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Invited Paper

AN INTERNATIONAL STUDY ON LAND-USE/TRANSPORT MODELLING

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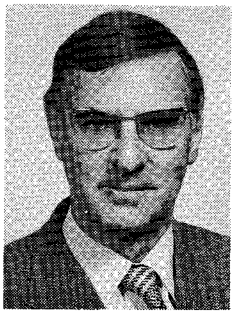

1. INTRODUCTION

Accessibility to jobs, shops, services, entertainment and to friends and family has always been an important factor in people's lives. But until at least the early part of this century any form of transport which was appreciably faster than the speed at which people could walk was limited to only a small proportion of the population. Most people, therefore, had to live as near as possible to the places where they carried out their various activities. This meant that in towns with very large populations, high density living was a necessity. As incomes grew so that the masses could afford to use the faster modes which were becoming more widely available, People were able to spread themselves and enjoy more pleasant surroundings, and despite the extra travel distance that this entailed, it did not in general require more time to be spent on travel. These advances in transport were fundamental in shaping present-day towns and cities. While the more dramatic changes have probably already taken place, there are nevertheless substantial changes in the transport scene which are currently taking place which will affect future land uses and the location of activities. One of these is the continuing growth in car ownership which gives people much greater freedom to travel where they like when they like. Another is the growth in new motorways, high-speed railways and other high-tech transport systems. Thus, the effect of transport on land use is important today even though most people already have good access to relatively fast mechanised modes of travel. Even a seemingly insignificant transport change, like a fares increase, can have far-reaching implications.

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Because of the continuing importance of this interaction between transport and land use, it is necessary for planners and policy makers to take it fully into account when formulating policies. The difficulty they face is in knowing how to do this. Because of the nature of this interaction, it is a long time before all the effects of a policy have worked through the system — possibly 20 or 30 years. This may tempt planners to consider only the immediate effects and ignore the longer-term effects on the basis that if they take so long to materialise they cannot be very important — but this would be a mistake. The length of time to work through the system bears no resemblance to the magnitude of the effect when it comes and in some cases the long-term effects are so great that they may completely nullify or even reverse the initial impacts.

However, the length of time before the various impacts of a policy materialise and the different time scales over which they operate make it a difficult area for study. Moreover, the impacts may be masked by other changes taking place which have nothing to do with the particular policy being studied. It requires a great deal of determination, dedication, time and money to carry out a study of these effects which may last for very many years, and not surprisingly such studies are thin on the ground. But even if the results of such studies were available they would not necessarily help a planner to decide which are the best policies because the circumstances may be different. So what can be done ? The only feasible alternative to ignoring the effects altogether (and this would not be sensible) is to seek to understand the individual mechanisms which are responsible for the various effects and to combine these into a mathematical model. Once such a model is available, 'before and after' studies of major land use or transport changes become invaluable sources of data for calibration and validation.

There are several land-use/transport models which have been, or are being, developed by teams all over the world, but until quite recently these had never been properly tested nor compared one with another. Because of this the UK Transport and Road Research Laboratory set up in 1981 a comparative study of the various models that were available. It was called the International Study Group on Land-Use/Transport Interaction (ISGLUTI for short) and this paper describes the progress made since it was set up and the results obtained.

2. THE ISGLUTI STUDY

(1) Aims and structure of the study

It can be seen from Table 1 that eleven teams from eight countries with ten models between them collaborated in this study. Some of the models were first conceived nearly 20 years ago while one or two are relatively recent. The study had two main aims : one was to make a thorough comparative assessment of the models (their mechanisms and their performances) and the other was to gain fresh insights into the impacts of a wide range of commonly applied transport and land-use policies. To achieve both aims it was necessary to set up a series of policy tests which could be applied by each modelling team using their own particular model. The simplest approach was to test the policies on the cities on which their models were already calibrated (the 'home' cities). This meant, of course, that the policy impacts estimated by one model were not strictly comparable with those estimated by another model because of the different cities involved, but this was the only practical approach at the time. In an attempt to isolate the effects arising from the different cities a second phase of the study was later set up in which a limited number of models were applied to several cities each. This was arranged in such a way that some cities were subjected to tests by two or three models so that the differences due to the models themselves could be determined. Phase 1 of the work is already published in book form (Webster *et al.*, Eds., 1988) and some preliminary results from Phase 2 were presented at the 1989 World Conference on Transport Research (WCTR) held in Yokohama [Echenique *et al.* (1989), Mackett (1989) and Mackett *et al.* (1989)]. The final results will be published in a series of papers in Transport Reviews starting with the October 1990 edition and ending with the July 1991 edition. Of course the crucial test of a model is a comparison of the predicted impacts of a major change in transport or land use with the actual observed impacts over a period of very many years.

Table 1 Participants of the ISGLUTI study.

COUNTRY	ORGANISATION	MAIN MEMBERS	NAME OF MODEL & YEAR FIRST DEVELOPED	MODEL CODE
Australia	Commonwealth Scientific and Industrial Research Organisation, Dept. of Building Research	J F Brotchie R Sharpe J R Roy	TOPAZ (1970)	T
Fed Rep of Germany	University of Dortmund	M Wegener	DORTMUND (1977)	D
Japan	(i) Universities of Tokyo and Nagoya	H Nakamura Y Hayashi K Miyamoto	CALUTAS (1978)	C
	(ii) University of Kyoto	K Amano T Toda H Abe	OSAKA (1981)	O
Greece	University of Thessaloniki	G Giannopoulos M Pitsiava	-	
Netherlands	University of Utrecht	H Floor	AMERSFOORT (1976)	A
Sweden	Royal Institute of Technology	L Lundqvist	SALOC (1973)	S
UK	(i) University of Leeds	R L Mackett A Lodwick	LILT (1974)	L
	(ii) Marcial Echenique and Partners	M H Echenique A J Flowerdew D Simmonds	MEP (1968) MEPLAN (1985)	M M*
	(iii) Transport & Road Research Laboratory	F V Webster P H Bly N J Paulley	-	
USA	University of Pennsylvania	S H Putman	ITLUP (1971)	I

It had been hoped originally that such a test would be carried out in a third phase of the study for at least one or two of the ISGLUTI models. However, the lack of a suitable data base for a major transport investment, together with resource limitations of the modelling teams, has so far prevented this phase from taking place, though it remains a possibility for the future. In the meantime the results of Phases 1 and 2 provide planners with reasonably comprehensive guidance on the selection of land-use/transport models and on the likely impacts of different types of policies and warn against numerous pitfalls that were not readily apparent before the ISGLUTI study began (and might still not be recognised universally even now).

(2) Models used

Each of the ten models included in the study and listed in Table 1 is described very briefly in the appendix to this paper. Two of the models belong to the same family (MEPLAN is a derivative of the earlier MEP model) and will be regarded as effectively the same model for most of this paper. Not all of the models attempted the policy tests for various reasons. Two models are 'optimising' models (SALOC and TOPAZ) : such models are geared to finding a set of measures which, if pursued, lead to a pre-determined desired outcome, for example, minimising energy use while still permitting an acceptable level of mobility. Because there is usually no behavioural mechanism in optimising models, the implicit assumption that people will live and work in the places suggested by the policy and travel in the manner proposed may not be realistic. Suitable behavioural mechanisms could be incorporated in such models so

Table 2 Policy tests and models used.

