TRANSPORT MODELING AND JUSTICE: THE CASE OF THE FOUR-STEP MODEL

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ABSTRACT
Transport demand models play a crucial role in the distribution of transport facilities, and hence accessibility, over population groups. The goal of this paper is to assess the distributive impacts of demand-based modeling, and more specifically the four-step model. Based on an initial analysis of this latter model, the hypothesis is formulated that the consecutive application of the model will widen existing gaps between high-mobile and low-mobile groups, in terms of available transport facilities and accessibility. A simplified four-step model is developed to test the hypothesis under different policy scenarios. The results are strikingly mixed. In each scenario, gaps between high-mobile and low-mobile groups are increasing and decreasing at the same time. Against our expectations, the distributive implications of demand-based modeling seem to depend on the situation: on the initial circumstances in which modeling is employed (e.g. level of population segregation, existing transport network, motorization levels), on the policy responses derived from the modeling results (provide or prevent approach), on the transportation good that is analyzed (facilities or accessibility), on the groups that are compared (areas, income, or mode groups), and on the benchmark that is used (before-after or with-without comparison). Given the unpredictable distributive impacts, it is suggested that explicit justice indicators be incorporated in transport modeling, if it is to contribute to a more just distribution of transport facilities and accessibility. The paper concludes with a call for the development of a social justice approach to transport analogous to fields like health and education.

KEYWORDS
Transport modeling, four-step model, social justice, distributive justice, accessibility

1. INTRODUCTION

Transport is a key responsibility of modern governments. Governments do not only set the regulatory framework, but also determine the size and scope of investments in transport facilities. Given the importance of transport in current high-mobile societies, the way in which governments distribute transport facilities over their citizens becomes of the utmost importance. And yet, little attention has been dedicated to the way in which governments allocate transport facilities, and hence mobility and accessibility.

The goal of this paper is to critically analyze the role of transport demand models in the distribution of transport infrastructure. These models are used throughout the world to forecast future demand for transport with the goal to assess the future performance of the existing or expanded transport system (Bates 2000). The results of transport modeling feed decision-makers with data on where to provide what kind of transport infrastructures. By doing so, transport models play a crucial role in the ultimate distribution of transport facilities over population groups.

The paper is structured as follows. First, a justice approach to transport is developed (Section 2). Then, the still-dominant four-step transport model is discussed and criticized from the perspective of justice. This results in the formulation of the hypothesis that the consecutive application of the four-step model over a period of time, with consequent development of transport infrastructure based on the model results at each stage, will exacerbate existing mobility and accessibility gaps between population groups (Section 3). We then present a simplified four-step model that will assist us in testing this hypothesis. Section 5 discusses the application of the model for a number of scenarios and presents the results. We end the paper with a discussion linking justice, transport and modeling.

2. JUSTICE AND TRANSPORT

Most contemporary scholars define social justice as *the morally proper distribution of benefits and burdens among members of a society* (Boucher and Kelly 1998; Miller 1999). Starting from this definition, human society is perceived first and foremost as a distributive community in which people produce things that are shared, divided and exchanged in specific ways (Walzer 1983). The way these ‘things’ – commonly defined as benefits and burdens or goods and bads – are and should be distributed is the subject of study. Thus, social justice scholars view fields like health, education or employment as areas in which a specific good or set of benefits and burdens is distributed over men and women, children and adults, rich and poor, white and black, and so on.

This paper will apply the distributive justice approach to the field of transport. Scholars of social justice have largely overlooked this issue, apart from a few authors that have dealt with it only in the sidelines (e.g. Walzer 1983; Sadurski 1985; Braybrooke 1987; Elster 1992; Miller 1999). A limited number of transport researchers have taken up a distributive approach, most notably with regard to road taxes (Altshuler 1979), public transport subsidies (Cervero 1981; Pucher 1981; Pucher 1982), and public transport services (Murray and Davis 2001; Cha and Murray 2002). But, to the best of our knowledge, no efforts have been made to analyze transport demand modeling from the perspective of distributive justice.

The application of the distributive approach to the field of transport requires a clear demarcation of three key elements: (1) the *goods and bads* or benefits and burdens that are subject of analysis; (2) the *members of society* between whom goods and bads are distributed;

and (3) the *distributive principles* that determine what is a fair distribution of the goods and bads under discussion. The study of social justice requires that explicit attention be paid to each of these elements and that they be linked to each other in a coherent way.

