Comparison of Interactive Land Use and Transport Models

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Changes in transport are likely to produce changes in land use, and these long-term effects of transport policy may be of considerable potential importance. Ultimately, progress in estimating and predicting these effects will depend on the development of reliable, quantitative models that embody two-way interaction between land use and transport. During the past decade or so a number of such models have been developed and have been used for policy testing and planning. Validation of these models is difficult because of the long time scales over which their mechanisms operate, and the Transport and Road Research Laboratory has initiated an international collaboration of seven countries to try to assess the plausibility of nine models by a comparative analysis of their structure and performance. The first phase of this study is now almost complete, and the International Study Group on Land-Use/Transport Interaction is about to publish its report in which the methodologies of the models are discussed and their behavior is compared when applied to a set of more than 40 standardized tests involving changes in population growth and composition, changes in the distribution of employment and shops, changes in travel costs and the transport network, and different sequences of transport investment. This paper contains a description of the study, a brief review of the models, discussion of results from a handful of the tests, and some general comments on the findings.

The need for models for use in predicting and assessing the outcome of transport policies and investment is generally accepted, and a wide range of models is in routine use. The end users of the information produced by the models may sometimes have reservations about how reliable it is likely to be, but by and large they accept that there is no alternative to modeling for providing quantitative estimates of the outcome. The four-step transport model, in particular, is used universally. This takes the pattern of land use as given and predicts from it how much traffic will be generated, which destinations it will go to, what modes it will choose, and which roads or rail lines it will use. Yet looking back on the history of urban development it is clear that not only are travel patterns dictated by land use but that, on a longer time scale, changes in transport have in their turn had a profound effect on land development. Indeed, this two-way interaction is often explicit in transport investments aimed at "opening up" or "revitalizing" areas considered ripe for development.

Thus if modeling is to predict the ultimate effects of transport policies, it cannot take land use as an exogenous input. The effects on land use may take a long time to appear fully, because urban development and renewal generally take decades rather than years, but they will inevitably modify the initial outcome of transport policies or investment, and in some cases the long-term effect could conceivably be quite different from the short-term effect. Planners are aware of this in a general way, of course, but the mechanisms involved are complex and inherently difficult to isolate and measure because the long time scale causes the effects to be obscured by the many other changes that occur in urban systems. Naturally, individual experience and expertise count for much, but without some framework on which to assemble knowledge of this sort it remains fragmented and is difficult to transfer to other situations or to other individuals. Progress in estimating these effects in a rational and quantitative way must depend ultimately on the development of such a framework, and part of this will consist of models that embody the two-way interaction between land use and transport.

This type of modeling received considerable attention during the 1960s. Lowry's Model of Metropolis *(1)* is generally regarded as the foundation of integrated land use and transport models, and this theme was quickly elaborated to provide more detailed descriptions of both the land use and transport sectors. Unfortunately, these first skirmishes with the problem ended in general disillusionment with large-scale computer modeling in the 1970s; the disappointment with, and criticism of, these models is well documented in papers by Lee *(2)*, Pack *(3)*, and Sayer *(4)*. This was largely a result of modelers trying to run before they could walk properly. They promised too much and failed to deliver. But in part the fault lay also with the users, who did not understand the limitations of an as yet undeveloped methodology and expected the models to provide answers beyond their capabilities. A few well-publicized failures produced a climate in which planners and other potential users looked askance at any newly developed large-scale model, however well it may have overcome earlier problems.

This climate appears to be improving; those who have to make decisions appreciate the need for guidance from whatever sources are available. If they ignore the potential usefulness of coherent, integrated, and rational models, decisions will be made on the basis of personal mental models embodying assumptions that are certainly no more clearly stated, better tested, more compatible, or less partial than those of the urban modelers. It is hoped that both modelers and users now have a clearer appreciation of the difficulties and limitations of modeling and understand the usefulness of models as tools to aid understanding rather than as all-powerful determinants of the "right" decision.

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PRESENT STUDY

There is no satisfactory alternative to some form of modeling, yet the modelers will readily admit that there is ample room for improvement in present modeling practice. Improvement can only come from assessing the models against reality. It might be noted that this has all too rarely been done with conventional transport models, but validation of the integrated land use and transport models is made especially difficult by the long time scale of the land use response. Much effort and money have gone into producing such models, and several of them have been used seriously to examine a number of policy questions. If planners and decision makers are to use the most appropriate models, they need to know what is available, how well-suited the models are to particular situations, and how reliable their predictions are likely to be. More generally, they can also make use of these models to understand more about the likely impacts of different policies in order to select broad urban strategies. The specific measures by which these strategies operate can then be tested using the most appropriate model. To provide this advice, in 1981 the Transport and Road Research Laboratory initiated the International Study Group on Land-Use/Transport Interaction (ISGLUTI), with the twin aims of

1. Providing a rigorous program of comparative testing of available models and
2. Assessing the impacts (and especially the longer-term impacts) of the more commonly used land use and transport policies.

The study group includes researchers from eight countries with nine operational models (Table 1). The data in the table indicate the length of experience of the modelers with this type of interactive model, though in most cases the model used in the ISGLUTI study is a much developed version, or an entirely different formulation, from the initial model constructed at the date shown.

