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Sustainable Transportation and Urban Development

Yoram Shiftan and Daniel Shefer

1. Introduction

The challenges facing transportation planners have grown continuously over the years owing to mounting problems of congestion, concerns with environmental degradation and global warming, enhanced awareness of safety, and the increasing complexity of travel behavior patterns associated with modern life.

Modern life has brought about more travel, more leisure time, and more engagement in out-of-home, non-work activities. Modern life, especially in more recent years, has also witnessed rapid population and economic growth in many urban areas and the decentralization of residential, commercial, and work places. It has also seen more women entering the labor market. Accompanying these changes has been the relaxation of some constraints, such as the need to commute at fixed hours, thus providing more degrees of freedom of travel. Because of the significantly increased alternative activities and travel patterns from which households can now choose, travel patterns have become more complicated. In addition, the total number of trips has increased, trip chaining is more frequent, and traffic peaks are becoming smoother. All this has resulted in making the analysis of travel behavior more complex.

Understanding travel behavior is a first necessity in the design of various policies towards sustainable transportation development that will on the one hand support economic growth and well-being of the population and on the other hand will minimize transport externalities. Road users create externalities, often referred to as social costs that are imposed on other road (and non-road) users and, therefore, are not considered by their generators. Newbery (1988a, 1988b) classified these social costs into four main types:

- (1) Congestion costs - These are considered the classic transport externalities. Imposed on all other road users by any vehicle entering already congested traffic, these costs reveal themselves primarily in increased travel time (or cost) but also in increased vehicle operating costs (because of excessive fuel consumption and wear and tear on the vehicle).
- (2) Road damage costs – Newbery (1988a, 1988b, 1989) treated road damage costs quite extensively in a series of published articles. He defined road damage externalities as the increased vehicle operating cost imposed on subsequent vehicles driving on an increasingly damaged road. Road damage costs are not trivial, particularly in developing countries, and therefore they should be taken into account in the cost-allocation calculus of road-user charges.
- (3) Environmental pollution costs - These are externalities imposed primarily on non-road users in the form of air pollution, noise, and obstructed vision (US Federal Highway Authority, 1982; Quinet, 1989; and ECMT, 1990). For example, Monzon and Guerrero (2004) estimated the annual health and social costs of transport-related air pollution in Madrid at 357 million Euros.
- (4) Accident externalities - These refer to the cost of road accidents which appears to be appreciably high, much higher than often thought (see, for example, Jones-Lee *et al.*, 1985; O' Reilly *et al.*, 1992; and Department of Transport, 1978a). Lemp and Kockelman (2008) estimated that the most significant externalities are associated with crashes and congestion. The U.S. National Safety Council in 1994 assessed the economic costs of motor-vehicle accidents, including deaths and disabling injuries, at \$176.5 billion (1995, p.78). In the Netherlands, the total cost of road crashes in 2004 was estimated at about 12 billion Euro, constituting about 2.5 % of the Dutch Gross National Product (GDP) (SWOV Fact sheet,

March 2007, p. 4); and in Israel, the annual cost of accidents was estimated at 4 billion USD, representing 2.5% of the Israeli GDP or \$450 per capita (Cohen, 2004 and 2006). In both these cases, the costs include fatalities and injuries, pain and suffering, property damage, traffic delays, and administrative costs. The significance of accident externalities and the inadequate knowledge concerning their generation prompted Newbery to address these issues in the following terms:

The present state of knowledge concerning accident externalities is very unsatisfactory, but on calculation suggests that these costs are so large that all classes of road users are being undercharged by the present system of road taxes. Further research on this topic would therefore seem to merit high priority. (Newbery, 1987, abstract)

These externalities are especially pertinent in metropolitan areas where the infrastructure networks are most intensively used and development densities are high. The phenomenon of transport externalities was analyzed in seminal work by such eminent classical economists as Pigou (1920) and Knight (1924) and later Walters (1961) and Vickery (1969), who also suggested ways to correct these market failures.

Increased externalities from motor vehicles called for the development of new policy and planning objectives toward sustainable transportation. These policies, varying from auto-restraint measures, such as congestion pricing and various parking arrangements, through emission-control programs to a wide array of urban design and land-use policies are aimed at reducing the greenhouse effect, improving air quality and public health, reducing congestion and road accidents, and enhancing the overall welfare and quality of life of inhabitants in urban areas. The World Bank (1996) listed as one of its most important objectives increasing the social sustainability of transport by making poverty reduction an integral part of national and local transport strategies.

The growing complexity of travel patterns and the need to estimate changes in travel behavior in response to new policies made transportation planning more challenging and called for a better understanding of travel behavior. This means responding to such issues as how travel behavior is affected by new information and communication technologies, how land use and growth management affect travel behavior, how travelers respond to auto-restraint policies, how much travel is induced as a result of a new infrastructure, and how the various policies affect equity issues. An understanding of such effects is essential for a better design of new policies. In this regard, travel behavior lies at the core of procedures for analyzing and evaluating transportation-related measures aimed at improving urban mobility, environmental quality, safety, and at achieving a wide variety of social objectives. Policy analysis and planning, then, rely on travel behavior studies and travel-demand models.