First, a decision has to be made with regard to the *goods and bads* that are the subject of analysis. Here, two possibilities can be distinguished. The first is to focus on *individual* goods and bads, including objects (cars, roads), services (bus lines, bicycle parking), taxes and subsidies, pollution, and congestion. The second approach is to conceive of transport itself as a good. In this case, transport is regarded as a *complex* good composed of various objects, services and other 'things' which, taken together, enable members of society to fulfill a specific want or need – commonly defined as 'transport' or 'accessibility' (Portugali 1980). Transport demand modeling directs the attention, first and foremost, to the distribution of infrastructure. However, investments in new transport infrastructure also shape the distribution of accessibility over people, which is arguably of even more importance to citizens. In the paper, we will analyze how transport demand modeling shapes the distribution of both goods.

The second element that requires demarcation concerns the *members of society* between whom goods and bads or distributed. The challenge here is to divide the members of society into meaningful groups so that potential injustices may be revealed. In case of transport demand modeling, a number of distinctions are relevant. One is by mode availability. This is especially important in case of investments in road infrastructure, as car availability is either a prerequisite to benefit from a road, or substantially increases the gains that can be derived from such infrastructure. Second, since transport infrastructure is located in space, a geographical distinction of population groups is also relevant. Groups living nearby a new or extended transport facility may be expected to benefit more from that facility than people living at a larger distance. Note that these distinctions are not only important in analyzing the distribution of transport infrastructure itself, but also in analyzing (changes in) the distribution of accessibility. Furthermore, since accessibility is not only a function of the availability and quality of transport facilities, but also of the financial ability of people to make use of these facilities, a distinction by income groups is also called for.

The third element that requires demarcation concerns the *distributive principle* that will be used as the yardstick to judge whether a specific distribution of the goods discussed above is just or not. Without an explicit and well-motivated decision which yardstick to use, any justice analysis is ultimately pointless. The principle often considered as the 'default' option is equality, which describes a distribution in which each recipient or group of recipients receives the same amount of a certain good (see e.g. Walzer 1983; Smith 1994; Miller 1999). Moreover, Smith (1994) argues that the challenge for scholars of social justice is to provide convincing arguments why to deviate from the criterion of simple equality. Lacking such arguments, equality remains as the correct yardstick to assess the distribution of a specific good.

The question that thus needs to be raised is whether good arguments can be given for providing the goods discussed above – transport facilities and/or accessibility – in any other way than according to the principle of equality. Since a full exploration of possible – and defensible – distributive principles applicable to these goods is beyond the scope of this paper, we will use the default option of equality as the yardstick to judge distributive patterns. More specifically, since current motorized societies display substantial gaps between population groups in terms of available transport facilities and accessibility (e.g.

Hine and Mitchell 2001; Blumenberg 2004), we will focus on equalization (cf. Smith 1994; Martens 2006). That is to say, we will assess to what extent transport improvements suggested by transport modeling lead to a decrease or increase in existing gaps between population groups. If the former holds, we consider transport modeling to contribute to a just distribution of transport.

The table below provides an overview of the three constitutive elements of a distributive approach to justice, and its application to the field of transport modeling as employed in this paper.

TABLE 1 Key Concepts Of A Distributive Approach To Social Justice And Practical Application To The Analysis Of Transport Demand Modeling

Key elements	Description	Application to transport modeling
Goods and bads	The 'things' that are distributed (shared, divided, exchanged, dispersed) in society	-Transport facilities - Mobility - Accessibility
Members of society	Recipients of goods or bads divided into groups based on characteristics that are relevant for the distribution of the good or bad under discussion	- By car ownership - By location - By income
Distributive principles or criteria	Principles that determine what distribution is just	- Equality / equalization

3. TRANSPORT DEMAND MODELING AND JUSTICE

Transport demand modeling has gained widespread use in the industrialized world since the late 1950s and is now an integral part of transport planning in virtually all motorized countries. Most of these countries still apply variations of the four-step model, despite widespread criticism and the development of more advanced activity-based models (Bates 2000; McNally 2000a). The four-step model forecasts future transport demand in four steps (see e.g. de Dios Ortuzar and Willumsen 2001; McNally 2000b): trip generation, which estimates the number of trips at the level of transport activity zones; trip distribution, in which trips are spatially distributed over attraction zones; mode choice, which determines the transport mode of trips between each origin-destination pair; and, finally, traffic assignment, which assigns the trips onto mode-specific transport networks. The four-step model ultimately results in a forecast of future travel demand, which in turn can be used to assess the future performance of the existing transport system, to identify transport links that lack sufficient capacity, and to assess the impact of various transport investments on the performance of the system.