POLICY TESTS++	MODELS# USED IN PHASE 1							CITY+/MODEL COMBINATIONS IN PHASE 2													
								Am.		To.		Dort.				Leeds				Bi.	
	A	C	D	L	M	O	T	A	L	C	L	D	L	M	M+	A	L	M+	T	M	M+
POPULATION CHANGES																					
12.1 Population grows at 2% pa: no land-use restrictions	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓	✓	✓	✓
12.2 Population grows at 2% pa: development restrictions on outskirts	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓-			✓	✓	✓	✓	✓
12.3 Zero population growth: no land-use restrictions	✓		✓	✓	✓		✓														
12.4 Zero population growth: development restrictions on outskirts	✓		✓	✓	✓																
EMPLOYMENT CHANGES																					
13.1 Half non-service jobs move from inner to outer areas	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
13.2 Half non-service jobs move from inner area to outlying industrial estate	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
13.3 All non-service jobs redistributed in proportion to population		✓	✓	✓	✓					✓	✓	✓	✓	✓	✓		✓	✓		✓	✓
SHOPPING POLICIES																					
14.1 Half inner-area retail floorspace redistributed to outer areas		✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
14.2 Additional peripheral shopping centre (≡ 1/4 city-centre floor space)			✓	✓							✓	✓	✓		✓		✓	✓	✓		✓
14.3 Unlimited free parking for city-centre shoppers				✓							✓		✓		✓		✓	✓			✓
14.4 Free off-peak transport to shops				✓							✓		✓		✓		✓	✓			✓
TRAVEL COST CHANGES																					
15.1 All travel costs up 50%	✓		✓	✓	✓														✓		
15.2 All travel costs up 100%			✓	✓	✓						✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
15.3 Car operating costs quadrupled			✓	✓	✓						✓	✓	✓	✓	✓		✓	✓		✓	✓
15.4 Central area parking cost made equal to mean travel cost			✓	✓	✓																
15.5 Central area parking cost made equal to 3 times mean travel cost			✓	✓	✓						✓	✓	✓	✓	✓		✓	✓		✓	✓
15.6 Public transport free			✓	✓	✓						✓	✓	✓	✓	✓		✓	✓		✓	✓
15.7 Public transport fares up 50%			✓	✓	✓																
15.8 Public transport fares up 100%			✓	✓	✓						✓	✓			✓		✓	✓		✓	✓
TRAVEL SPEED CHANGES																					
16.1 Speeds of all mechanised modes up 20%	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓		✓	✓
16.2 Speeds of all mechanised modes down 20%	✓	✓	✓	✓	✓	✓	✓														
16.3 Public transport speeds up 20%, other speeds down 20%			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓		✓	✓
16.4 Speeds down 15% in inner ares, 25% in outer areas			✓	✓	✓																
16.5 New outer orbital motorway: operating speed 80 km/hr			✓	✓	✓							✓	✓		✓		✓	✓		✓	✓
16.6 New inner ring road: operating speed 60 km/hr			✓	✓	✓							✓	✓		✓		✓	✓		✓	✓
16.7 New cross-town transit line: line haul speed 40 km/hr			✓	✓	✓																
16.8 New cross-town transit line: line haul speed 60 km/hr			✓	✓	✓							✓			✓		✓	✓		✓	✓
16.9 Car ownership same as base forecast: no extra transport investment			✓	✓	✓																
16.10 Car ownership grows at 2% pa more slowly than in 16.9			✓	✓	✓																
16.11 car ownership grows at 2% pa more rapidly than in 16.9			✓	✓	✓																
TIMING OF INVESTMENT																					
17.1 Public transport speeds and road capacity gradually double over 20 years			✓	✓	✓																
17.2 Public transport speeds doubled over first 10 years, road capacity doubled over next 10 years			✓	✓	✓																
17.3 Road capacity doubled over first 10 years; public transport speeds doubled over next 10 years			✓	✓	✓																
17.4 Public transport free in first 10 years; remains free thereafter			✓	✓	✓																
17.5 Public transport subsidy removed in first 10 years: not replaced			✓	✓	✓																
17.6 Public transport free in first 10 years; subsidy removed over next ten years			✓	✓	✓																
17.7 Public transport subsidies removed in first 10 years; travel becomes free over next 10 years			✓	✓	✓																
CHANGES IN ECONOMIC CLIMATE																					
18.1 Employment cut by 20%; travel costs increased by 20%			✓	✓	✓		✓												✓		
18.2 All people move into same income group	✓		✓		✓																
BASE FORECAST	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

\# See Table 1 for model names

\+ City abbreviations: Am. = Amersfoort; Bi. = Bilbao; Dort. = Dortmund; To. = Tokyo

++ See the full report of the Phase 1 work (Webster et al (Eds.), 1988) for more detailed description of the tests (the tests are numbered as in the Phase 1 book) that the optimal measures determined by them would then be in accordance with the behavioural characteristics of both the people and firms concerned, but this has not yet been done, though TOPAZ does incorporate some predictive mechanisms in its structure. As a result SALOC could not be used for any of the policy tests which were of the type "what would happen if …". TOPAZ, because of its predictive capabilities, was able to be used for some, but not all the tests. The other eight models were all 'predictive' models i. e. they predict the various impacts of applying a particular policy and were therefore suited to the type of tests set up. All these models tackled at least some of the policy tests, except ITLUP where resource constraints prevented this. Only three models, DORTMUND, LILT and MEP carried out practically all the tests in Phase 1 and these models were predominant in the Phase 2 tests also.

(3) Policies tested

The agreed set of policies tested by the modelling teams fall into seven main groups:

- (i) policies affecting the growth of population, with and without development restrictions applied to the peripheral areas
- (ii) policies affecting the location of non-service employment within the urban area and other policies affecting the location of retail facilities
- (iii) parking and public transport policies to assist central-area facilities
- (iv) policies which change the cost of travel by car and/or public transport
- (v) policies which change the speed of travel by car and/or public transport
- (vi) investment policies for roads and public transport phased over a 20-year period in a variety of ways
- (vii) economic policies affecting income distribution and the costs of travel

Table 2 lists all 39 policies and indicates which models carried out which tests in both Phase 1 and Phase 2 of the study.

3. COMPARISON OF MODEL STRUCTURES

Table 3 summarises the main structural features of the various models represented in the ISGLUTI study and, as mentioned earlier, the appendix gives a brief description of each model.

Unlike other models which are purely locational models or transport models, all the ISGLUTI models possess an interactive facility between land use and transport which makes them especially suitable for forecasting and assessing the impacts of urban policies. All but two of the models are predictive models, only SALOC and TOPAZ are of the optimising type. Three of the models are essentially land-use models with only a rudimentary representation of transport:

AMERSFOORT, which has no transport network and no representation of modal split

OSAKA and SALOC, which do not explicitly represent travel although calculated accessibility indicators based on detailed travel characteristics determine where activities take place.