Travel behavior changed over time in parallel with changes in transportation systems, planning goals, and travel behavior. In the 1960's, the development of the American interstate highway system led to the development of an operational macro-level system of models providing planners and engineers with travel demand forecasting tools. This system (also known as the four-step process) which depends on statistical tools enables the forecast of various travel behavior elements in an aggregate manner, given a certain spatial distribution of land use and the socio-economic characteristics of the population. In the late 1960's, additional emphasis was placed on economic approaches, this motivated by the need not only to better understand travel behavior but also to derive a value of behavioral travel time saving for cost benefit

analysis. In the 1970's, the economic theory of the allocation and valuation of time has developed toward an econometric approach in providing a framework for modeling travel behavior. This approach was based on random utility modeling (RUM). Thereafter, a growing interest in and the need to better understand the motivation of travel behavior prompted the involvement of psychology, among other social sciences, which questioned whether the RUM paradigm could accurately represent the set of decisions that travelers use. A rules-based paradigm was developed as an alternative method. In both approaches, the econometric and the social science, there was a move toward an activity-based framework, in which an effort was made to understand travel behavior as derived from activity participation and time-use behavior.

Policy-making today requires more sophisticated tools, and these have been developed in terms of advanced models, most of them activity-based, that go into different levels of detail on various scales: spatial, temporal, and social. Together with the development of activity-based models, various specific models have been estimated and implemented in support of sustainable policy analysis, some of them as auxiliary to activity-based models and some of them as stand-alone models. Scenario analysis has also been widely used to analyze sustainable transportation policies. The purpose of this paper is to highlight and emphasize the important role of understanding travel behavior and the complex relations between the various travel externalities to the development of sustainable transport policies. Sustainable transportation also mean a safe one with minimum number of casualties, therefore we first (Section 2) introduce the complex relations between congestion, speed variance, vehicle mix and road safety. We then (Section 3) present our view of the required actions for the transition toward sustainable transportation-planning practice and the role of better understanding of travel behavior in this process. Section 4 provides few examples where modeling and evaluation have contributed to understanding the potential effect of various sustainable transport policies. Section 5 provides, with some examples, an overview of activity-based models as improved tools to understand travel behavior and explain their contribution to travel behavior in support of sustainable transportation planning. Finally, Section 6 suggests some future research and implementation recommendations.

2. Congestion, speed variance, vehicle mix, and road safety

Among the factors influencing the number of fatalities on highways are the following: speed, speed differences, and traffic composition. The lower speeds caused by congestion will lead to a lower number of fatal accidents. As a result, we expect a parabolic relationship between density and fatal accidents on highways. When densities increase, there will first be a positive relationship because of the increase in the number of cars in the system. However, when density becomes so high that speeds are influenced negatively, the number of accidents will decrease. The conclusion is that a positive impact exists in addition to the negative impact of congestion in terms of time losses, since fatalities are reduced. Some supporting evidence is found in a number of countries where relatively low numbers of fatalities are observed during the morning peak hours (see Shefer and Rietveld, 1997).

2.1 Road Fatalities and Density

Based on the hypothesis that the rate of road fatalities is closely related to traffic density and speed (flow), a gradual increase in cars while the level of the road capacity is held constant follows the

curve described in Figure 1. This is certainly a possibility if we postulate that travel speed decreases with the increase in density stemming from congestion, thus causing a reduction in the number of road fatalities (see the movement on the curve in Figure 1 from point B to point A). It should be emphasized that we are specifically and intentionally limiting our analysis to the case of fatalities. (It is conceivable that with the increase in density, the number of road accidents may still continue to increase; however, the reduction in travel speed will cause these accidents to result only in injuries or in physical damage to the motor vehicles involved).

A social objective with respect to road fatalities is the minimizations of fatalities. Such an objective could be attained in an unrealistic situation, such as imposing a ban on the use of vehicles or, alternatively, creating such a high level of congestion that travel speed is reduced to zero - a gridlock situation (see Shefer, 1994). (Both of these extreme conditions are described by the far left and far right, respectively, of the curve in Figure 1.)

Figure 1: Hypothetical road fatalities: Rate-density function (About Here)

2.2 Road Fatalities and Speed Variance

In recent years, a heated debate has been waged by several scholars over the effect of speed variance, rather than average speed, on the rate of highway fatalities. The links between speed variance and accident rates was first studied by Solomon (1964), who argued that the relationship between car accidents and the speed of travel could be described by a U-shaped curve. Variations around the average speed of travel, whether above or below it, are associated with an increase in the rate of car accidents. The background of this result is that the rate of car accidents is closely linked to the number of over-takings, and over-takings are closely related to speed differences. The introduction of a minimum speed limit (in addition to a maximum limit) would decrease total costs. This assertion concurs with Hauer's conclusion that "the indiscriminate public crusade against speeding should be replaced by a balanced approach emphasizing the dangers of both fast and slow driving" (Hauer, 1971, p. 7). Solomon's findings were subsequently corroborated by several other studies, including that of Lave (1985), which sparked a debate in the *American Economic Review* (see Levy and Asch, 1989; Fowles and Loeb, 1989; and Snyder, 1989). Further reviews are given by Fildes and Lee (1993) and Finch et al. (1994). The higher the speed differences the higher is the probability that a driver will be involved in an accident. The question in the present context is, To what extent are these speed-difference related costs internal or external. This question is important, since differences that lead to external costs would be a source of unnecessarily high levels of social costs of transport (for more on this issue, see Rietveld and Shefer, 1998).