From a social justice perspective, the linchpin of the four-stage model lies in its aim to forecast future travel *demand*. As Sheppard rightly points out, the concept of travel demand should be treated with care: 'Conventionally it implies the notion that consumers have freely chosen one possibility over all other, which in turn suggests that the observed pattern of trips represents the best possible set of actions that individuals could have taken given their preferences and the spatial structure of the city' (Sheppard 1995). However, current travel demand is as much the result of constraint as it is of choice. This implies that transport modeling that starts from current travel patterns may actually reinforce existing differences in accessibility between population groups.

A further analysis of the four-stage model can strengthen this argument (see Martens forthcoming). From a social justice perspective, the first step of the model is of key importance. In this step, the number of trips per household is predicted for some year in the future. Generally, households are distinguished according to a number of characteristics, the most important of which are household size, car ownership levels, and household income. Then, for each household type, the average number of trips is calculated, using large-scale travel data. This approach typically results in large gaps in average trip rates per household, with higher trip rates linked to higher levels of income and car ownership. These differences in trip generation rates obviously translate into the results of the transport model and, ultimately, into suggestions for major transport capacity improvements.

What is ignored in the four-step model, and even in more recent activity-based models, is that current travel patterns are a reflection of the way in which transport (roads, parking, public transport, etc.) was distributed in the past. By using current travel patterns as the starting point, these modeling approaches actually strengthen the position of those who received transport facilities in the past and are thus more likely to travel (typically the car owner given the extensive road building over the past decades), and weaken the position of those who did not receive many facilities and are thus limited in their possibilities to travel (typically the car-less given the reduction in public transport services during the same period). In this way, the transport models actually create a loop: they start with the current high trip rates among car owners and high income groups, then predict high trip levels among comparable future population groups, and subsequently suggest ways to cater for this growth through improved services (road building or high quality public transport services), which in turn results in higher trip rates among car owners and high income groups. From here on, the loop starts again.

Given the link between current travel patterns and future demand, we expect that the consecutive application of the four-step model over a period of time, with the consequent development of transport infrastructure based on the model results at each stage, will exacerbate the existing gaps between high-mobile and low-mobile groups, in terms of available transport facilities and accessibility.

4. TOY MODEL

The hypothesis outlined at the end of the previous section has been tested using a simplified version of the four-step model. This ‘toy model’ is tested in a simple environment consisting of three residential zones (R) and one attraction zone (A). Each R contains a fixed number of households that does not change over time. R’s differ in terms of socio-economic composition and subsequently in their initial level of car ownership. $R_{p(oor)}$ is the poorest residential area, followed by $R_{m(iddle)}$ and $R_{r(ich)}$. The socio-economic composition does not change over time, but car ownership levels can change as a result of car purchases by households. Each R is connected to A by road and transit. In the initial situation, the road is faster but more costly than the transit mode. The initial quality of both road and transit, in terms of travel speed and time, is identical for each R, but can change over time as a result of changes in traffic volumes and/or investments in transport infrastructure. Each trip generated in any R has destination A, while A does not generate any trips.

Since in this simple model environment there is only one destination and one link for each transport mode, the steps of trip distribution and trip assignment become completely trivial. The toy model can thus be limited to the steps of trip generation and mode choice. In addition, in line with state-of-the-art models, a car-ownership feedback loop is added to the toy model.

The trip generation step requires input with regard to total number of households by category, and trip rates per household category. Households are classified according to income level and car ownership, as detailed above. For the initial situation, the figure on the size of each household category is derived from the model specifications, and subsequently adjusted based on the results of the car ownership model. The trip matrix is considered fixed throughout all runs of the model, i.e. trip rates remain the same for each category of households. In line with actual practice, trip rates go up with increases in household income and car ownership. For reasons of simplicity all trips are executed during one time interval.

The mode choice step consists of a computation of the distribution of total trips over the two available modes (car and transit). The calculation is based on a simple utility function representing the generalized cost of each mode, which is a function of: (1) level of service provided by each mode (travel time and cost); and (2) socio-economic situation of the trip maker. Poor households are assumed to attach more weight to money and less to time, while the opposite holds for rich households. The probability of using a specific mode is inversely related to the mode's cost, in a way that resembles common practice in discrete choice analysis (Ben-Akiva and Lerman 1985).