Four of the models, AMERSFOORT, ITLUP, SALOC and TOPAZ, are relatively simple, have modest data requirements, are easy to use and are fairly readily transferable to other cities. At the other end of the scale DORTMUND has by far the largest number of categories of population and employment, as shown in Table 3. It is the most detailed and least transferable of all the ISGLUTI models. The strength of two of the models, CALUTAS and OSAKA, is in their ability to deal with enormous populations in exceptionally large metropolitan areas (Tokyo with 28 million people in an area of 14 500 sq km and Osaka with 14.5 million people in an area of 8 000 sq km). This is achieved by having a hierarchical zonal structure in which the main land-use/transport interactions take place in the larger zones at the higher level leaving the lower level, with its large number of zones (14 500 in the case of CALUTAS applied to Tokyo), to provide much greater spatial detail in land use, the location of activities and travel patterns. DORTMUND and MEP also have hierarchical systems initially intended to cover large regions of West Germany and Spain respectively: the models used in the ISGLUTI application were in both cases the

Table 3 The main characteristics of the models.

MODEL:	AMERSFOORT	CALUTAS	DORTMUND	ITLUP	LILT	MEP+	OSAKA	SALOC	TOPAZ
MODEL TYPE:	Predictive	Predictive	Predictive	Predictive	Predictive	Predictive	Predictive	Optimising	Optimising
MODELLING TECHNIQUES USED:									
Spatial interaction	✓	✓	✓	✓	✓	✓			✓
Utility maximising		✓	✓		✓	✓	✓	✓	
Market equilibrium		✓	✓			✓	✓		
Cohort/Markov survival			✓		✓				
Input/output economic base						✓			
Micro simulation			✓				✓		
Linear regression		✓					✓		
Mathematical programming								✓	✓
LAND-USE LOCATION:									
Number of categories of:									
population	3	1	80	4	3	4	1	1	1
housing	1	2	30	-	1	++	-	2	1
employment	1	15	40	4	12	5	18	2	1
Workplaces	-	-	40	-	12	++	-	-	-
Model includes: land prices		✓	✓			✓	✓		
housing rents			✓			✓			
TRANSPORT REPRESENTATION:									
Model predicts: trip pattern	✓	✓	✓	✓	✓	✓			✓
traffic congestion		✓	✓	✓	✓	✓			
car ownership			✓		✓				
Number of: trip purposes	1	5	4	2	5	4			4
transport modes	1	2	4	2	3	3			2
DATA BASE:									
City on which model was originally calibrated (and used in Phase 1)	Amersfoort	Tokyo	Dortmund	San Francisco Bay Area	Leeds	Bilbao	Osaka	Uppsala	Melbourne
Population (thousands)	153	27,904	1,075	4,064	497	970	14,556	160	2,697
Area (square kms)	202	14,565	833		164	355	8,000		3,000
Number of: internal zones	26	76	30	30	28	28	40	49	41
external zones *	12				12				
lower level zones **		14,500					840		

NOTES:
+ MEP superseded by the more generalised MEPLAN model, which is used in the Phase 2 applications.
++ Supply of accommodation is represented by available floorspace for which the different categories of demand compete.
* External zones to handle in-and out-commuting.
** Models contain two level zonal hierarchy: larger number of zones at lower level offer greater spatial detail.

Source Webster et al (Eds),1988

middle-stage of a 3-stage hierarchy.

All the models allocate population and employment to the various zones of the area : some represent the housing stock also so that mismatches between supply and demand can be identified (i. e. vacant or overcrowded homes). DORTMUND and LILT also treat the workforce and jobs separately so that vacant jobs and workers without jobs can be identified. In only four models (CALUTAS, DORTMUND, MEP/MEPLAN and OSAKA) is money represented explicitly in all the major components of the models — land and house prices, rents and travel costs, but only DORTMUND and MEP/MEPLAN allow prices to change to match supply and demand. CALUTAS and OSAKA calculate a 'bid rent' for land which is based on the 'utility' of the particular location. An alternative to a pricing mechanism in the land-use submodel is a set of procedural rules and proxies for the true events. In the case of housing, for example, LILT assumes that the different social groups have particular locational preferences.

The transport module in most of the models which represent travel in some detail is based on the conventional 4-step transport model (the four steps being trip generation, trip distribution, modal split and assignment). Only three models (DORTMUND, LILT and MEP/MEPLAN) give a finer categorisation of modes than just public and private and these (except MEP) are the only ones to include walking as a mode in its own right. All the models with a detailed transport submodel represent trips to work and most represent shopping, education, other home-based trips and non-home-based trips also. They all have highway networks representing in most cases all the major roads in the area (some have railway networks also) and most are able to represent congestion on the various links as flows approach capacity. Most of the models ignore minor roads but MEPLAN includes a spider network to represent all roads not covered by the major network. None of the models represents intra-zonal trips in any detail. Only two of the models (DORTMUND and LILT) have a mechanism to change the level of car ownership in relation to changing travel costs, incomes and other relevant variables. The other models rely on exogenous changes in car ownership to modify the parameters affecting travel decisions.

With regard to the structure of the models, most rely on basic employment as the driving force in much the same way as set out by Lowry in his model of Metropolis (Lowry, 1964). The principle behind this is that basic employment needs workpeople and other industries to service it, the workers and their families require shops, educational facilities and other services and these in turn require more workers who require more services and so on. Basic employment was originally interpreted as being primary industry and most of the manufacturing sector, but in the context of these models it includes all those industries and commercial activities which generate the wealth of the region i. e. their products and services are exported outside the region and not consumed within it. The total is an exogenous input and in MEPLAN in particular it comprises all primary industry, a high proportion of manufacturing industry and a proportion of the financial and other service sector as well. The other aspect which is common to all these models is the existence of a trade-off between accessibility (and other desirable attributes of a particular area) and expenditure on housing, land, office or industrial space (or, where there is no price mechanism, some proxy for this). This requires a knowledge of how accessibility between different industries, commercial activities, population and markets affect locational choice.

All the models are quasi-dynamic and move from one time period to the next with all the interactions taking place within the simulation period (generally 5 years) or lagged by one or two periods. Travel and traffic tend to respond quickly to changes while land use takes considerably longer to respond. Of course, once having responded (usually in the next simulation period), the travel patterns will quickly readjust to the new land-use pattern and these changes will then foster further land-use changes in a later simulation period and so the effect continues through time. Space is modelled in all cases by dividing the area into zones but the models vary considerably in the level of detail represented, as indicated in Table 3.