Speed variance positively affects the level of road safety, particularly the road-fatalities rate. When speed variance is held constant and the average speed of travel increases, the level of road safety decreases. Likewise, when travel speed is held constant and the speed variance increases, the level of road safety also decreases. These suppositions have far-reaching implications for public policies on road safety. For example, the debate over whether to increase speed limits should be discussed jointly with policies aimed at reducing speed variance so as to achieve any improvement in road safety. This raises the issue of introducing minimum speeds in conjunction with maximum speed limits. (A more detailed analysis of the

role of average speed and variances in speed as determinants of accidents can be found in Shefer and Rietveld, 1997.)

2.3. Road Fatalities and Vehicle Mix

A similar argument may be presented with respect to traffic composition, or vehicle mix. As the share of heavy vehicles (trucks) in the traffic on highways increases, the level of road safety is more adversely affected. Given a certain fixed level of speed, an increase in the traffic composition reduces the level of road safety; by the same token, holding traffic composition constant and increasing speed also reduces the level of road safety. This provides another good reason for separating heavy vehicles and private cars as has been implemented on particular roads in metropolitan areas in several countries, notably the United States and the Netherlands. Another positive effect of such a separation is that it more easily enables the imposition of different speed limits according to type of vehicle (car versus truck). After separation, different speed limits do not have an adverse effect on speed variance. Especially relevant for urban areas, too, is the barring of vehicles with hazardous freight from particular routes.

The joint effect of speed variance and traffic composition is apparent. If one variable is held constant and the remaining variable increases, then the level of road safety is expected to decrease. Again, the ramifications of this for public policies on road safety are far reaching; i.e., the level of road safety is jointly determined by speed, speed variance, and traffic composition. Legal speed limits both within and outside urban areas will have an effect on both average speed and speed variance and, thus, positively affect safety on roads (for an analysis, see Rietveld and Shefer, 1998).

The mixture effects mean that different types of vehicle use the same roads. This leads to high potential risks, especially for non-motorized road users (mainly bicycles and pedestrians). Separation of road-user types (through, e.g., the construction of bicycle lanes but also the barring of vehicles with hazardous freight from certain routes) will substantially improve safety. On roads where only motorized traffic is allowed, mixture continues to play a role (cars, trucks, motorcycles). The mixture effect and the speed variance effect are to some extent related, but not always. There still may be a speed variance effect with completely homogeneous road-users (no mixture effect) (for more on this issue, see Shefer and Rietveld, 1997; Rietveld and Shefer, 1998). This effect is especially relevant when accounting for accidents on expressways. Officials should consider homogenizing speeds, not only maximum speeds but also minimum speeds.

In addition to the costs of congestion in the form of time losses and (possibly) higher levels of pollution, there is a potential gain that is often overlooked: congestion leads to lower numbers of fatalities. The reason for this is that, with lower speeds, the probability of fatal accidents will be reduced. Congestion will also indirectly affect safety, because the longer travel times by car lead to a shift in modal choice toward public transport. This has a favorable effect on safety because safety levels are higher in public transport than in private cars.

2.4 Congestion and Cost-Benefit Analysis (CBA)

Congestion has relevance for cost-benefit analyses because it demonstrates that external effects are interdependent. Ignoring such interdependencies may lead to sub-optimal results. In cost-benefit terms, it shows that reducing congestion not only has beneficial effects (in terms of time gains and emissions rates), but also negative effects in terms of an increase in the number of fatalities. This does not imply, of course that congestion should just be allowed to continue for the sake of traffic safety. There are most probably more cost-effective ways to improve safety.

A reduction in the level of road congestion and in road fatalities represents two conflicting objectives. Thus, public policies, such as improving road capacity in order to reduce congestion, could inadvertently produce an increase in the number of road fatalities, as well as in total emissions if more cars use the road as a result of the improved capacity. By the same token, policies that yield the largest reduction in road accidents are not necessarily the best or most socially desirable policies. The most effective policy is the one that yields the highest net social benefits. The optimal level of a program is reached when the marginal social costs of the program equals the marginal social benefits. Every intervention policy entails some direct and indirect costs; thus, it is imperative to perform a comprehensive benefit-cost analysis for each alternative intervention policy. These analyses will enable decision-makers to select the most cost-effective policy aimed at reducing congestion or reducing the number of road accidents with fatalities.

The foregoing discussion leads to the unavoidable and critical question: What is the socially optimal combined level of congestion, fatalities, and emissions? Although decision-makers may continue to avoid this sensitive, even highly explosive, issue, it is clear that a public program is justified only when the total social benefit exceeds the total social cost.