The car-ownership feedback model is a crucial part of the toy model. The model relates a household's decision to purchase an additional car to two factors: (1) the advantage of car use over transit use; and (2) household income. The first is calculated as the ratio of generalized costs of car and transit, and thus depends on travel speed and costs of each mode. Growth in car ownership is subsequently calculated per income group using a linear function of these two components. The function computes, for each model iteration, the probability for each population group that a household will buy a car. Growth in car ownership is limited by the model stipulation that households cannot purchase more than two cars. This limit has been set in order to avoid endless growth in car ownership and trip rates. The result is that growth in car ownership evens out in the later iterations of the model, starting with the highest income group.

The toy model has been applied a number of times in a row in order to explore the implications of the consecutive application of the four-step model in a real-life situation. In most cases, the experiments have been limited to five model runs, but we have also carried out experiments of up to twenty model runs in order to explore the consequences of model application over a longer 'time period'. Each run of the model can be considered to represent a fixed time interval of, for instance, ten years. At the end of each model run data are generated on e.g. number of trips, car ownership, modal split, road congestion, etc. These data – most notably the updated figures on car ownership per income group and data on increased transport capacity – are subsequently fed into the next run of the model.

The model has been applied to three scenarios. In the do-nothing scenario S_0 no improvements are made in existing transport facilities (road and transit). Like in the other scenarios, in each model run households determine whether or not to purchase a car. Households that buy a car will 'move up' in the trip matrix and generate more trips than in the previous run. Most of these trips will be made by car, but some by public transport. The growth in trips results in increased congestion on road and transit, and subsequently in increased travel times.

The predict-and-provide scenario S_1 represents the transport policy applied throughout much of the second half of the 20th century, in the US and elsewhere. In S_1 road capacity is added whenever volume exceeds capacity by more than 20% and severe congestion occurs. In that case, road space is added in fixed portions till the ratio of volume over capacity is less than 120%. No improvements are made in transit service in S_1.

The predict-and-prevent scenario S_2 follows more recent policy lines that seek to limit the environmental impacts related to increasing car use (e.g. Vigar 2002). In S_2, transit services are improved in order to divert predicted increase in car use to transit and thus prevent a growth in car trips. For reasons of comparability between scenarios, transit service is improved in the same way as the road system, i.e. through the addition of capacity. And like in the case of road infrastructure, increased capacity raises travel speeds of the transit service. This methodology reflects the real-life link between transit capacity (as measured in e.g. seat-kilometers), transit frequency, and travel times by transit. No improvements are made in road infrastructure in S_2.

The impacts of the scenarios on the distribution of the selected transport goods (facilities and accessibility) will be explored through: (1) a before-after analysis; and (2) a with-without analysis. In the first method, for each scenario the final situation will be compared with the initial situation, in order to assess whether gaps have increased or decreased. In the second method, S_0 will serve as the 'without' case and the final situation in S_1 and S_2 will be compared with the final situation in S_0. The latter approach is in line with assessment methodologies applied in, for instance, cost-benefit analysis.

5. MODEL RESULTS

The model and scenarios have been used to test the hypothesis formulated above – i.e. the hypothesis that a consecutive application of the four-step model will widen existing gaps between high-mobile and low-mobile groups in term of transport facilities and accessibility - in a variety of environments. Below we present the results.

Facilities

The first analysis of transport facilities explores the distribution over R's. In this case, the before-after and with-without comparisons are identical. Following the basic characteristic of the four-step model, it is expected that most transport facilities will be allocated to the areas with the strongest growth in travel demand as measured in total trip numbers. Facility is measured here in terms of capacity, with capacity defined as the maximum number of vehicles that a link can serve, as is common in road planning. The same methodology has been used for transit, but here the initial capacity is not optimal. This makes it possible to apply identical speed impedance functions for road and transit, while enabling speed improvements for transit above the initial level.

In accordance with expectations, total trip numbers increase most in R_r and least in R_p, in both S_1 and S_2. This is the combined result of (1) the stronger tendency among richer households to purchase cars, and (2) higher trip rates among car-owning households. The distribution of transport facilities follows suit, with most investments flowing to R_r and least to R_p. While difficult to compare, it is interesting to note that S_2 requires substantially more additional transport facility than S_1 for an overall lower increase in total trip numbers.