Despite the similarity of the basic ideas behind the models, there is considerable variation in the theoretical framework used, the degree of complexity and the level of detail. The two optimising models are quite different even in principle and are the only ones to use mathematical programming techniques to perform the optimum calculations. MEP/MEPLAN is the only model to use input/output relationships to determine the strengths of the interactions between the various activities and the population. They are used to represent industry's requirements for employees, their requirements for homes and residents' requirements for places to shop. These interactions are then converted to passenger and vehicular flows in the transport module. All the models except OSAKA and SALOC use spatial interaction techniques (generalisations of the original gravity model) to estimate the amount of interaction between the various zones (usually as a function of their size or attractivity and the costs of travelling between them). They are mostly used in these models to predict the location of residences given the distribution of employment or the location of employment given the distribution of residences. The same type of mechanism is used in some of the models to predict the resulting trip patterns. Several of the models employ utility maximisation techniques for choosing between housing types or between particular residential locations (as in OSAKA and SALOC), where the choice depends mainly on accessibility relating to the exisiting travel demand. OSAKA uses linear regression techniques, instead of entropy-based functions, to relate population to employment and service employment to population. Both CALUTAS and OSAKA use linear regression to equate the price of land to its locational utility expressed as a linear function of a variety of locational factors (such as commuter travel times and costs) and other factors representing land attractiveness. DORTMUND and OSAKA use microsimulation techniques to model a household's search for a new home in the housing market. DORTMUND and LILT are the only models to use cohort/survival techniques to represent the ageing process of people and, in the case of DORTMUND, their homes also. The four models which calculate prices (land, rents, travel costs) use market equilibrium techniques to equate supply and demand, though only MEP/MEPLAN contains a full market clearing mechanism which adjusts prices in the face of competition until demand balances supply. DORTMUND takes a similar approach but allows prices to be adjusted in the subsequent simulation period.

While the output from most of the models can in theory be used in an economic assessment of particular policies only MEP/MEPLAN and CALUTAS have a formal integrated economic evaluation package. Benefits to both producers and consumers from both land use and transport changes are calculated in MEP/MEPLAN while in CALUTAS the evaluation refers only to the land-use changes.

4. ASSESSMENT OF MODEL PERFORMANCE (PHASE 1 TESTS)

Table 2 lists the complete set of tests agreed by the participants of the study and indicates which tests were attempted by which teams. In all cases the impacts of the policies were judged against a background trend (the base forecast), which represents a continuation of past trends and generally includes all committed land-use and transport changes. The values of the parameters at the end of the 20-year forecast period (and at other times also when necessary) are compared with corresponding values for the base forecast, i. e. with what would have happened had the policy not been applied.

Perhaps not surprisingly, the models predicted impacts of widely differing magnitudes and in some cases of different direction too, as is shown in Webster *et al.* (Eds.) (1988). Despite this, practically all of them support the view that the location of employment is more sensitive to changes in travel costs than is the distribution of population, that retail employment is more responsive than non-retail service employment, which in turn is more responsive than non-service employment. And in those models which disaggregate polulation the individual social groups show considerable movement even when the population as a whole is relatively static. On the transport side, the models predict only minor changes in the modal split when policies are implemented which cause substantial outward movements of population and/or employment. This raises the question whether the models underestimate the difficulty that public transport would have in serving more dispersed areas. On the other hand, the models suggest that measures which increase bus speeds at the expense of car speeds attract only a small number of extra bus

Table 4 Subjective assessment of the applicability of the models (Model symbol given where model is likely to be suitable, asterisk where specially suitable).

PREDICTION OF IMPACT ON:	TYPE OF POLICY					
	LAND USE			TRANSPORT		
	Regulation (eg zoning, density limits)	Pricing (eg property taxes or subsidies)	Investment (eg new infra-structure, public housing	Regulation (eg traffic management, parking, priorities)	Pricing (eg fuel tax, public transport subsidies)	Investment (eg new roads, improvements, new rail lines)
Population location	A* C* D* L* M* OT*	CD* M*	A* C* D* L* M* O* T	D* L* M* O	DL* M	AC* D* L* M* O*
Social structure	A* D* L* M*	D* M*	A* D* L* M*	D* L* M*	DL* M*	D* L* M*
Industrial location	C* D* L* M* OT	CD* M*	CD* L* M* OT	D* L* M* O	DL* M	CD* L* M* O
Retail location	C* D* L* M* O	CD* M*	CD* L* M* O	D* L* M* O	DL* M*	C* D* LM* O
Price of land/building	CD* M*	D* M*	CD* M*	D* M*	DM	CD* M*
Work trip patterns (time, distances, costs)	AC* D* L* M* T*	CD* M*	ACD* L* M* T*	D* L* M* T	DL* MT	ACD* L* M* T
Other trip patterns	CD* L* M* T*	D* M*	CD* L* M* T*	D* L* M* T*	DL* MT*	CD* L* M* T*
Modal split	D* L* M* T*	D* M*	D* L* M* T	D* L* M* T	DL* MT*	CD* L* M* T*
Car ownership	LD	-	LD	LD	L	LD
Distribution of benefits/costs	DM*	DM*	DM*	DM*	M	DM*

Source: Webster et al (Eds), 1988

passengers, implying that public transport is not unduly favoured by the models.

Much of the variation in the results is undoubtedly due to the different characteristics of the cities used (and the Phase 2 tests discussed later will show how important these charcteristics are on the model predictions), but the bulk of the variation probably results from the models themselves. The difficulty is knowing which models are giving the best predictions, because even if several models agree on the impact, it does not necessarily follow that it is the correct result. Nevertheless, the results of the policy tests taken in conjunction with the comparative assessment of the model structures and mechanisms used, can shed a great deal of light on the usefulness of the models for carrying out particular tasks and for assessing the likely impacts of particular policies. This was done in the course of Phase 1 and Table 4 summarises the collective views of the modellers involved in the ISGLUTI study. It suggests that most of the models are suitable for examining policies concerned with regulation and investment in both the transport and land-use fields but fewer models are suitable for investigating pricing policies. This is because so few models predict land and house prices (or rents) and have a proper market mechanism to equalise supply and demand. Zoning regulations and priority rules for allocating homes are likely to be a poor proxy for a suitable monetary mechanism. Use of a bid rent for land also has its problems if the rent is based solely on locational utility and ignores the effect of competition between potential users. Most of the models do not handle transport costs well either (if at all). DORTMUND, for example, uses a household travel budget which acts as a constraint on car ownership and on the amount of mechanised travel consumed, so that if public transport is made free, it assumes that more money is available for travel thereby causing both car ownership and use to rise. This aspect of the model has now been corrected.

Some models do not disaggregate population into the different social groups so cannot replicate the complex pattern of relocation which takes place within the existing housing stock and cannot therefore be used for studying policies which act differentially on the different social groups. Similarly, models which do not disaggregate employment are not able to model the competition for land or floorspace between the different sectors (for which a price mechanism would also be required), nor the relocational effects of the different sectors arising from policy changes. Some models on the other hand, are capable of a wider range of applicability than was required in the ISGLUTI tests; for example, CALUTAS and OSAKA, with their two-stage zonal hierarchy, are able to represent extremely fine detail within an enormous urban area.