Congestion increases air pollution in urban areas, but at the same time, as discussed earlier, it may reduce the number of road fatalities. Thus, the optimal level of congestion must be determined while simultaneously taking into account all direct and indirect social costs and benefits. The optimal level of congestion will be found at the point where the social marginal cost is equated to the social marginal benefit. At this point, the total social net benefit will be maximized. A more appropriate social objective is one that tries to minimize road fatalities, subject to a certain agreed (acceptable) level of mobility (accessibility) or some maximum acceptance cost entailed by the reduction in opportunities for travel.

The trade-off that exists among congestion, safety, and pollution costs is especially important for sustainable transport planning in metropolitan areas, where these problems are of paramount importance. As mentioned, this will also have implications for the need to develop infrastructure for other transport modes.

3. Sustainable transportation planning

Better understanding of travel behavior, in particular of drivers' responses to various policies instruments, improved evaluation tools, better institutional and planning organizational forms, and greater public participation in the planning process can contribute to the successful implementation of sustainable transportation planning. These issues are discussed in the following subsections.

3.1 Modeling tools

Most Metropolitan Planning Organizations (MPO) use the traditional aggregate four-step model as their main travel demand model for investment programs and policy analysis. These models, which were developed in the United States in the 1950s and 1960s for planning and evaluating the interstate highway system program, were mainly intended to analyze road infrastructure. Although these models have improved with the years to better analyze transit alternatives, they still have many limitations when it comes to analyzing policies toward sustainable transportation (Shiftan and Suhrbier, 2002; Shiftan, 2000, 2008), mainly because our understanding of the impacts of such measures lags behind our understanding of the impacts of new transportation-infrastructure projects. Much has been written on the problem of uncertainty in travel demand models (see, for example, Skamris & Flybjerg 1997; Walmsley & Pickett, 1992; Pickrell, 1990; and Stopher, 1993). This problem is magnified in the evaluation of transportation policies. Our inability to correctly predict travel behavioral responses to such policies and, as a consequence, to evaluate their benefits results in more barriers to their implementation. Policy-makers understand the criticism of these models and question analyses based on them. This lack of trust in the potential impact of such policies may discourage policy-makers from implementing them. There is also some evidence that these models overestimate highway project benefits and underestimate transit and auto restraint policy benefits (Shiftan et al., 2008).

3.2. Evaluation tools

Better evaluation tools constitute an important element to support the implementation of various transportation policies by showing policy-makers and the public the full benefits and costs of such policies which is not a simple task as also discussed in Section 2.4. The World Bank (1996) indicated the need to understand the mechanism by which environmental and ecological impacts emerge and the values that society places on them as still another obstacle in the way of sustainable transportation. However, to date, no adequate framework for appraisal, funding, implementation, and monitoring of integrated transport policies is available (Hatzopoulou and Miller, 2006, 2008). Hatzopoulou and Miller (2008) propose assessing the extent of institutional integration in the appraisal, funding, and implementation of transport policies and stressed the need for cross-sector evaluation of transport policies.

For the evaluation procedure to better account for and promote sustainable transportation policies, it should include wider impacts and benefits of transport improvements (see, for example, Graham 2005, 2006; Vickerman, 2007). New road-safety and environmental impact analyses should be integrated in the evaluation procedure, since ignoring these impacts may bias the evaluation in favor of highway projects. Other impacts include equity considerations, as well as accessibility and level-of- service indices. The

World Bank (1996) also pointed out that full accounting for external effects and rigorous economic appraisal procedures were crucial for sustainable transportation development.

3.3. The Metropolitan Planning Organization (MPO)

When discussing different barriers to the implementation of sustainable transport policy measures, Banister (2002) points to the institutional/political structure as one such barrier. Significant progress has been made in using regional strategies, but tension continues between issues of efficiency and privatization, on the one hand, and equity and the provision of public good, on the other (Haynes et al., 2005). In the context of metropolitan transportation in the United States, interest in the regional operation of metropolitan transportation facilities and the provision of transportation services in metropolitan areas has raised issues of coordination among jurisdictions to facilitate, oversee, and monitor the implementation of new technologies in the transportation area (Haynes et al., 2005). In this context, the World Bank (1996) listed another challenge to the transition toward sustainable transportation: this is the relegation of public sector transport functions to the level at which they are most effectively performed, with the corresponding transfer of technical and financial assistance and the separation of a system's operations as much as possible from direct political influence.

Shiftan et al. (2003) showed that agreement exists among policy-makers, academicians, and practitioners in Israel as to the efficacy of establishing a metropolitan transportation planning organization to help overcome barriers toward sustainable transportation in the Tel-Aviv Metropolitan area, the principal and largest metropolitan area in Israel.

3.4. Public participation

Public participation is an important element in the transition toward sustainable transportation development for two reasons. First, by involving the public in the planning process, it may be possible to better assure the public's support of policies and thus to eliminate potential objections. Second, sustainable transportation development should reflect the public interest. Involving the public in the planning process can assure that policies are designed and implemented with the public's consent and welfare in mind. The World Bank (1996) has also advised engaging non-governmental local community organizations in the planning, supply, and management of local transport services.