The second analysis explores the distribution of facilities over income groups. For this comparison, capacity per household has been calculated in a way that links capacity to trips, i.e. the more trips a household makes the more capacity it receives. The obvious consequence of this measure is that in the initial situation, higher income groups will receive more capacity than lower income groups, simply because they make more trips. Furthermore, most additional capacity will flow to the income groups with the strongest overall increase in total trips. Recall that the latter increase is a direct result of car purchases.

The with-without analysis shows that in both S_1 and S_2 gaps between income groups are growing. In both cases, the richer income groups (INC3 and 4) benefit substantially more from the additional capacity, whether it is road capacity in S_1 or transit capacity in S_2. Interestingly, the before-after comparison shows somewhat different results. In case of S_1, INC2 profits most from the additional road capacity. INC3 and 4 benefit less, mostly because of the maximum number of cars per household specified in the model. This specification impacts richer households first, as they start off with higher car ownership levels and have the strongest tendency to purchase cars. They will therefore reach the maximum first, de facto blocking further growth in trip numbers. The result is that in S_1, gaps are shrinking between INC2 and the higher income groups, while gaps are growing for poorest income group (INC1). The results thus neither confirm nor refute the hypothesis (Table 2).

The situation is different in S_2. Here, transit improvements reduce travel time differences between car and transit. This reduces the incentive to purchase cars, especially among poorer households, and thus limits growth in trip rates for these groups. The result is that INC3 and 4 profit most from increases in transit capacity, while INC1 hardly benefits at all. Thus, while initially gaps in transit provision are small, gaps grow at a high rate over time.

In contrast, in S_0 the gaps between income groups are decreasing, most notably for car capacity. This is due to the fact that poorer income groups increase their share in total number of trips, which is explained by low initial share in trip numbers and relatively strong growth in car ownership. Taken together, this increases the poorer income group’s share in the existing, fixed, capacity.

TABLE 2 Increase In Transport Capacity Per Household, Before-After Comparison

Residential area	Income group	S_1: car capacity			S_2: transit capacity		
		Initial capacity	Additional capacity	Final capacity	Initial capacity	Additional capacity	Final capacity
R_p	INC1	0.62	0.54	1.15	1.07	1.07	2.14
	INC2	2.69	2.51	5.20	2.42	2.58	5.00
	INC3	4.43	1.97	6.40	2.59	3.18	5.77
	INC4	6.86	1.37	8.23	3.30	4.10	7.41
R_m	INC1	0.62	0.62	1.24	1.06	1.09	2.15
	INC2	2.99	2.43	5.42	2.35	2.64	5.00
	INC3	4.51	2.10	6.60	2.56	3.21	5.77
	INC4	6.86	1.60	8.46	3.29	4.12	7.40
R_r	INC1	0.66	0.57	1.23	1.06	1.17	2.22
	INC2	2.68	2.57	5.24	2.40	2.77	5.17
	INC3	4.48	1.95	6.43	2.56	3.43	5.98
	INC4	6.82	1.42	8.24	3.28	4.39	7.66

Travel Time

Travel time has been used as a first indicator of accessibility. First, a with-without assessment of changes in travel times has been carried out. Naturally, travel times are shorter in the policy scenarios than in S_0. But there are substantial differences in travel time savings between the two policy scenarios. In case of S_1, car-drivers (owners and buyers) reap substantially more travel time savings than car-less households, enlarging the time gaps between both groups in comparison to S_0. Car-drivers residing in R_p are better off than those residing in richer areas. This is a combined result of low initial road capacity and a large pool of potential car-buyers generating a relatively large increase in total trip numbers. In S_2, car-less households reap substantially more time savings than car-drivers. The result is that gaps in travel times are sharply reduced, although car-drivers remain in a better position than transit users after five model runs. Car-less households in R_r benefit slightly more than those in poorer areas. This is caused by the large share of high income groups, which are more inclined to choose road rather than transit. Transit service thus has to improve more in the richer areas, in order to prevent additional car use. Note furthermore that car-drivers are somewhat better off in S_1, while car-less households are much better off in S_2. In terms of distribution of travel times, the results show that gaps in travel times are increasing in S_1 and decreasing in S_2.