The program of work has been developed to provide results in consecutive phases. Phase 1 of the study is the least ambitious, though it has nevertheless proved to be a difficult and substantial achievement. Each model has been applied to an agreed series of "standard" tests. In all, 43 tests were formulated in several different categories dealing with effects of population growth, changes in the distribution of employment and shopping, changes in transport costs and travel speeds, impacts of roads and metro lines, changes in car ownership and effects economic recession, and effects of introducing transport investment and public transport subsidies in different time sequences. Naturally, with limited resources available, it has not been possible for all of the modelers to carry out all of the tests, but to date the study has results from 158 combinations of models and tests, and three of the models, DORTMUND, LILT,

TABLE 1 PARTICIPANTS IN THE ISGLUTI STUDY

Group Members	Organization	Name of Model and Year First Developed	Model Code	City Modeled
J. Brotchie J. Roy R. Sharpe	Commonwealth Scientific and Industrial Research Organization, Australia	TOPAZ 1970	T	Melbourne
M. Wegener	University of Dortmund, Federal Republic of Germany	DORTMUND 1977	D	Dortmund
G. Giannopoulos M. Pitsiava	University of Thessalonika, Greece			
K. Amano T. Toda H. Yamanaka	University of Kyoto, Japan	OSAKA 1981	O	Osaka
H. Nakamura Y. Hayashi K. Miyamoto	Universities of Tokyo and Nagoya, Japan	CALUTAS 1978	C	Tokyo
H. Floor T. de Jong	University of Utrecht, Netherlands	AMERSFOORT 1976	A	Amersfoort
L. Lundqvist	Royal Institute of Technology, Sweden	SALOC 1973	S	Uppsala
R. Mackett	University College, London, United Kingdom	LILT 1974	L	Leeds
M. Echenique A. Flowerdew	Marcial Echenique and Partners, United Kingdom	MEP 1968	M	Bilbao
V. Webster P. Bly N. Paulley	Transport and Road Research Laboratory, United Kingdom			
S. Putman	University of Pennslyvania, United States	ITLUP 1971	I	San Francisco

and MEP, have been able to complete the great majority of the tests. An analysis of the behavior of the models, a comparative assessment of model structures, and the main findings of applying particular urban policies will be published shortly in the first report of the study.

In this first phase, the tests have been completed using the models as calibrated on their own base data, so that for each model the results relate to a different city. This was a practical way to proceed, but of course it complicates the comparisons because it is not clear whether differences in the results are due to differences in the models or to particular characteristics of the cities to which they were applied. It is hoped that the questions raised by this extra complication will be answered in a more ambitious Phase 2, which requires the transfer of models between data sets so that the behavior of several models can be judged using the same data base for each and the effect of different city types can be assessed separately by comparing the behavior of a given model across several different data sets. This work is well under way, and so far there have been nine transfers of models from one data base to another, with a maximum of four different models recalibrated to one city data base and a maximum of four cities represented by one model. This phase of the study will be reported in 1988.

All testing of the models is restricted to assessing one model against the others and judging the general plausibility of their behavior. The ultimate test, of course, is to compare the long-term predictions of the effects of some major transport change with long-term observations of what actually happened. It is possible that such an exercise might constitute a future Phase 3 of the study, but the possibility of doing this depends on the availability of satisfactory before-and-after data sets, across a sufficiently long period, that contain a transport change that is sufficiently large to produce land use effects that are unambiguously identifiable against a constantly changing background. This is a demanding set of requirements and so far no satisfactory case has been identified.

MODELS

Because the models are intended to examine much the same aspects of transport and urban development, it might be thought that they would be fairly similar in construction. Certainly, they all operate by dividing the area they represent into discrete zones and allocating to each zone units of activity (people, housing, jobs) in a way that depends on the accessibility of that zone to other zones as well as on the inherent attributes of the zone itself. They all proceed through time by estimating changes in land use patterns and travel between one time point and the next (in 5-year intervals, in most cases). Beyond these quite broad characteristics, however, comparison of the structure of the models provides an impression of considerable variety rather than of similarity. It would be inappropriate to discuss these comparisons in detail here, but it will be helpful to give a brief description of the main characteristics of each model. Table 2 gives a summary of these, though the reader will appreciate that in imposing these standardized descriptions this brief review omits much interesting detail. Moreover, in some cases the form of the model used in ISGLUTI has a coarser categorization or spatial representation, or both, than is present in other versions; this applies especially to ITLUP, MEP, and TOPAZ.

The overview given here does no more than sketch the most important features of each model. The ISGLUTI report will provide a detailed comparative discussion of the theories and mechanisms underlying each model, the ways in which they allocate land use, the form of their transport models, and the built-in interactions between transport and land use. The report will include an examination of the calibration and validation of the models, the form of their data bases, the types of output they provide, and their computing requirements. It will also provide brief descriptions of the ways in which these models, and variants of them, have been applied. All of these models are fully operational, all have been used to examine genuine policies, and all except DORTMUND and OSAKA have been transferred to other data bases. Some have been used quite extensively indeed: MEP models have been applied to 17 different cities or areas, ITLUP to 10, and TOPAZ to 7. It can be seen from Table 2 that, as a group, the models have been designed to represent a wide range of city sizes (from the 28 million population of Tokyo to 150,000 in Amersfoort) and cultural backgrounds; they operate at quite different levels of detail; and they embody a considerable variety of theoretical underpinning and modeling techniques. Some of these differences make comparison more difficult, of course, but the study provides an amply wide scope for assessing the strengths, weaknesses, and range of applicability of this type of modeling.