4. Case studies

4.1 Employer-Provided Transportation

Shefer et al. (1999) examined the effect of employer-provided transportation by three large Israeli employers in the Haifa Bay Area in reducing private auto use. Israeli employers have been providing transportation services for employees for many years. Although this policy was initially designed as a social policy, it could also be effectively used for achieving environmental goals, as has been done in other countries.

A survey was designed for this purpose and distributed among employees of the three companies including both revealed preference (RP) and stated preferences (SP). Logit mode choice models were estimated based on the SP data and applied to analyze individual choices under various scenarios and estimate the effect of three different scenarios on vanpool use and emissions:

- Scenario I: No vanpool services. The objective of this scenario is to estimate the contribution of current vanpool programs to air quality.
- Scenario II: Enhanced vanpool services, mostly by improved frequency.
- Scenario III: Radical changes in the metropolitan transportation system, providing significant travel time advantage to vanpools over private cars.

Results of Scenario 1 show that current vanpool programs are estimated to reduce weekly car-trips from 70% to 57% and, therefore, save about 140,000 km of travel by private car annually. The improved frequency of the vanpools in Scenario II significantly improves vanpool share from its current 20% to about 40% and reduces the car share from its current 50% to about 43%. VKT by car would decrease up to 27%, and kilometers traveled by bus would increase up to 50%. With more significant investments in improving vanpool services and their travel time compared to cars (Scenario III), the car-use rate would drop to lower than 40% and vanpool-trips would exceed 40%. The kilometers traveled by cars would decrease to 60% of the current rate, and the kilometers traveled by buses would increase by 67%.

The annual emissions of cars and buses were estimated by multiplying the annual kilometers traveled by their respective emissions factors. The results show that when vanpools are offered as a travel mode alternative to about 7,000 workers in the city of Haifa, CO annual emissions are reduced by approximately 100 tons (Current vs. Scenario 1), HC emissions by 7 tons, and NO_x emissions by more than 5 tons. The improved vanpools frequency (Scenario II) could lead to significant reductions in the emissions generated by work-trips. Annual CO emissions would be reduced by 50 tons, and both HC and NO_x emissions by approximately 3 tons. Further improvement of vanpool services, by providing them with a time advantage using HOVs (Scenario III), could reduce annual CO emissions produced by work-trips to the three workplaces by 75 tons, HC emissions by 5 tons, and NO_x emissions by about 4.5 tons.

4.2 Fuel tax and partial congestion tolls

Shiftan et al. (2000) compared the effectiveness of a partial (second best) congestion toll and a fuel tax as alternatives to full (first best) congestion pricing, in which every driver is charged the difference between the marginal cost he or she imposes on the system and the average cost the driver pays in terms of travel time. Such full-congestion pricing has been shown to be the best approach to minimizing total system travel time; however, the implementation of such a toll is in practice not feasible. For this reason, we simulated drivers' behavior in the city of Haifa under different scenarios. Total traffic demand was assumed to be constant; i.e., only the impact of changes in route-choice behavior was evaluated. Obviously such pricing scenarios can also affect mode, time, and destination choices, as well. The simulation was performed using EMME2 software and the equilibrium-assignment procedure.

The following scenarios were simulated:

- Existing condition.
- Optimal congestion pricing.
- Selective congestion pricing (3 scenarios, in each of which various segments of the main congested roads are tolled).
- Selective congestion pricing on all segments, with $V/C > 1.25$.
- Fuel tax (constant fee cost per km)

Except for optimal congestion pricing, all the other scenarios were simulated using Wardrop's first Principle of User Equilibrium reflecting individual behavior. For the optimal congestion pricing scenario, Wardrop's second Principle of System Equilibrium was used, in which the average (or total) travel time on the system is minimized, reflecting the situation that can be achieved with optimal congestion pricing as discussed above.

Table 1 shows the results of the different scenarios. As can be seen, the full congestion pricing of MC-AC will minimize the system's total travel time and reduce average trip time by 3%, which can accumulate to a significant saving in system travel time. However, selective congestion tolls, a fuel tax, and a fixed toll per km will all increase total system travel time compared not only to optimal congestion-pricing scenarios but also to existing conditions. This implies that such second-best solutions will not always improve congestion and must be carefully analyzed before implementation. However, the reader should take note that this examination took into account only route-choice behavior and assumed no mode or destination changes. Obviously such pricing mechanisms may have other long-term effects.

Table 1: Results of the Different Scenarios Examined (About Here)

4.3 Transport Control Measures and the Location of Businesses in Central Business Districts

Shifan et al. (2004) studied the effect of various transport control measures on the location decision of small businesses in the midtown business district of Haifa. They looked at three policies implemented in this area: parking restrictions, pedestrian mall (pedestrianization of one of the main streets), and a bus lane tried to evaluate their impact on the dispersal of businesses away from the center. An understanding of the responses of visitors and business to auto-restraint policies will aid planners in designing effective policies and in finding the preferred mix and balance among the various policies to be implemented. On the one hand, such a mix should encourage travelers to shift from private vehicles to public transportation or to travel during less congested times; on the other hand, they should not force travelers to switch to other destinations so as eventually to cause the relocation of businesses from the CBD.