Whereas some of the models are able to represent transport in only a rudimentary way, others are able to capture some of the complexity which is so much a part of travel behaviour : for example, that cars left at home by commuters who switch to public transport are available for use by other members of the household during the rest of the day. In view of the importance of the availability of a car in travel and locational decisions it is surprising that so few models make car ownership levels responsive to changing costs and incomes, though researchers have had problems in this area. Perhaps more surprising, however, is the lack of a walk mode in most models in view of its importance (in most towns and cities nearly one third of trips are on foot) and its relevance to modal shift (public transport tends to draw trips from walk and loses them to both walk and car). Those models which do not include walk have to resort to other measures to overcome this omission. For example, MEP generates extra trips in response to lower overall travel costs before distributing them to the modes represented, but in the case of free public transport the extra trips become so numerous that car travel increases also. This fault does not arise in MEPLAN, which has a walk mode. On the whole the models are able to reflect a good deal of the adaptation that takes place in real life both by people and firms when responding to transport or land-use changes. This is shown in the complex pattern of changes in mode of travel, choice of destination, distance, time and cost of journeys and ultimately in the location of homes and workplaces.

Table 5 Likely impacts from land-use and transport policies.

IMPACTS ON: \ POLICIES	LAND ZONING				TRAVEL COSTS				TRAVEL SPEEDS		TAXATION
						Taxation on private car			(Capital investment)		
	Development restrictions (Green belt)	Closer proximity of homes and jobs	Peripheral industrial estates	Out-of-town shopping centres	Public transport subsidies	on car use	on car ownership	on central area parking	Road improvement	New public transport lines	
	1	2	3	4	5	6	7	8	9	10	11
POPULATION	C	?	d	D?	d	d	?	?s	d	?	D?
High income	c?	c?	D	D?	d	?	?	?s	d	?	C?
Low income	C	d?	C?	?	c?	?	?	d	?s	d?	D?
EMPLOYMENT	C[1]	D	D	D	C	C?	D	D	?	c	d
Retail	C	?s	D?	D	C	C?	D	D	C	c	D
Non-service	c	D	D	?s	c	?s	d	d	?s	c	?s
DENSITY	++	+	?s	+?	-	-	+	-	?s	?s	?s
HOUSING PRICES											
Land	++	+	?s	?s	+	-	+	++	+	?s	--
Homes	?	+	?s	+	+	?	+	++	+	?s	--
ACTIVITY OF CENTRE											
All	++	--	--	--	+	++	-?	--	++?	++	--
Work	+	--	--	--	+	+	--	--	++?	++	?
Shopping	++	+	?	--	+	++	-	--	++?	++	--
MODAL SPLIT											
Public transport	+	?s	--?	-	++	++	++	-	?	++	?s
Car	-	?s	-	+	--	--	--	+	+	-	?s
Walk	+	?s	+	+	--	++	++	++	--	--	?s
AMOUNT OF TRAVEL											
Distance	-	-	?	--?	++?	--	--	?s	++	++	?s
Cost	+?	-	++?	--?	--[2]	++[3]	--[4]	+?	++	++	?s
Time	-	?s	?	?	++?	?	++	?	--	-?	?s
Energy	-?	-	?s	?s	?	-?	--	?	++	?s	?s

Source: Webster et al (eds), 1988

Key:
- C : tends to be relatively more centralised (c: effect is small))
- D : tends to be relatively more decentralised (d: effect is small)) relative to
- ? : influence could go either way (?s: ditto, but effect is likely to be small)) background
- ++ : relative increase (+: effect is small)) trend
- -- : relative decrease (-: effect is small))

Notes:
- (1) tends to be the inner suburbs, rather than the central area, which gains most employment
- (2) decline in travel costs ignores the cost of subsidy
- (3) overall travel costs likely to be reduced if extra taxation is discounted
- (4) decline in travel costs ignores extra cost of car ownership

5. IMPACTS OF POLICIES TESTED IN PHASE 1

The second aim of the ISGLUTI study was to gain some insight into the likely impacts resulting from applying the land-use and transport policies listed in Table 2, but it is not possible in this short paper to do justice to the vast amount of results recorded in the 500 page Phase 1 report (Webster *et al.*, Eds., 1988). All that can be done is to comment briefly on the main impacts as summarised in Table 5. The terms "centralisation" and "decentralisation" (denoted by the letters C and D in the table) refer to the movement of population or employment (relative to the base forecast) between the central area of the city and the suburbs. The ISGLUTI Phase 1 report gives a more precise definition, but it should be noted that in many cases 'centralisation' denotes merely a slowing down in the rate of decentralisation.

The tests indicate that development restrictions applied to the outskirts of a city mainly achieve their objectives of slowing down decentralisation and increasing activity in the town centre. Land-zoning policies which allow development in out-of-town areas naturally have the opposite effect and while this may not be a desirable outcome of the policy it is a side-effect which those responsible should be fully aware of. Use of interactive land-use/transport models can give a useful indication of how severe this effect might be. Most land-use policies of this type reduce the mean trip distance, but not necessarily the travel time or the cost, and even though the policy of putting homes closer to jobs appears to be successful in its aims of reducing travel distances and costs, the gains are surprisingly modest and decentralisation accelerates resulting in fewer activities remaining in the town centre.

Policies which change the cost of travel have larger and more consistent effects on employment than on population, with public transport subsidies and higher taxation on car use reducing the rate of employment decentralisation with a corresponding strengthening of the town centre. Higher central-area parking costs on the other hand, cause employment to move away from the more central areas but car use in total does not diminish. Car and walk journeys both increase in the outer areas. Higher costs on car ownership also cause employment to move further out with car trips to the central area giving way to more local trips by bus and on foot. Public transport subsidies cause both car use and walking to decrease and journeys to lengthen, while extra tax on either car use or ownership results in shorter journeys in distance, but not in time, because of the shift from car use to walk and public transport.

Road and rail investment measures which increase travel speeds have a generally centralising effect on employment and a decentralising effect on population with an increase in activities in the town centre. They result in a shift from walk to mechanised modes and increase the mean distance travelled, the cost and energy consumption of a trip, but not the duration.

While some of the effects of policies diminish over time, new ones emerge as people adapt to their new situation, so that the benefits obtained from a particular measure are often in a different form from that originally envisaged — usually in the widening of choice of destination, rather than in the saving of time or money. In some cases the impacts may be modified to such an extent that the ultimate effect is in the opposite direction from that of the initial response. Planners should take note that if particular policies do not offer people what they want, they will seek more suitable alternatives elsewhere, even if present constraints prevent them from taking up these alternatives immediately. The non-interactive type of land-use model or the conventional transport model tends to ignore all but the first-round effects of a policy so that many of the important adaptive responses of both people and firms are excluded.