Again, the results are somewhat different in case a before-after evaluation is carried out. In that case, gaps between car-owners (CO) and car-less households (CL) are decreasing in all scenarios (Table 3). In S_0, both CO and CL face an increase in travel time, but the latter substantially less then the former. This is due to the preference for the car over transit, which results in a stronger increase in road congestion and thus in travel time. In S_1, CL experience a small reduction in travel time, due to a decrease in transit ridership and related increase in transit speed. CO, in turn, are faced with a light increase in travel time, despite investments in roads infrastructure. This is largely a result of model specifications, which define no congestion in the initial situation but increasing congestion till a fixed maximum during the model runs. This specification also plays a role in S_2, in which case CO face a small increase in travel time too. CL, as well as car-buyers (CB), face a large reduction in travel time, substantially reducing the travel time gaps in comparison to the initial situation. The difference between both groups disappears completely after more model runs, in which case transit becomes as attractive as the car, reducing car purchases till the minimum.

TABLE 3 Changes In Travel Time Per User Group As A Result Of Transport Investments, Before-After Comparison

	Initial travel times		S_0 do-nothing			S_1 provide			S_2 prevent		
	Car	Transit	CO	CB	CL	CO	CB	CL	CO	CB	CL
R_p	20.78	33.14	+5.87	-6.49	+0.96	+1.22	-11.13	-0.17	+1.34	-11.02	-10.16
R_m	20.78	33.18	+5.14	-7.31	+1.06	+0.96	-11.49	-0.20	+1.33	-11.12	-10.24
R_r	20.84	33.02	+4.61	-7.84	+0.83	+1.15	-11.30	-0.29	+1.28	-11.17	-10.61

Expected Utility

Utility associated with trips, and more specifically expected utility (henceforth E(u)), is a widely used measure of accessibility (see e.g. Miller 1999, Levin and Garb 2002), particularly in use as part of advanced activity-based transport modeling approaches (Dong, Ben-Akiva *et al.* 2006). It takes into account both the benefit, i.e. the desirability, of a destination, and the cost of reaching it. In our model, the benefit derived from each trip is identical, so only variations in costs play a role. Car-owners may choose between car or transit, so that their expected utility is a weighted average of the utilities of both modes, while the car-less are bound to use transit.

Note that since higher income groups ascribe higher values to time and since time is more dominant in the utility function than the cost element, higher income groups will always have the lowest utility (or: largest disutility) in the initial situation. This complicates the equity analysis, as the equality criterion now suggests that utility of high income groups should be brought on par with that of the lower income groups. De facto this would mean investing in transport facilities that primarily serve rich and already high-mobile groups. While perhaps logical from an economic perspective, this seems counter-intuitive from a justice perspective. So rather than focusing on an equalization of E(u) for all income groups, the focus of analysis has shifted to the *additional* E(u) received by each income group, using equality as the equity yardstick. Note that this implicitly assumes that the existing distribution of E(u) is just.

The results of the with-without analysis show that higher income groups receive most additional E(u), in both S_1 and S_2, and in all R's. This is the combined result of the transport investments in the policy scenarios, which reduce travel times in comparison to S_0, and the fact that higher income groups attach higher value to the time savings generated by these investments. Note that gaps between income groups in additional E(u) are substantially larger in S_2 than S_1. This is a result of the fact that upgraded transit facilities decrease travel time for both car and transit. Higher income groups thus also profit from the large decrease in transit time in S_2, despite the fact that the car remains the fastest mode (at least after five model runs). Furthermore, each income group reaps more additional E(u) in S_2 than in S_1. Once again, this is the result of a decrease in transit time and a relatively small increase in car time in S_2. In sum, while S_2 makes everybody substantially better off than S_1, S_2 is also the scenario with the largest gaps in the distribution of additional E(u). The before-after comparison shows comparable results.

The problems related to the E(u) measure disappear when expected utility is compared *within* income groups. In that case, the income effect on time and cost valuation disappears and the attention can be redirected towards total rather than additional E(u). Because of this, the measure is well-suited to assess the distribution of accessibility over groups distinguished by mode availability. The results of the with-without comparison show that in case of S_1, CO always reap more additional E(u) than CL. This is obviously the result of investments in road infrastructure, which substantially improve car speed but only slightly reduce congestion on transit services and thus transit travel time. The result is that gaps between CO and CL in total E(u) increase, for all income groups and in all R's. In contrast, in $S_{2,}$ CL experience a stronger increase in additional E(u) than CO. The result is that the gaps between both groups decrease substantially in comparison to S_0, even to such an extent that CL are better off after five model runs than CO in terms of total E(u).