A survey designed for this purpose was conducted among shop and office owners currently operating in the midtown business area, as well as among those who had operated there in the past but have since moved to another location. The results indicated that among the policies that were investigated, shortage of parking spaces and parking fees ranked as the most important factors causing businesses to leave the CBD. The bus lane had only a marginal effect, and the pedestrian mall influenced only 10% of the businesses, principally businesses already located on the pedestrian mall. Overall, the results show that the implementation of auto-restraint policies in the CBD caused businesses to a great extent to move away from the CBD.

Businesses currently operating in the CBD were also asked about their potential response to the application of a number of hypothetical auto-restraint policies. The results showed that a scenario excluding private cars from the CBD caused most of the businesses to declare that they would either move out or consider moving out. The two scenarios of eliminating parking on the street on which the business was located and of creating a pedestrian mall on that street elicited a similar response. Shops were somewhat less affected by a scenario of pedestrian mall than were offices. The scenario of reducing the number of parking spaces in the CBD elicited a response similar to the doubling of parking fees there. The scenario that had the smallest effect on business relocation was the dedication of traffic lanes to public transport on all of the main streets of the CBD. No significant differences in responses to the different scenarios were detected between offices and shops.

Among all the auto-restraint policies employed in the CBD, it appears that restrictions on the supply of parking caused the largest number of businesses to leave the area. Parking fees elicited somewhat less sweeping responses, and it appears that this policy has a smaller impact on the location decision of businesses than does the reduction in parking supply. The two hypothetical scenarios of “reducing the number of available parking spaces” and “doubling the parking fee” produced almost identical responses; however, parking supply was indicated as a more important location factor and a stronger reason for leaving the Hadar CBD.

5. Activity-Based Modeling and Sustainable Transportation Development

Activity-based modelling treats travel as being derived from the demand for personal activities. Travel choices, therefore, become part of a broader activity- scheduling process, based on modelling the demand for activities rather than merely trips. The explicit modelling of activities and the consequent tours and trips enable a more credible analysis of responses to policies and their effect on traffic and air quality, thus, can better support the evaluation and implementation of such policies.

5.1 Travel Behaviour

Ben-Akiva et al. (1996) proposed a practical activity-based modelling approach in which a comprehensive travel demand-modelling framework captured the mobility, activity, and travel decisions of individuals and households. A corresponding system of models can be used for planning and policy analysis. Since then, researchers have continuously tried to improve our understanding of activity participation and travel behavior, calling for a need to analyze, as well, the context of the activities: the why, when, with whom, and how long, in addition to the sequence of those activities (see Bhat and Koppleman, 1999; Goulias et

al., 2004). Required, too, is a detailed understanding of how households and individuals acquire and assimilate information about opportunities for activity participation and travel options, how this information is used to determine time allocation for activities and travel, and whether the attributes of activity episodes are determined jointly or sequentially (Bhat and Koppelman, 1999).

Some researchers have claimed that for a good understanding of activity participation, there is need to understand the evolution of activity schedules from intentions to final outcomes over the period of a week (Lee and McNally, 2003) Our understanding of the scheduling process, furthermore, can be advanced by observing household scheduling behaviour in realistic planning conditions (Doherty and Miller, 2000).

Activity-based models improve our ability to analyze sustainable transportation policy measures mainly because of their ability to predict how a person's entire daily activity pattern may change as a result of a specific measure taking individuals' time and space constraints into consideration. For example, assume that newly imposed congestion pricing causes a commuter to change his or her mode from drive alone to transit; because the person no longer drives to work, there may be other adjustments to the commuter's daily activity schedule, such as being unable to stop on the way back home to buy groceries. Upon returning home, the person may then take the car and drive to some other store. A view of the person's detailed daily activity pattern may reveal that it is not really feasible for this commuter to shift to transit and only an activity-based model can deal with these types of responses. Land-use policies can affect all activity and travel decisions; therefore, only an activity-based model can be sensitive to such measures through its ability to consider adjustments in one's daily activity pattern. However, relatively few studies have applied the activity-based framework to investigating the relationships between urban forms and travel behavior (Zhang, 2005). The effects of ICT on daily activity pattern and travel behavior are far more reaching than impacting specific trips and in similar fashion, only an activity-based model can capture these effects. One of the main contributions of one such activity-based model, the Portland model, is its ability to distinguish between in-home and away-from-home activities and to make the trade-off between work and any other activity at home or away from home as was demonstrated by Shiftan and Suhrbier (2002).

The importance of activity-based modelling to better analyze various policies also lies in its ability to account for latent demand or, more generally, in its sensitivity to level-of-service variables at all dimensions of travel choice, including trip generation. This is a critical issue in policy-making in regard to transportation investment. The benefits from a new highway can be significantly biased by not taking into account induced demand as travel speeds will be much lower in such cases. It has been shown that this overestimation of benefits outweighs the benefits to new users, who are not considered by the traditional models (Williams and Yamashita, 1992; Shiftan et al., 2008). The advantage of activity-based models lies in their integrated approach, including log-sum variables that bring level-of-service variables up the structure to the daily activity pattern model. Thus, the decision to participate in various activities may be a function of the accessibility of opportunities.