AMERSFOORT

This is a relatively simple model that follows the original Lowry model in locating population relative to employment via an entropy-maximizing form of the gravity model, but it does not locate employment endogenously at all (though later versions have located shopping). Instead it relies on exogeneous forecasts of total employment and its location. Unlike some of the more complicated models, however, it makes a distinction between the distribution of housing and the location of population, so that houses may remain empty and the social grouping of their occupants may change. The different social groups have a hierarchical choice of housing, so that the more affluent have a freer choice. Travel impedances are represented only by interzonal distances, so that the model predicts the pattern of travel to work but provides no detail about mode use, times, or costs. Because of this simplicity, the model's data and computing requirements are quite modest, and transfer from one data base to another is correspondingly easy. A detailed description can be found in Floor *(5)*.

CALUTAS (Computer-Aided Land Use–Transport Analysis System)

This utility-based model calculates a "locational surplus" of utility minus cost to determine where both population and employment will locate and to produce estimates of land prices. Employment is categorized in some detail, but population is not, though the present version of the model separates

TABLE 2 MAIN CHARACTERISTICS OF THE MODELS

	Model								
	A	C	D	I	L	M	O	S	T
Model type (predictive or optimizing)	P	P	P	P	P	P	P	O	O
Modeling techniques used[a]	E	E,U,M,R	E,U,M,C,S	E	E,U,C	E,U,M,I	U,M,S,R	U,P	E,P
Land use location[b]									
Population	3	1	30	4	3	4	1	2	1
Housing	1	–	30	–	1	**	–	–	–
Employment	–	10	40	4	12	5	17	–	1
Workplaces	–	–	40	–	12	**	–	–	–
Land prices		√	√			√	√		
Housing rents			√			√			
Transport representation									
Trip pattern	√	√	√	√	√	√			√
Number of purposes	1	5	4	2	5	4			4
Number of modes	1	2	4	2	3	3			2
Traffic congestion		√	√	√	√	√			
Predicts car ownership			√		√				
Data base									
City represented	Amersfoort	Tokyo	Dortmund	San Francisco Bay Area	Leeds	Bilbao	Osaka	Uppsala	Melbourne
Population (000s)	153	27,904	1,075	4,064	497	970	14,556	160	2,697
Area (km^2)	202	14 565	833		164	75	8000		3000
Number of zones	26 (12)+	76 (14,500)++	30	30	28 (12)+	28	40 (840)++	49	41

NOTE: – = not represented; √ = item is represented; + = external zones to handle in- and out-commuting; ++ = two-level zonal hierarchy: larger number of zones at lower level offers greater spatial detail; ** = supply of accommodation is represented by available floor space, for which the different categories of demand compete.

[a]E = spatial interaction models, mostly of entropy-maximizing Wilson Types 1, 2, 3, and 4; U = utility maximizing models; M = market equilibrium models; C = Cohort/Markov survival models; I = input-output economic base models; S = microsimulation; R = linear regression models; P = mathematical programming.

[b]Numbers refer to number of categories used, where appropriate.

household types by composition. Housing is not distinguished from population, so it is assumed that the supply of buildings is identical to the demand. In addition to travel between home and work, the travel model represents trips for shopping, education, and "other purposes," and non-home-based trips on public and private modes and takes account of the effect of traffic congestion on road speeds. To represent a vast metropolitan area at an adequate level of detail, the model adopts a two-stage approach: it allocates activities to 76 large zones and then reallocates the total activity in each large zone to a lower-level system of kilometer-square zones. This produces a remarkably fine level of spatial detail, though there is no feedback to the coarser aggregation. A detailed description can be found in Nakamura et al. *(6)*.

DORTMUND

This model is not very detailed spatially, but it is extremely detailed in other respects, with many different categories for population, housing, employment, and workplaces. Like AMERSFOORT it makes a distinction between the housing and the people who live in it (which many of the models do not), but it also distinguishes between employment and the buildings in which the workplaces are established. Its structure embodies a wide range of modeling techniques, and various simulation procedures represent the aging of both population and buildings and estimate the profitability to developers of conversion, demolition, and new construction. Thus the model predicts both land prices and building rents. The transport model is similarly detailed, representing travel for four different purposes by car, bus, rail, and walking, and using capacity-constrained assignment to represent the effect of congestion on road speeds. The model also predicts car ownership on the basis of household budgets and travel costs, so that changing conditions will affect car availability. A detailed description can be found in Wegener *(7)*.

ITLUP (Integrated Transportation and Land-Use Package)

ITLUP has quite a long history. It was developed initially from the PLUM and IPLUM models of the San Francisco Bay Area *(8)*. It incorporates the residential location model DRAM, which has been used extensively separately from the package, and the employment location model EMPAL. It is based on Lowry-like mechanisms for generating population from basic employment, and service employment from population, and for locating population in relation to employment. The location of employment differs from the Lowry approach, however; it uses a combination of extrapolations of past trends, interindustry accessibilities, and accessibility to workers. It operates at a

medium level of categorization of activities and offers travel predictions for public and private modes, for work and shopping trips, and with capacity-constrained road assignment. Although the ISGLUTI application uses relatively few zones to cover this large area, in other applications as many as 290 zones have been used. A detailed description can be found in Putman *(8)*.