Conclusion

Table 4 provides a qualitative overview of the impacts of each scenario on the distribution of the selected transport goods over population groups. The most striking result is that the hypothesis formulated above cannot be confirmed throughout. In each scenario, gaps between high-mobile and low-mobile groups are increasing and decreasing at the same time. This result is most clear for S_2, but it also occurs for S_1. While some distributional trends may be the result of model specifications, it is clear that the four-step model has less clear-cut distributive implications than expected at the outset.

TABLE 4 Overview Of Distributional Impacts Of All Scenarios[a]

Good	Comparison	Scenario	Distinction of population groups by		
			R	INC	Mode
Capacity	Before-after	S_0	Not relevant	Not relevant	Not relevant
	With-without	S_1	+		
		S_2	++		
Capacity per household	Before-after	S_0	0	-	Not analyzed
		S_1	0	0	
		S_2	--	++	
	With-without	S_1	0	+	Not analyzed
		S_2	--	++	
Travel time	Before-after	S_0	Not relevant	Not relevant	+
		S_1			-
		S_2			--
	With-without	S_1	Not relevant	Not relevant	+
		S_2			--
Expected utility	Before-after	S_0	Not analyzed	Not relevant	0
		S_1			+
		S_2			--
	With-without	S_1	Not analyzed	Not relevant	+
		S_2			--
Additional expected utility[b]	Before-after	S_0	Not analyzed	+	Not analyzed
		S_1		++	
		S_2		+++	
	With-without	S_1	Not analyzed	++	Not analyzed
		S_2		+++	

[a] The table should be interpreted as follows:
+(+) gaps increase (strongly)
-(-) gaps decrease (strongly)
0 no clear tendency

[b] For additional expected utility, the number of '+' signs indicates the size of the deviation from an equal distribution of the good in favor of richer income groups.

6. DISCUSSION

In this paper, we have tried to link two fields that traditionally do not meet: transport modeling and distributive justice. Based on an initial analysis of the still-dominant four-step model, we formulated the hypothesis that the consecutive application of the model will widen existing gaps between high-mobile and low-mobile groups, in terms of available transport facilities and accessibility. Subsequently, we have developed a simple model to test the hypothesis. The results of the paper provide food for thought on two levels.

The first level concerns the distributive implications of the application of transport demand modeling, and more specifically the four-step model. Despite its limitations, we feel that the simple model and the 'longitudinal' modeling approach applied in this paper have helped to shed light on these distributive implications. The results of our simple model show that the hypothesis formulated above cannot be confirmed. Against our expectations, the distributive implications of demand-based modeling seem to depend on the situation. They depend on the initial circumstances in which modeling is employed (e.g. level of population segregation, existing transport network, motorization levels), on the policy responses derived from the modeling results (provide or prevent approach), on the transportation good that is analyzed (facilities or accessibility), on the groups that are compared (areas, income, or mode groups), and on the benchmark that is used (before-after or with-without). Thus, while transport demand modeling has built-in tendencies to strengthen high-mobile groups at the expense of low-mobile groups, the actual application of the model may neutralize these tendencies. While the latter may not have occurred throughout much of the period in which the predict-and-provide approach was prevalent, it is a real possibility now that the predict-and-prevent policy is gaining in importance. Since in real-life it will be difficult to assess whether the built-in tendencies will be neutralized or not, the danger remains that transport modeling will exacerbate existing gaps in mobility and accessibility. These observations suggest that, if transport modeling is to contribute to a more just distribution of transport facilities and accessibility, it will at least be necessary to incorporate explicit indicators concerning the distribution of transport improvements over population groups.

This brings us to the second level: the integration of social justice considerations into mainstream transport modeling and planning. The increasing importance of mobility and accessibility in current societies, and the increasing evidence regarding the impacts of inadequate transport services on everyday life (e.g. Hine and Mitchell 2001; Blumenberg 2004), suggest that the issue of distribution can no longer be ignored in the field of transport. However, where a distributive approach is well-developed in fields like education and health (see e.g. Elster 1992), there has been hardly any reflection on distributive issues in the field of transport. This includes the three basic questions outlined at the beginning of the paper: Which good are we actually distributing? What are the relevant population groups to distinguish? And how do we judge whether a certain distribution is just or not? The limited research in the field does not address these questions in any systematic way. Much of the work focuses on simple transport goods, like transit subsidies and road taxes, while it could be argued that accessibility is much more important for citizens. Likewise, much of the literature implicitly or explicitly uses equality as the yardstick to assess the distribution of transport-related goods, without providing convincing arguments that this is the morally proper criterion to apply in the field of transport. It may be clear that these questions need to be answered first, before distributive criteria can be fully integrated into transport modeling and planning.