Recent developments in activity-based models have placed emphasis on aspects of behavioural realism that are important for the analysis of sustainable transportation policies. In the Tel Aviv Model, for example, emphasis was placed on such policies as parking supply and fees and congestion pricing. For this purpose, a special parking survey was conducted to collect data on parking demand and supply, as was a stated

preference survey of potential travellers' responses to such policies. These data were used to estimate parking search time, walking time to one's destination, and parking fees at each destination zone, all of which are important determinants of travellers' choice behaviour. A detailed time-of-day model was also estimated to support the analysis of these various policies by time of day.

In San Francisco, the supply, fees, and availability of parking were developed from a variety of sources, including parking surveys, a stated preference survey, parcel data, and aerial photographs of on-street parking. The San Francisco model also developed a policy variable to measure the potential impacts of an improved pedestrian system and of expected growth, which would likely influence future travel demand (Outwater and Charlton, 2006).

5.2 Air Quality

Activity-based models provide better outputs of vehicle-miles travelled and vehicle-hours travelled, which are needed as inputs for emission modelling and air-quality analysis and which enable a better prediction of changes in these variables. The prediction of trips as part of a tour and of tours as part of a daily activity pattern can also identify whether a trip is a cold or a hot start, which is very important for emissions analysis. Activity-based models can predict the time and location of all starts and trips at much better resolution than traditional models, as well as identify the vehicle class and model that makes each trip. Integration with dynamic traffic-assignment models, which are now evolving (Lin et al., forthcoming), will provide much better input for emissions analysis by enabling the development of driving profiles. Activity-based models therefore provide input for emissions and air-quality analysis that is simply not provided with the traditional four-step models (Shifan, 2000)

5.3 Road safety

Like better input for emissions modelling in terms of vehicle-miles travelled and vehicle-hour travelled, this input is also important for better analyses of accidents and road fatalities. Activity-based models can provide additional important input for accident analysis that is not provided by traditional models. This input includes accumulated hours of travel, which can indicate driver fatigue, as well as other details concerning the person's activity that have been shown to affect the probabilities of being involved in accident (Elias, 2008)

5.4 Application to Policy Analysis

Few authors have tried to use the activity-based approach to analyze the potential effects of transport policies. Recker and Parimi (1999) used an activity-based approach with the Portland data as a case study to show the potential of Transportation Demand Managements (TDM) to reduce vehicle emissions. They estimated an upper bound for such emission reductions by posing the research question as: "Given a set of activities, location, and various constraints, if all individuals were to act to minimize CO emissions by trip chaining and ridesharing in the most efficient way possible, what activity patterns would result, and how would they differ in CO emissions from their observed patterns?" Kitamura et al (1995) used a dynamic and integrated micro-simulation forecasting approach to test few TDM in the Washington D.C. area. (see also Pendyala et al, 1997). Kitamura

(1997) also provided a review of studies in which activity-based models have been applied to demand forecasting and policy analysis comparing structural equation model systems and micro-simulation model systems. Shiftan and Suhrbier (2002) used the Portland activity-based model to analyze the potential impact of various sustainable transportation policies including pricing of automobile use (rising parking prices in the city centre and peak hour toll for single occupancy vehicle drivers), telecommunication incentives, transit improvements and a combination of the three. They showed that the evaluated pricing policies have a large impact in reducing travel to the central business district, especially during the morning peak period. Overall regional travel, though, is not significantly impacted. Telecommuting reduced the number of work-tours but there is a higher reduction in transit-tours than auto-tours and part of this reduction is offset by increase of other tours. The proposed comprehensive improvements to bus transit produce the desired decreases in auto travel, although the number of tours occurring by walk and bicycle also are decreased. Approximately one-third of the increase in bus travel is forecast to take place for non-work trip making. The synergistic effects estimated for the particular mix of policies analyzed in this Portland testing were slightly negative rather than positive as normally hypothesized. Once a shift in individual transportation behavior is induced, additional transportation actions that are directed towards the same end would have a decreasing marginal effectiveness. Reductions in vehicle miles of travel and emissions for the combination of the three transportation policies may be less than expected given the nature of the TDM policies being analyzed. Emissions during the A.M. peak period for the Portland analysis region are estimated to be reduced by approximately three percent.

Shiftan (2008) also explained and illustrated the potential of these models in analyzing various land-use policies. Using again the Portland case study he showed the potential effects of a package of various land use and transport policies encouraging people to move the urban growth area. The results showed that also 6% of the suburban population would move to the urban growth area increasing the urban center population by 16% and the rest of the urban growth area by 13% under such a scenario the impacts on regional travel would be marginal. Overall, there is an increase in the number of tours by all modes and even a slight increase in auto tours (2.5%) as a result of improved accessibility. Average trip length decreased by 9% but the combined effects of shorter trips and more trips is an overall increase of 1.4% in VMT.

6. Conclusions and Future Research Directions

Transportation and travel have many positive characteristics both for the individual user and for society as a whole. This explains why the transport sector, for several decades now, has shown unprecedented growth. At the same time, transportation has undesirable side-effects. The almost unlimited demand for transportation cannot be facilitated on an equal basis by the construction of new infrastructures, which induce more traffic and continues to leads to congestion. Other concerns relate mainly to safety and emissions.