LILT (Leeds Integrated Land-use/Transport Model)

This is essentially a Lowry-type location model coupled to a four-step transport model, using a population location mechanism that allows the different social groups a hierarchical choice of housing. It distinguishes between demand and supply of both housing and employment, so that housing and jobs can remain vacant and houses can be demolished or overcrowded. It provides a medium to high level of detail in its categorizations, and the travel model offers car, bus, and walk modes for the same five trip purposes used in CALUTAS and a congestion-constrained road network. This and DORTMUND are the only models that predict car ownership levels as responses to travel costs. A detailed description can be found in Mackett *(9)*.

MEP (Marcial Echenique and Partners)

This model of Bilbao is one of a whole family of models that have been developed by Marcial Echenique and Partners and applied to a large number of cities around the world. The basic employment–population–service-employment iteration of the Lowry model is retained, but the interactions among the various employment activities and population are governed by input-output matrices. The supply side is represented by provision of floor space, which may be occupied at variable density and for which the different population categories and some categories of employment compete. A market equilibrium mechanism reconciles demand with supply and produces estimates of both land prices and housing rents.

Generally the model operates at a medium level of detail, but the transport networks are particularly detailed, representing travel for shopping, education, and other purposes in addition to work trips. A hierarchical modal split between car and public transport and then between bus and rail is used. Both public and private networks are capacity constrained, and car ownership is a function of income in the four social groups but not of transport costs. Much attention has been paid to an economic assessment of both land use and transport changes in the model. A detailed description can be found in Geraldes et al. *(10)*.

OSAKA

This model is faced with a problem that is similar to that faced by CALUTAS: trying to represent an enormous metropolitan area. It uses a similar hierarchical zoning system, with 840 zones at the lower level. It adopts the Lowry procedure for generating population from employment, but its allocation mechanisms depend on linear regression relationships that, at the lower level, produce land price estimates. Allocation depends on zonal accessibilities calculated from travel times by car and rail in quite a detailed way, but it is essentially a land use model and does not attempt to predict travel patterns. Employment is categorized in some detail, with different formulations for the interactions among the categories. A detailed description can be found in Amano et al. *(11)*.

SALOC (Single Activity Location model)

So far, all of the models described have been predictive in the sense that they purport to predict the likely outcome of imposing a specified set of conditions. The remaining two models in the study have an entirely different philosophy. They are optimizing or normative models in the sense that they determine land use patterns that are optimal relative to a specified objective. The concept of SALOC, in particular, is quite different from that of the other models—so much so that the ISGLUTI program of tests was not really appropriate to this model and a supplementary investigation was undertaken instead. The model estimates where additional population (or housing, but not both because it deals with a single activity) should be located to optimize a multiple-objective function representing local planning policy. In the Uppsala application the generalized cost (time and money) of access to work is traded against the infrastructure costs of sewerage, water, and education facilities and the desirability of keeping communities self-contained as far as possible.

Density constraints are applied to the new development. Mathematical programming techniques enable the model to sketch out rapidly a whole range of housing allocations that satisfy the objectives and identify those solutions that keep a maximum number of good options open for the longer-term future when the prevailing conditions may change. The model does not locate employment, which must be input exogenously, nor does it make any explicit representation of travel patterns, though the estimates of accessibility are based on a public-private modal split model. A detailed description can be found in Lundqvist and Mattsson *(12)*.

TOPAZ (Technique for Optimal Placement of Activities in Zones)

This is another optimizing model that uses mathematical programming to locate both population and employment. In this case the allocation minimizes the sum of travel costs and infrastructure costs for development subject to density and other planning constraints. It provides relatively little categorization in its ISGLUTI version, though other applications have provided much greater detail. It is coupled to a conventional, and moderately detailed, predictive travel model with public and private modes and travel for shopping, other purposes, and non-home-based trips in addition to work journeys. Its structure is such that it can be applied to most of the tests in the ISGLUTI program, but the optimizing nature of its locational mechanisms requires a different interpretation of the results from those of the predictive models because it is describing a land use pattern that best meets the stated objective, not necessarily one that is likely to be produced by the prevailing forces. A detailed description can be found in Brotchie et al. *(13)*.

COMPARISONS OF MODEL BEHAVIOR

As noted earlier, the study contained a program of more than 40 tests. Clearly, it is not possible to give more than a sample of the results obtained from this large program. At the time of writing, analysis of the results is still continuing, so it would be inappropriate to attempt to summarize the findings. Instead, it will have to suffice to provide a brief glimpse of the sort of results obtained by examining a few examples.

Naturally, the models were designed with a specific application in mind, and they were originally organized to produce output appropriate to that application. Consequently, they provided quite disparate sets of outputs, with relatively little common ground for comparison. It was necessary for ISGLUTI to specify a set of "standard" indicators and to modify each model to produce as many of these as possible in a standard format on magnetic tape. This often required considerable aggregation: where appropriate, population categories were collected into three social or income groups; employment into retail, non-retail-service, and nonservice categories; modes into public and private; and so on. One of the most important, and most difficult, aggregations was the comparative representation of land use patterns. The modeled areas were divided into three concentric aggregations of zones, labeled central area, inner suburbs, and outer suburbs. This division was rather subjective and not entirely satisfactory, but by examining the proportions of population or employment in each area it was possible to say whether a particular test encouraged more or less centralization of land use.

Not every model was able to provide every standard indicator, or course, but with a maximum of 94 indicators from each test for each model there was a large amount of data to analyze. The whole process of organization and presentation was computerized so that a range of tabulations and diagrammatic comparisons could be produced, at a greater or lesser level of detail, on request.