6. APPLICATION OF MEPLAN TO THREE CITIES

So far this paper has been reporting on results obtained in Phase 1 of the ISGLUTI study where each of the models was applied to the 'home' city. Phase 2, which tries to overcome some of the problems arising from the application of policies to a variety of cities, is not yet complete, but preliminary results are available. This part of the paper describes some of the results obtained from the application of MEPLAN

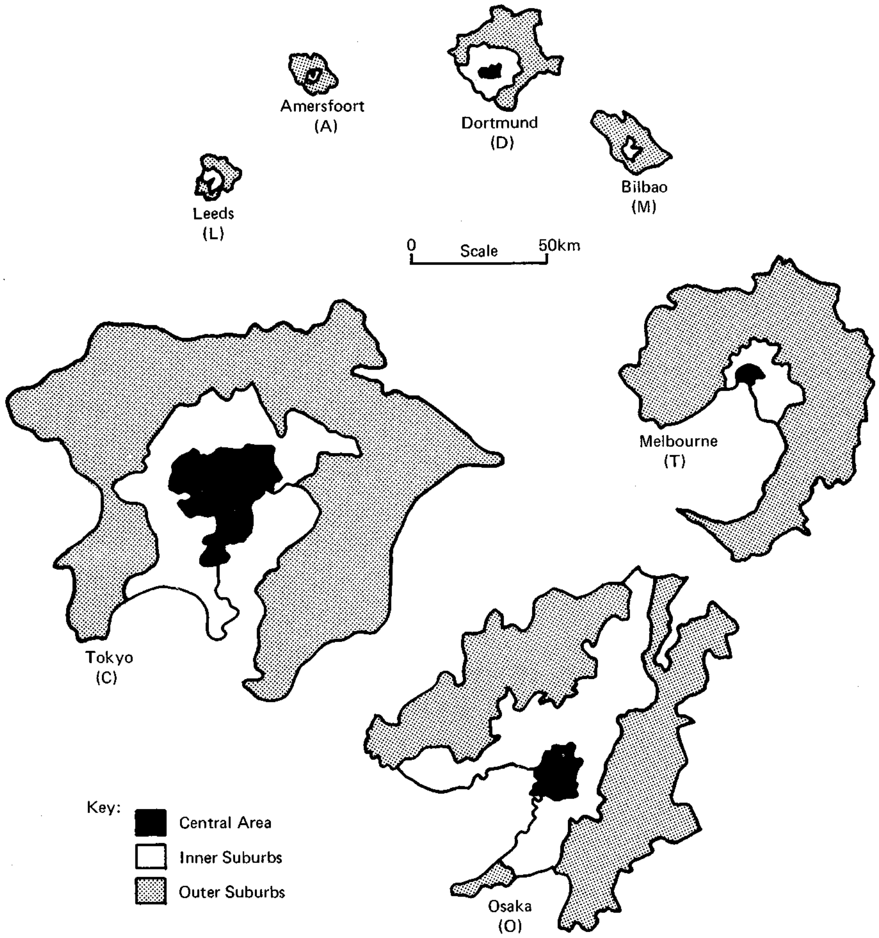

Fig. 1 The study areas (drawn to approximately the same scale).

to Dortmund, Leeds and Bilbao. In the next section, the application of LILT to Dortmund, Leeds and Tokyo will be discussed in relation to the same batch of policies. The section following that will compare the impacts of a number of policies on one particular town, Dortmund, as predicted by three different models, DORTMUND, LILT and MEPLAN.

The results given here are drawn from the paper by Echenique *et al.* (1989). The three cities tested are of comparable size and characteristics : Leeds has a population of approximately half a million, whereas the other two cities have about a million people within the boundaries of the study area, but the boundary for Leeds was drawn particularly tightly. In Leeds, the whole study area is confined to the administrative boundary so there is significant commuting from outside and much scope for decentralisation beyond the study boundary. In Dortmund, on the ther hand, the study area contains villages and towns (one of similar size to Dortmund itself) beyond the administrative boundary. The Bilbao zoning falls between these two extremes. Fig. 1 shows the relative sizes of the various cities in the ISGLUTI study. All three cities are similar in that they are suffering from economic decline due to the shrinking economic base of heavy industry.

The tests reported here are concerned with changes in travel costs and speeds. Table 6 shows how the modal shares for car and public transport respond and what happens to the decentralisation trend of population and employment. The steep increase in car running costs in Test 15.3 results in both public transport and the walk mode gaining at the expense of car in all three cities, but especially walk in Leeds (car travel is down by 11 percentage points, public transport is up by only 2.5). When public transport

Table 6 Changes in modal shares and decentralisation trends.

Type of policy	Test no.	Policy description (cf Table 2)		Change in percentage modal shares* (all travel)			Decentralisation trend+	
				Dortmund	Leeds	Bilbao	Popul -ation	Employ -ment
Travel costs	15.3	Car costs x4	Car PT	-11.7 5.6	-11.1 2.5	-9.3 6.2	C	D
	15.8	PT fares x2	Car PT	2.2 -5.5	0.8 -3.3	0.6 -1.3	c	D
	15.2	All travel costs x2	Car PT	-0.5 -5.1	-3.5 -2.7	-3.0 1.1	C	D
	15.6	PT free	Car PT	-3.7 7.5	-0.4 5.5	-1.3 1.9	D	C
	15.5	Central area parking costs up	Car PT	-2.8 2.5	-0.2 0.0	-0.6 0.4	?	D
Travel speeds	16.1	All speeds x1.2	Car PT	1.9 0.3	1.2 0.5	-0.2 0.9	d	C
	16.3	PT speed x1.2 Car speed x0.8	Car PT	-7.0 5.0	-2.0 1.1	-2.7 2.3	d	D

* Figures represent difference in percentage points. Thus, if trips are divided equally between car, public transport and walk, the actual percentage change is obtained by multiplying by 3.
\+ C = centralisation or a slowing down in the decentralisation trend
D = speeding up of the decentralisation trend
c or d indicates that only 2 of the 3 cities have the trends shown
? indicates no obvious pattern

fares double (Test 15.8) there is a shift to walk as well as to car but especially so in Leeds where car gains only slightly. The opposite effect occurs when public transport is made free in Test 15.6 : the shift from walk is particularly large in the case of Leeds. For both fares tests the effect on public transport is greatest in Dortmund, with its efficient urban rail system and least in Bilbao, where fare levels are currently very low. When all travel costs are doubled (Test 15.2) both public transport and car travel lose out to walk in both Dortmund and Leeds (especially public transport in Dortmund), but in Bilbao, the relatively large loss of car trips actually boosts public transport use. When central area car parking costs are increased (Test 15.5) public transport gains only very slightly at the expense of car travel in Leeds and Bilbao, though for work trips to the central area the effect is much larger (4 and 0.5 percent respectively). The effect is much larger in Dortmund, however, because of the very large area designated as the central area in the study.

With regard to the policy which raises travel speeds by all mechanised modes (Test 16.1), there are shifts from walk to both car and public transport in all three cities, but in Bilbao there is an additional shift from car to public transport which reduces car travel overall. When policies are implemented which allow bus speeds to increase at the expense of car travel (as would happen with bus lanes) the effects are in the same direction as those for increasing car costs (Test 15.3) but the magnitudes are much less, especially in Leeds and Bilbao.