Governments and other stakeholders are generally aware that policy measures are needed in order to find a balance between accessibility, safety and sustainability, taking into account the various effects of alternative transportation policies. This is an enormous challenge, and the question arises as to how one finds the right balance among economic growth, congestion, safety, and pollution in order to maximize social welfare.

Travel behavior lies at the core of procedures for the analysis and evaluation of transportation-related policies that are aimed at improving urban mobility, environmental quality, road safety, and social objectives. Analysis and planning of a sustainable transportation policy is the main objective of travel behavior studies and travel-demand models. Travel behavior has advanced over the years, and the new generation of travel-demand models, activity-based models, is now making the transition from theory to practice and is starting to assist decision-makers in policy analyses toward sustainable transportation. This paper has shown the importance of improved behavioral realism in travel demand models in order to better understand travelers' responses to policy measures and better analyze their benefits and costs.

More research is required to further improve behavioral and travel demand models, our evaluation tools, and the design of policy measures that best achieve this balance (and trade-off) among economic growth, congestion, safety, and pollution. Activity-based models have been advanced significantly in the past decade, but practical activity-based models have only recently become operational. This is the time to test these models, use them for policy analysis, and make the transition toward a wider use of activity-based models. To make this transition, future research should point to the balance and trade-off between behavioral realism and complexity so that they can be widely used by planning agencies.

Evaluation tools should be improved to better estimate the various externalities, in particular emissions, pollution, and road safety. To find the right balance, however, better understanding is also required of the impact of transport projects on economic growth and regional development, as well as of such issues as the benefits of improving travel time reliability and the effects of private financing of public infrastructure. To this end, comprehensive risk analysis, system analysis of urban safety impacts, and the new activity-based models should be incorporated into the evaluation procedure.

From a policy point of view, one of the main challenges is how to improve and accelerate the transition toward sustainable transportation planning. While there is some agreement on desired policy measures toward sustainable transportation development, their implementation is lagging. Better insight into transition management is required to assist policy-makers and stakeholders to speed up implementation.

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Table 1: Results of the Different Scenarios Examined

<u>Scenario</u>	<u>Total travel time (hour)</u>	<u>Average travel time (min)</u>
Existing cond.	29,555.3	22.26
Opt. cong. pric.	28,700.9	21.61
Selective tolls 1	29,860.0	22.48
Selective tolls 2	30,159.0	22.71
Selective tolls 3	30,177.0	22.73
Avg. per km.	32,551.4	24.51
Toll on $v/c > 1.25$	30,085.0	22.66

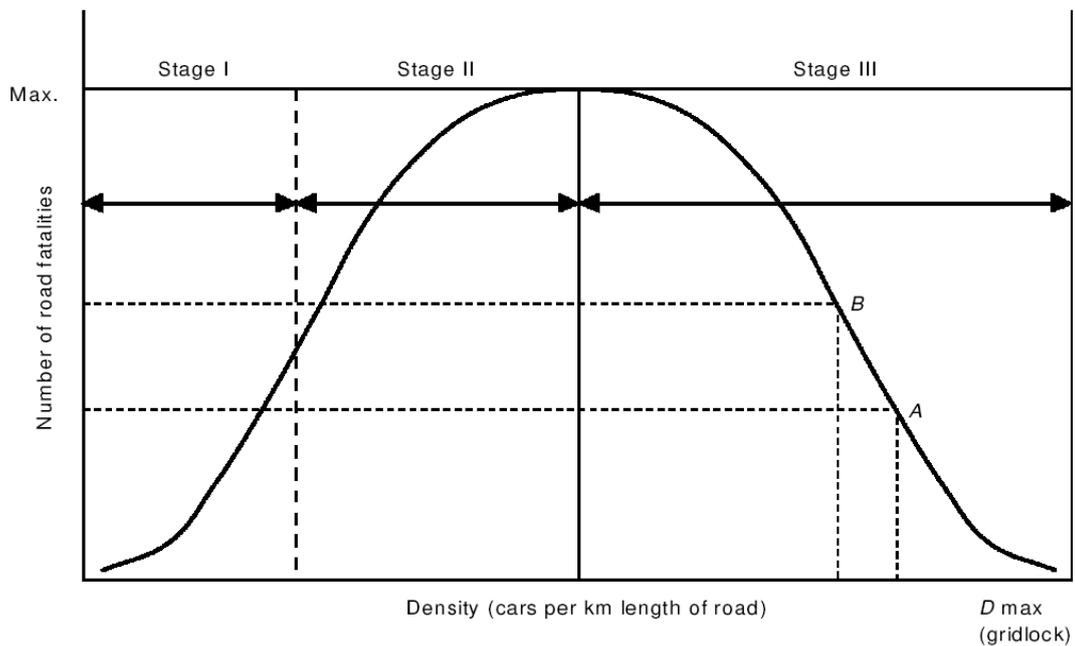


Figure 1: Hypothetical road fatalities: Rate-density function