Because each model represented a different city, the effects of the tests had to be judged relative to different background trends in each case. Consequently, the estimated land use patterns and travel characteristics at the end of the 20-year forecast period starting at the base calibration year were compared not only with the situation in the base year but also with the "most likely future" situation at the end of the 20-year period. For the predictive models the latter is the base or "do nothing" forecast, which assumes that the prevailing conditions will continue to change in line with present trends, that present policies will continue, and that development and investment will be consistent with existing plans. For the optimizing models, the test results are compared with the optimum configuration under the conditions "most likely" to prevail in 20 years' time.

So far, no test results have been obtained from ITLUP and SALOC, though it is hoped that some will be available shortly. Other models completed only a portion of the tests, to which a higher priority had been attached. Even if a test has been completed, many of the standard indicators may not be available from some models. Consequently, comparisons of behavior have to be made across different subsets of the models for different indicators and different tests.

A brief illustration of the findings from three tests is presented in the following subsections. In the first two the effects of changes in travel speeds and costs, respectively, on land use patterns are examined. In the third the effects of redistributing employment are considered.

Example 1: Speeds of All Mechanized Modes Increased by 20 Percent

Historically, the impact of mechanized transport on encouraging urban dispersion is clear. Growing car ownership is still increasing the travel speed available to people on average, and in some cities improvements in public transport are also providing higher average speeds, though the changes today are proportionately small compared with the increases that mechanized transport initially offered compared with walking. The global change considered in this example is more of a sensitivity test than a specific policy, though, of course, investment in both road capacity and public transport infrastructure and services could increase travel speeds across the board. Interpretation of this test was fairly straightforward in most models; generally a 20 percent increase in line-haul speeds results in a much smaller percentage decrease in the generalized costs of travel, and for this reason the effects of the test were likely to be intrinsically smaller in most models than in OSAKA, where the interzonal accessibilities were based primarily on travel times, and in AMERSFOORT, where the test was interpreted by reducing the effective interzonal distances, which acted as travel impedances, by the full 20 percent.

Naturally, these changes in speed cause changes in the travel patterns in much the same way as would be shown by any conventional transport model (though the size of the changes will be modified by the responsive land use). Thus there are a general increase in average trip distance and a shift from car to public transport because the logit form of the modal split function encourages a shift toward the slower mode. Average journey time declines, but average money cost per trip increases because of the extra distance, except in TOPAZ where the shift to cheaper public transport outweighs this effect. Both DORTMUND and LILT predict a slight reduction in car ownership: in the former model because the higher cost of the longer journeys leaves less money in the travel budget for car ownership, in the latter model because of the net shift to public transport. Both of these models also show a shift from walking to both public transport and car, as would be expected.

Thus the models are in general agreement about the direction of the transport effects, though the absolute sizes of the changes vary somewhat from one model to another. Of more interest in these interactive models, however, are the changes in land use. These are represented in Figure 1 by the changes in the proportions of population and employment in the outer suburbs (as defined for ISGLUTI). It can be seen that these proportions have grown over the 20-year period of the base forecast, as all the cities modeled have become decentralized in both population and employment. The optimizing model TOPAZ shows no appreciable effect of the higher speeds in the test (T) because locational distributions that minimize travel costs do so at any level of unit cost. The other models show that higher speeds encourage more rapid decentralization of population as the outer zones become relatively more accessible. The effect is quite small in DORTMUND (D) and LILT (L), which are based

on cities with negative or zero population growth, respectively, so there is relatively little expansion in housing compared with the other cities. Much larger effects are seen in AMERSFOORT (A), CALUTAS (C), MEP (M), and OSAKA (O), where the cities are growing and so are able to take more advantage of the higher speeds.

Movement of the population is constrained by inertia in the allocation of available housing in AMERSFOORT, DORTMUND, LILT, and MEP, which all distinguish between population and housing, but within the distribution of housing Figure 1 shows that the movements of the different social groups are generally larger than that of the population in total. In particular, AMERSFOORT and LILT show the bottom social groups (SG3) remaining relatively more centralized than in the base forecast, in contrast with the movement of the other social groups. In these models the bottom social group has last choice of housing because of the economic "pecking order" and tends to get pushed out of the more spacious outer suburbs as the higher social groups disperse further.

Figure 1 shows that employment also becomes relatively more decentralized when speeds increase in CALUTAS, MEP, and OSAKA. AMERSFOORT does not locate employment. LILT shows a centralizing tendency because, in this model, employment location appears especially sensitive to the quality of public transport. Given the largely radial nature of the public transport network, it is plausible that it would tend to focus activity in the city center, but this effect is certainly much more marked in LILT than in the other models. DORTMUND shows a similar tendency for service employment, but there is little effect on employment overall. In this test, and in general across all the tests, retail employment is most responsive to transport changes (and to shifts in the distribution of population) and nonservice employment least responsive, though OSAKA shows a similarly strong response in all employment categories. Indeed, OSAKA's accessibility-based location mechanisms appear to operate at much the same strength across both employment and population. OSAKA and LILT show the strongest response to the speed change (though in opposite directions), CALUTAS and MEP a weaker one, and DORTMUND the weakest response of all overall.