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REFERENCES

Altshuler, A. *The Urban Transportation System*. MIT Press, Cambridge, MA, 1979.

Bates, J. History of Demand Modelling. D. A. Hensher and K. J. Button, *Handbook of Transport Modelling*. Oxford, Pergamon, 2000, pp. 11-34.

Ben-Akiva, M. and S. R. Lerman. *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press, Cambridge, MA, 1985.

Blumenberg, E. A. Engendering Effective Planning: Spatial Mismatch, Low-Income Women, and Transportation Policy. *Journal of the American Planning Association*, Vol. 70, No. 3, 2004, pp. 269-281.

Boucher, D. and P. Kelly. Introduction. D. Boucher and P. Kelly, *Social Justice: From Hume to Walzer*. London/New York, Routledge, 1998, pp. 1-16.

Braybrooke, D. *Meeting Needs*. Princeton University Press, Princeton, NJ, 1987.

Cervero, R. Efficiency and Equity Impacts of Current Transit Fare Policies. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 799, TRB, National Research Council, Washington, D.C., 1981, pp. 7-15.

Cha, H.-S. and A. T. Murray. *Assessing Public Transit Service Equity in Colombus, Ohio*. Presented at The Association of American Geographers, Los Angeles, 17-23 March 2002, 2002.

de Dios Ortuzar, J. and L. G. Willumsen. *Modelling Transport*. John Wiley & Sons, Chichester, 2001.

Dong, X., M. E. Ben-Akiva, et al. Moving from Trip-Based to Activity-Based Measures of Accessibility. *Transportation Research Part A: Policy and Practice*, Vol. 40, No. 2, 2006, pp. 163-180.

Elster, J. *Local Justice: How Institutions Allocate Scarce Goods and Necessary Burdens*. Cambridge University Press, Cambridge, 1992.

Hine, J. P. and F. Mitchell. Better for Everyone? Travel Experiences and Transport Exclusion. *Urban Studies - Special Issue on 'The barrier free city: possibilities and prospects' edited by R. Imrie*, Vol. 38, No. 2, 2001, pp. 319.

Martens, K. *Integrating Considerations of Equity, Fairness and Justice in the Israeli Cost-Benefit Analysis*. Jerusalem, Israeli Ministry of Transport, 2006.

Martens, K. Basing Transport Planning on Principles of Social Justice. *Berkeley Planning Journal*, forthcoming.

McNally, M. G. The Activity-Based Approach. D. A. Hensher and K. J. Button, *Handbook of Transport Modelling*. Oxford, Pergamon, 2000a, pp. 53-69.

McNally, M. G. The Four-Step Model. D. A. Hensher and K. J. Button, *Handbook of Transport Modelling*. Oxford, Pergamon, 2000b, pp. 35-52.

Miller, D. *Principles of Social Justice*. Harvard University Press, Cambridge/London, 1999.

Murray, A. T. and R. Davis. Equity in Regional Service Provision. *Journal of Regional Science*, Vol. 41, No. 4, 2001, pp. 577-600.

Portugali, J. Distribution, Allocation, Social Structure and Spatial Form: Elements of Planning Theory. *Progress in Planning*, Vol. 14, No. 3, 1980, pp. 227-310.

Pucher, J. Equity in Transit Finance: Distribution of Transit Subsidy Benefit and Costs among Income Classes. *Journal of the American Planning Association*, Vol. 47, 1981, pp. 387-407.

Pucher, J. Discrimination in Mass Transit. *Journal of the American Planning Association*, Vol. 48, No. 3, 1982, pp. 315-326.

Sadurski, W. *Giving Desert Its Due: Social Justice and Legal Theory*. D. Reidel Publishing Company, Dordrecht, 1985.

Sheppard, E. Modeling and Predicting Aggregate Flows. S. Hanson, *The Geography of Urban Transportation*. New York/London, The Guilford Press, 1995, pp. 100-128.

Smith, D. M. *Geography and Social Justice*. Blackwell, Cambridge, 1994.

Vigar, G. *The Politics of Mobility: Transport, the Environment and Public Policy*. Spon Press, London, 2002.

Walzer, M. *Spheres of Justice: A Defense of Pluralism and Equality*. Basic Books, 1983.