. and Stowers, J. R. (1995) *Alternatives to Motor Fuel Taxes for Financing Surface Transportation Improvements.* TRB NCHRP Report No. 377 (Washington, DC: National Research Council).
Rietveld, P. and Bruinsma, F. (1998) *Is Transport Infrastructure Effective? Transport Infrastructure and Accessibility: Impacts on the Space Economy* (Berlin: Springer).
Rydin, Y. and Pennington, M. (2000) Public participation and local environmental planning: the collective action problem and the potential of social capital, *Local Environment,* 5(2), pp. 153–169.
Small, K. A. and Gomez-Ibanez, J. A. (1998) Road pricing for congestion management: the transition from theory to policy, in: K. J. Button and E. T. Verhoef (Eds) *Road Pricing, Traffic Congestion and the Environment: Issues of Efficiency and Social Feasibility,* pp. 213–246 (Cheltenham: Edward Elgar).
Soberman, R. M. (2002) 'Smart' transportation for sustainable development: a case study of Toronto, In: W. Kulyk (Ed.) *Urban Transportation System: Ensuring Sustainability through Mass Transit,* Proceedings of the 2nd International Conference, 14–18 April 2002, Alexandra, VA, available at: www.pubs.asce.org
Tolley, R. (1997) *The Greening of Urban Transport: Planning for Walking and Cycling in Western Cities* (Chichester: Wiley).
Toronto Transit Commission (1975) *Transit in Toronto: The Story of the Development of Public Transportation in Toronto, from Horse Cars to Modern, High-speed Subway System* (Toronto: TTC).
Transportation Research Board (1998a) *Funding Strategies for Public Transportation.* TCRP Report No. 31 (Washington, DC: National Academy Press).

Transportation Research Board (1998b) *Transit-friendly Streets: Design and Traffic Management Strategies to Support Livable Communities.* TCRP Report No. 0309062659 (Washington, DC: National Academy Press).

Transportation Research Board (2001) *Report of the Committee for the National Conference on Transportation Finance, Scottsdale, Arizona, August 20–23, 2000* (Washington, DC: National Academy Press).

US Department of Transportation (1992) *Examining Congestion Pricing Implementation Issues, Searching for Solutions.* Policy Discussion Series No. 6 (Washington, DC: US DoT).

US Department of Transportation (1998) *Public/Private Partnerships: Implications for Innovation in Transportation* (Washington, DC: US DoT).

US EPA (1999) *Indicators of the Environmental Impacts of Transportation,* 2nd edn. EPA 230-R-99-001 (Washington, DC: US EPA).

Vuchic, V. (1981) *Urban Public Transportation Systems and Technology* (Englewood Cliffs, NJ: Prentice-Hall).

Vuchic, V. (2002) Bus semi-rapid transit mode development and evaluation, *Journal of Public Transportation,* 5(2), pp. 71–96.

White, R. (2003) *Urban Infrastructure and Urban Growth in the Toronto Region 1950s to the 1990s* (Toronto: Neptis Foundation).

World Bank (2002) *Cities on The Move: A World Bank Urban Transport Strategy Review* (Washington, DC: World Bank).