In MEP's economic assessment the higher speed produces a sizable net transport benefit, as would be expected, but there is little net land use benefit in line with the small changes seen in overall land use, though there is a slight increase in land prices

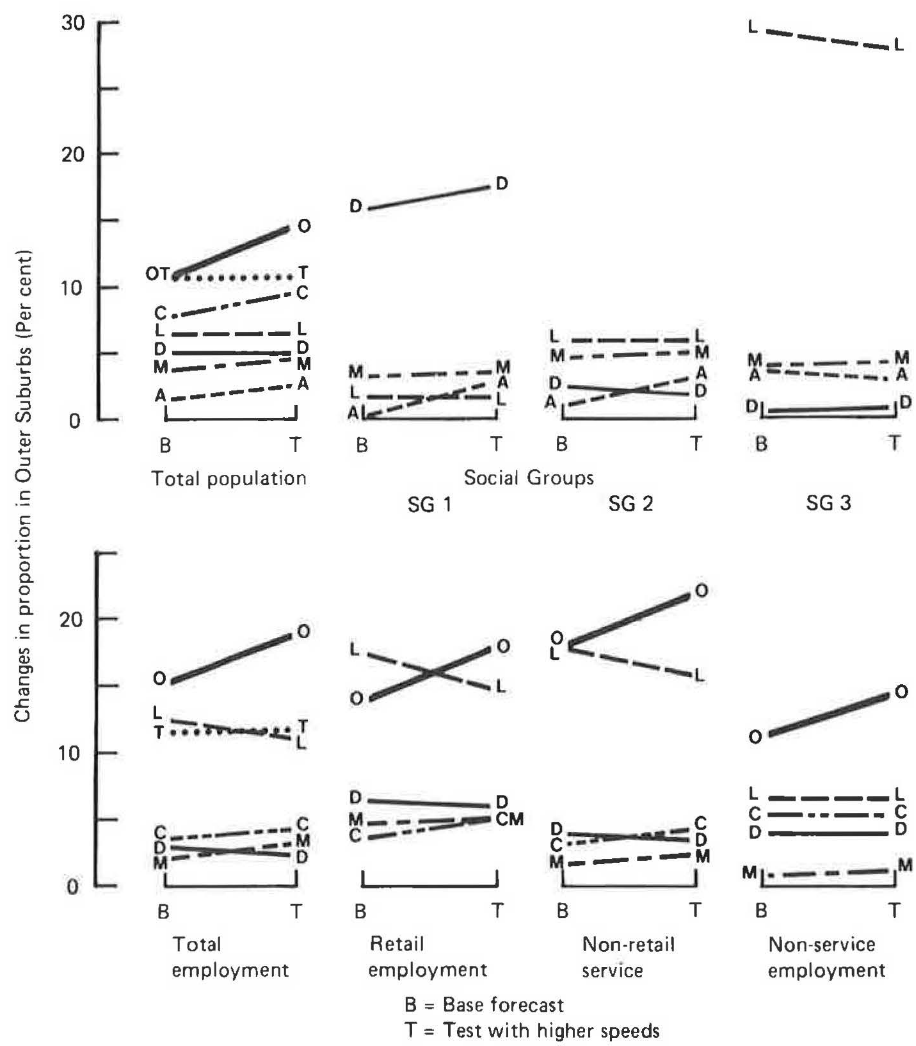

FIGURE 1 Changes in distribution of population and employment when speeds of mechanized modes are increased 20 percent.

on average. CALUTAS predicts a 15 percent rise in land prices, because the improved accessibility increases zonal locational utilities, and a marked land use benefit. DORTMUND suggests little change in land prices but a 3 percent increase in housing rents.

Overall, the effects of the 20 percent increase in speed are more or less as expected on the transport side, and the land use effects are also quite plausible, though there are some differences of detail that may be a function of the different city bases as much as of the different model structures. The land use effects are generally quite small, except in Osaka and in employment location in Leeds. In these cities, the interactive models suggest effects that are different in some important respects from those that a purely transport model would predict. In the other models the overall land use changes are small, which might suggest that in these particular cases there was less need to use an interactive model. Nevertheless, within these relatively unresponsive land use patterns overall, there are substantial movements in some individual sectors of the population and employment, and at a more disaggregate spatial level there are also larger movements than are evident in the extremely aggregate comparisons used in the study.

Example 2: Large Increase in the Cost of City Center Parking

This test required that car parking charges in the central area be set at three times the average cost of travel for car trips to the area. Because in all cases the average parking charges in the base were appreciably less than the average travel cost, this represents a fairly punitive increase. This test has been completed only by DORTMUND, LILT, MEP, and TOPAZ.

Naturally, the main effect of the test is to discourage trips to the center areas, as Figure 2 shows, and to encourage a more dispersed pattern of destinations. In LILT this diversion of trips is sufficiently large, particularly for work trips, to offset entirely the effect of the high parking charges on the cost of the average journey, but other models show the expected net increase, especially in DORTMUND despite the appreciable transfer from car to public transport and reduction in average trip distance. Changes in average trip time are small in all cases.