Looking at the land-use effects of all these policies, it seems that population decentralisation generally is slowed down when travel costs by any mechanised mode rise and when travel speeds fall. This arises because distances are reduced when either money costs or time costs rise, causing the whole urban system to contract (or expand more slowly). Table 6 suggests that employment generally moves in the opposite direction from that of population. When costs rise or speeds fall, employment moves outwards to be closer to the workforce, but when car travel becomes slower and bus travel faster by the same proportion (Test 16.3), the response is affected more by the lower car speeds than by the higher bus speeds, because in-vehicle time forms a greater proportion of the generalised cost of car travel than it does with bus travel. In general, the changes in the decentralisation trends seem reasonably consistent between cities and policy tests, as would be expected, because the same model is used for all three cities and for all tests. However, not all the findings are in line with the concensus view given in Table 5, which was based on the results from all the ISGLUTI models applied to their respective cities. This is particularly so with policies which affect car running costs.

7. APPLICATION OF LILT TO THREE CITIES

Preliminary results from applying LILT to Dortmund, Leeds and Tokyo were reported in Mackett (1989). This paper draws from those results and some more recent ones which will be reported later in Transport Reviews. Dortmund and Leeds are relatively small cities compared with Tokyo, which is a massive metropolitan area of some 28 million people (see Fig. 1). The employment characteristics are very different too, with about half the jobs in Dortmund and Leeds in the non-service sector compared with only a quarter in Tokyo. This difference would not be quite so marked if the boundaries of the three cities had been drawn on similar criteria. The Leeds study area is very tight compared with Dortmund, as mentioned earlier, but both are tight compared with Tokyo, where the designated central area alone is as large as the whole of the Dortmund region. Using LILT on cities of such different types and sizes is pushing the model to its limits and care is required in interpreting the results, especially those concerning the movement of population and employment.

The policy tests discussed here are the same as those described in the previous section. The effects on modal split of changes in travel costs and speeds were almost always in the same direction as those in the MEPLAN tests for Leeds and Dortmund, as shown in Tables 6 and 7. The modal shares (including walk) and the distances travelled were found to respond far more to changes in travel costs in Dortmund and Leeds than in Tokyo. This is partly because car ownership in the Tokyo version of LILT does not respond to changes in car costs, whereas it does in the Dortmund and Leeds versions, but it is also because there is more opportunity to switch to walk when travel costs rise in the more compact cities. With higher central area parking costs (Test 15.5), LILT suggests that public transport gains at the expense of car in Tokyo (see Table 7), but in Dortmund and Leeds public transport, as well as car, loses out to walking because of a shift of activities from the town centre to the outskirts. Because of its dependence on relatively long rail journeys, Tokyo shows a more pronounced change in mean journey cost than the other cities when public transport costs are changed and a smaller effect when car costs are changed.

With regard to changes in the decentralisation trends of employment, Table 7 suggests that the effects of increases in car costs and public transport fares are cumulative in Tokyo i. e. decentralisation slows down

Table 7 Changes in modal shares and decentralisation trends according to LILT.

Type of policy	Test no.	Policy description (cf Table 2)	Change in percentage model shares* (all travel)				Employment decentralisation trend *+		
				Dortmund	Leeds	Tokyo	Dortmund	Leeds	Tokyo
Travel costs	15.3	car costs x 4	Car PT	-11.3 9.3	-7.3 6.6	-2.2 2.1	C (5.7)	C (3.7)	C (0.7)
	15.8	PT fares x 2	Car PT	2.3 -8.1	1.3 -11.0	1.7 -1.9	D (-2.6)	D (-6.6)	C (1.1)
	15.2	All travel costs x 2	Car PT	-0.3 -6.1	-1.6 -9.8	0.9 -1.2	D (-0.3)	D (-5.6)	C (1.4)
	15.6	PT free	Car PT	-2.6 11.1	-3.9 28.6	-1.7 2.0	C (4.0)	C (8.8)	D (-1.3)
	15.5	Central area parking costs up	Car PT	-0.2 -0.2	-0.3 -0.2	-1.4 1.3	D (-0.6)	D (-9.1)	D (-1.3)
Travel speeds	16.1	All speeds x 1.2	Car PT	-0.4 3.4	0.2 1.4	0.5 -0.4	C (0.8)	C (1.3)	D (-0.7)
	16.3	PT speed x 1.2 Car speed x 0.8	Car PT	-3.5 5.8	-0.3 1.4	-2.2 2.2	C (3.3)	C (1.1)	- (0.0)

* Percentage modal shares and meanings of C and D are as defined in Table 6

\+ The figures in brackets give the percentage shift of employment from the outer to the inner area of the city over the 20 year period under the given policy minus the same quantity in the base forecast.

when either car costs or fares are increased and slows down even more when both are increased : conversely, it speeds up when public transport is made free. In Dortmund and Leeds, by contrast, the changes work in opposite directions. Free public transport (which is mainly radial in these cities) strengthens the central area quite considerably, particularly in Leeds which is highly dependent on public transport, while lower car costs encourage suburban development. When all travel costs double, the public transport effect in these two cities outweighs the car effect so that employment decentralisation speeds up. This boost to central area activity in Dortmund and Leeds when car travel costs are raised will encourage public transport use and this will reinforce the move away from car. The direct elasticities estimated from the modelling are —0. 29 in Leeds and —0. 23 in Dortmund. Similarly, the lowering of fares will help to strengthen the central areas in Dortmund and Leeds and reinforce the modal-split change, giving a larger long-term fares elasticity (—0. 58 in Dortmund, —0. 65 in Leeds), whereas in Tokyo, the land-use effects mitigate against the initial effects giving a very small elasticity of —0. 03. It may be noted that the MEPLAN study estimated smaller fares elasticities (—0. 22 for work travel in Dortmund and —0. 38 for non-work travel). The movements in employment suggested by LILT are similar to those suggested in the MEPLAN tests for fares changes but are opposite for car cost changes. Whereas plausible explanations for the changes are provided in each case, they cannot both be tenable.

In the travel speed tests, there is the expected modal shift to public transport in all three cities when public transport speed increases and car travel slows down, but when both modes speed up by the same proportion there is a relative shift to the slower mode in all cases, as would be expected on theoretical grounds, i. e. to public transport in Dortmund and Leeds and to car in Tokyo (see Table 7). In Leeds both mechanised modes gain at the expense of walk ; in Dortmund public transport gains at the expense of both car and walk, while in Tokyo car gains at the expense of both public transport and walk. The differences arise mainly from differences in the proportions of generalised cost which represent in-vehicle time and the ease with which walk and mechanised journeys can be substituted for each other. MEPLAN predicted a generally greater shift to car in Test 16. 1 than LILT did. Regarding employment decentralisation, Table 7 shows that increasing public transport speed, whether car speed is increased or decreased, affects the three cities in the same way as free public transport, though to a much lesser extent. In general, where policies make the car more expensive or public transport cheaper (in either time or money) the effect in Dortmund and Leeds is a slowing down in the decentralisation trend. In Tokyo, only an increase in time or money cost by either mode has the effect of slowing down decentralisation. This is because Tokyo is a vast metropolitan area with many important sub-centres, so that there is a weaker link between central area activities and access by public transport than there is in Dortmund and Leeds.