The generally small effect this test has on modal split may appear surprising, but it stems from the diversion of trips away from the center. This in turn is reflected in, and is in part a consequence of, a relative reduction of employment in the central area and a displacement toward the outer suburbs, as shown in Figure 3. The effect is especially marked in LILT and TOPAZ, with a smaller response in MEP, and very little effect in DORTMUND. The result for TOPAZ contrasts with its unresponsiveness in the previous test: the large cost changes in the central area are sufficient to discourage locating any more employment there. DORTMUND actually shows a relative centralization of service employment, partly because the shift to public transport focuses the travel pattern on the center

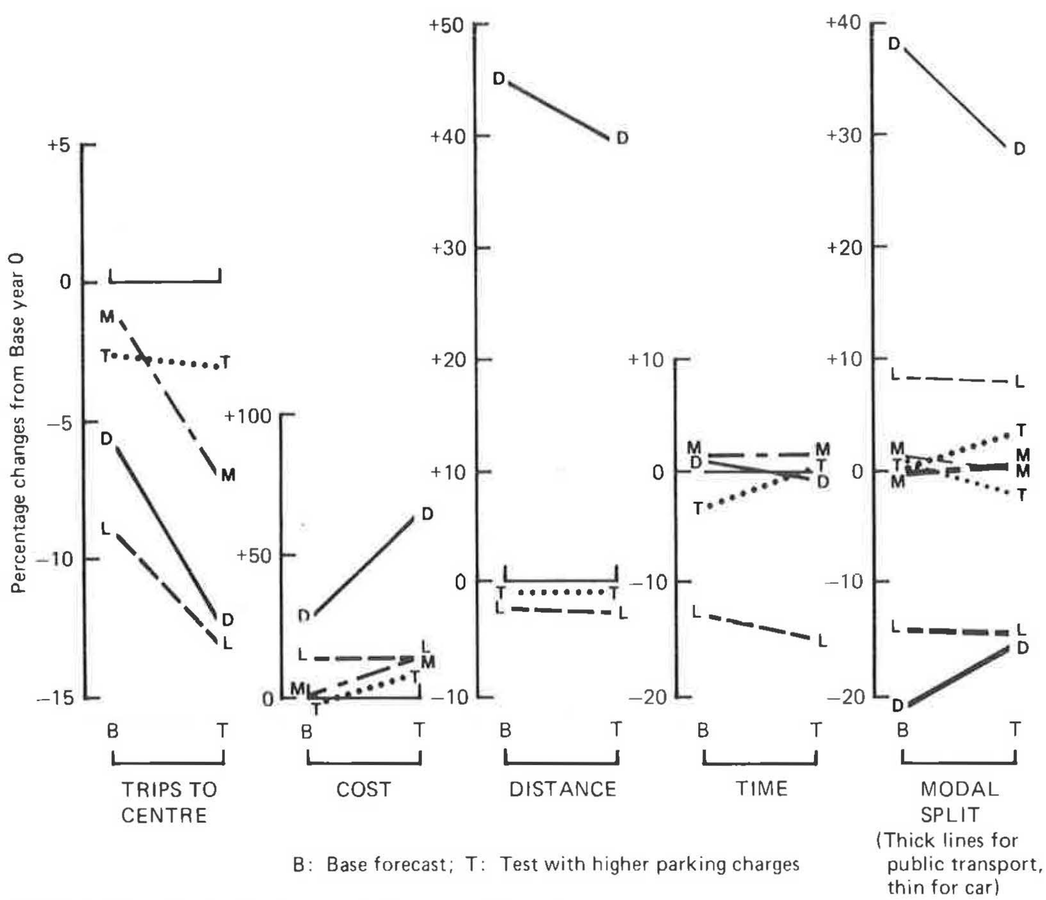

FIGURE 2 Effect of higher central area parking charges on proportion of travel to center, average journey cost, distance, time, and modal split.

more, but largely because this model predicts a 20 percent reduction in car ownership. Some reduction is plausible, but this appears large, and, in general, the expenditure budget basis of DORTMUND's car ownership model appears to make it oversensitive to changes in travel cost.

Figure 3 shows that retail employment is more responsive than the other categories, as was noted in the first example. In LILT, MEP, and TOPAZ at least, it appears that the imposition of high parking charges in an attempt to restrain car use in the area may have seriously unwelcome side effects on commercial activity in the city center. This test provides a good example of the importance of using a fully interactive land use–transport model to examine a transport policy; the land use aspects are probably more important to the city authorities than are the direct transport effects. The test also illustrates the type of divergence between the behavior of the models that on occasion has led the modelers to conclude that a particular mechanism might usefully be modified for future versions of the model; for example, for some applications modification of DORTMUND's car ownership model would be desirable.

Example 3: Bringing Jobs Closer to the Workers

It is often argued that if employment were distributed in closer relation to the population there would be less need to travel, which would save travel time, cost, and energy. This test looked at this situation by distributing all nonservice employment throughout the urban area in proportion to population: in most models, this was interpreted as requiring the same percentages of total nonservice employment and total population in each zone. Over the 20-year prediction there was a tendency for this redistribution of employment to gradually move back toward the distribution seen in the base forecast, except where constraints were placed on relocation to maintain the prescribed balance. This forced redistribution of nonservice employment had relatively little effect on the eventual distribution of either population or service employment, and indeed little is to be expected because with nonservice employment so dispersed there is little the population can do to improve its accessibility to employment by relocating. This is not to say that this distribution of employment necessarily maximizes accessibility: in some cases a more centralized distribution might be better, but once the dispersed location is achieved the pattern of accessibility provides little incentive for any further redistribution.

TABLE 3 EFFECTS OF BRINGING EMPLOYMENT CLOSER TO THE POPULATION ON CAR OWNERSHIP AND JOURNEY CHARACTERISTICS

	Percent Change Relative to Base Year 20 According to Model			
	C	D	L	M
Car ownership		–0.8	–0.3	
Average journey characteristics				
Average time per work trip	0.2	–5.2	3.7	–1.5[a]
Average distance per work trip		–1.1	0.4	
Average money cost per work trip	0.6	–3.4	–1.1	–0.8[a]
Total travel time per head	0.7	–2.3	1.4	–0.8
Average energy use per head		–0.6	–0.7	

[a]All trip purposes.

The main aspects of interest here lie in the response of the travel pattern, however. Naturally, general decentralization produces a decline in the proportion of trips made to the central area, but changes in overall modal split are relatively small: DORTMUND shows the net transfer from public transport to car that might be expected from the more dispersed travel pattern, but in LILT and MEP there is very little change at all. Table 3 gives a summary of the changes in the other travel parameters where they are available from the models (OSAKA also completed the test but provides no explicit representation of the travel pattern). Both LILT and DORTMUND predict a small reduction in car ownership because of a transfer to walking, and most of the models predict a reduction in travel time and money cost. DORTMUND predicts a reduction in

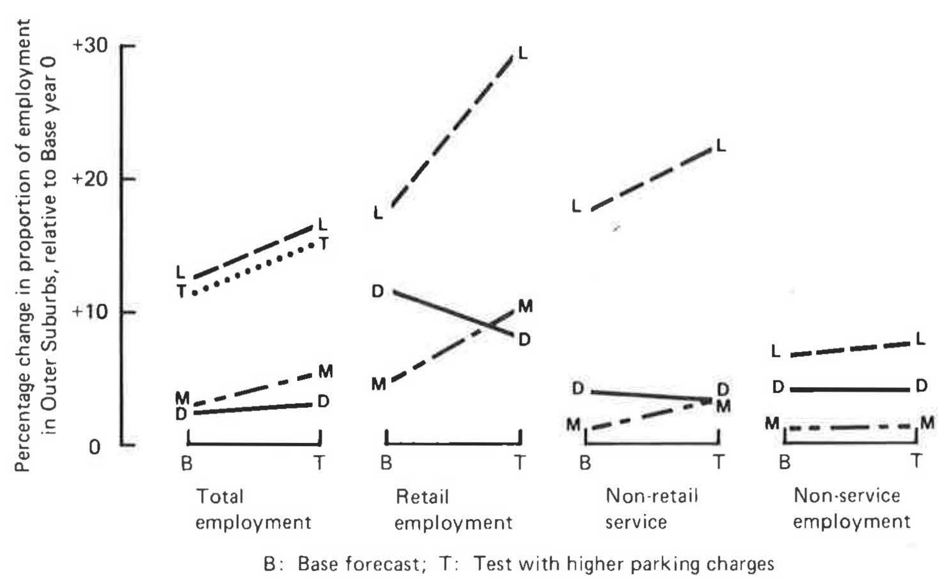

FIGURE 3 Effect of higher central area parking charges on distribution of employment.

average distance to work, but LILT shows a slight increase. DORTMUND and LILT both predict a reduction in energy use. Thus bringing employment closer to the workers has achieved some saving in transport resources, but the models suggest that this radical relocation of employment would in practice have a remarkably small effect on overall travel costs, time, or energy. It appears that people would still travel as much as ever to maximize their choice of employment.

CONCLUSION

The ISGLUTI study was acknowledged from its inception to be a rather ambitious project. Comparison of so many complex models is a difficult and time-consuming business. For the researchers involved, the process has been educational—not the least of the benefits has been that the modelers themselves have learned more about their own models than they would have in the absence of the study. What appeared to be an overwhelming jumble of data has been tamed, and convincing and consistent conclusions are being extracted. The report of the first phase of the study should be published in the second half of 1987.

In this paper it has been possible to provide only the briefest overview of the models and the bare bones of three of the tests to illustrate the procedure. On the basis of individual tests it is not generally possible to say whether differences in response between the models are due to differences between the cities on which they are based or to different mechanisms within the models themselves. This difficulty persists throughout the program of tests, but by viewing all of the results together it becomes possible to identify the characteristic behavior of individual models, to judge to some degree their plausibility, and to identify certain aspects that require improvement.

In this exercise, these models are being exposed to a more searching scrutiny than most of the models in current use have ever experienced. Comparison on this scale is probably unique. Certainly, there are areas in which the behavior of some of the models appears unsatisfactory. There have been other examples in which, on closer inspection, an apparent implausibility has been seen to be entirely realistic and has contradicted the initial intuitive expectation. These occasions are, of course, especially valuable because these models are not to be used unthinkingly but to challenge and, if necessary, modify the user's view of the world. For the most part, the models have proved plausible across a wide range of conditions.

Many questions remain unanswered, of course. The compounding of city differences with model differences confuses some of the analysis of the first phase of the study, but the second phase, with its transfer of models between the data bases, should go a long way toward separating the effects and identifying more reliably areas of agreement and disagreement among the models. In addition to providing information about the relative merits of the modeling, the study is also gathering many pointers and much food for thought about the effects of a wide range of land use and transport policies. In the end, it is likely that the study will achieve general agreement about the directions of these effects, but questions will remain about their strengths. To solve those reliably, suitable opportunities and adequate data must be awaited to compare the model predictions with reality across some major, and well-monitored, transport investment.

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