It is apparent therefore that using the same model on different cities produces results which are different in magnitude and sometimes in direction also. The results seem plausible and the differences cannot be ascribed to the model structure, but to the characteristics of the cities concerned. It can be concluded that at least some of the variation of the Phase 1 results must be due to the models being applied to different cities.

8. THREE MODELS APPLIED TO DORTMUND

The two previous sections have shown how the results vary when the same model is used to test the same policies in different cities : this section looks at what happens when different models are applied to the same city. A preliminary analysis is described in Mackett *et al.* (1989) and refers to the application of DORTMUND, LILT and MEPLAN to the city of Dortmund.

There are two main aspects to this comparison. The first relates to the base forecast and the second to the actual policy impacts. While some policy impacts are almost independent of the background trend against which they are measured (the base forecast), this is not true of others. It is therefore of some importance that the models should be capable of predicting a base forecast which is as realistic as possible.

Table 8 Relocation of population and employment in base forecast.

Variable	Population/employment changes in inner city areas (percentage difference between 1970 and 1990*)			
	Actual (1970-87)	Predicted by DORTMUND	LILT	MEPLAN
Population	-4.1	-4.6	-0.6	-2.1
Employment	-4.2 (not available)	-2.75 (-7.4)	-4.8 (-8.9)	-1.4 (+0.6)

* The figures show the percentages of the total population and employment in the central plus inner area in 1990 minus the corresponding values for 1970. The figures in brackets refer to the central area only (a more appropriate measure for employment purposes).

In the case of Dortmund the base year was chosen to be 1970 so that the 20-year forecast is in reality an ex-post forecast. Provided the necessary data exists, it can be compared with the actual development which has taken place within the region, but unfortunately only global figures from the latest census taken in 1987 were available. Between 1970 and 1987 the population of the whole region fell by nearly 5 %, but this was a combination of a much greater fall in the central area (nearly 20 %) and an actual increase of 5 % in the outer suburbs. The same decentralisation trend was shown in employment which fell by 10 % in total (16 % in the central and inner area with a gain of 1 % in the outer suburbs). In the same period car ownership doubled.

All three models correctly predicted the decentralisation of population, as shown in Table 8, though Dortmund was closest to the actual changes. With regard to the different social groups the models predicted different locational changes : DORTMUND was nearest in predicting a faster than average decentralisation of higher income households. MEPLAN suggested that the middle class would suburbanise most while LILT suggested the opposite of this. For the predictions of employment relocation MEPLAN actually suggested an increase in central area jobs (see Table 8), but it is not yet possible to make a proper comparison with reality. Figures are available, however, for the central and inner area combined and on this basis DORTMUND and LILT are reasonably close to reality, but MEPLAN suggests too little decentralisation.

With regard to the travel parameters, all three models correctly reproduced the trend to more car trips at the expense of public transport and to longer trips in general. All in all DORTMUND produced the most realistic base forecast, but this is to be expected since it was designed for that city and all the data it required was readily available, which was not the case for the other models. As mentioned earlier, an inaccurate base forecast does not necessarily mean that a model's predictive capability is badly impaired, but a reasonably realistic base forecast is obviously a point in its favour.

To compare the predictive capabilities of the three models, the early analysis reported in Mackett *et al.* (1989) used the results from policy tests concerned with travel cost and speed changes applied to Dortmund. To make a really satisfactory assessment of the models, it is necessary to know what the correct impacts are. Unfortunately, these cannot be known with any precision so other techniques had to be used. Using conventional wisdom the expected range of values for the various transport and land-use impacts were estimated and it was found that the mean impacts (averaged over all three models) were very much in line with theoretical expectations, though an appreciable proportion of the impacts from the individual models fell outside this expected range. However, these were fairly evenly distributed amongst the models, the types of tests and the types of impacts, as indicated in Mackett *et al.* (1989). This suggested that deficiencies in calibration and empirical validation were likely to be a greater cause of the discrepancies than any fundamental weaknesses in the models themselves. When using a model on a new data set, experience has demonstrated the value of taking great care in setting up the model, calibrating and validating it and obtaining a satisfactory base forecast. With the resource constraints imposed on the teams in the ISGLUTI study, it was not always possible to spend the time that was really required to perform these preliminary stages properly (sometimes there was not even sufficient time or resources to obtain all the data that was required). There was also the problem that idiosyncrasies in the models which had come to light during the testing programme had not been corrected in time for the early Phase 2 tests so that the spread of results was undoubtedly wider than it would have been if the corrections had been made then.

After the rather disturbing findings were reported at the Yokohama conference, the range of policy tests was widened, the inadequacies identified in some of the models were corrected and greater effort was made in the calibration and validation stages and in the way the tests were implemented. These actions have resulted in much greater convergence of the results so that any differences which now remain are more likely to arise from genuine differences in the way the different modellers see the real world and try to represent the actual processes which are taking place. The final results were not available for presentation in this paper, but they look most promising and will be given in the issue of Transport Reviews already referred to.

9. CONCLUSIONS

During the course of the ISGLUTI study nine modelling teams from seven countries spread across the world have collaborated in a joint exercise which has put their models to the most rigorous programme of testing ever carried out on models of this type. It has drawn attention to both the strengths and weaknesses of the various models and has indicated which models are best for which types of tasks. The study has examined the longer-term impacts of a range of land-use and transport policies and gained fresh insights into the various interactive effects. It has pinpointed the dangers of taking a "blinkered" approach to land-use and transport planning in which the interaction between the two is ignored — unfortunately an all too common practice even today.

Analysis of Phase 2 is not yet complete so any conclusions are rather tentative, but the study has highlighted some of the difficulties in using a model on a new data set, especially when the characteristics of the city to which it is being applied are very different from those of the city for which the model was originally designed. The study showed that when one model was applied to several cities there was generally a good deal of consistency in the predicted effects which mostly, but not always, moved in the same direction, though with varying magnitudes. Explanations for the different impacts in terms of the characteristics of the cities were easy to find, and this lent a credence to the accuracy of the predictions. But when two or more models are used to investigate the same policies applied to one city only, there was a tendency for the models to disagree not only on the magnitude of the effect, but more often than was desirable, on the direction also. This is, of course, a much tougher test of a model. An examination of these early results suggested that at least some of these differences were not directly associated with the different theoretical bases or modelling techniques used, but were more likely due to deficiencies in calibration and validation. As a result, new efforts were made to improve calibration and validation where necessary and to correct some of the model faults identified in Phase 1. Although this work is not yet complete, it is clear that these efforts have resulted in a substantial improvement in the consistency of the findings compared with the earlier work, so that any remaining discrepancies are most likely due to different perceptions of the modellers in how the various processes in the real world actually work.

The ISGLUTI study has drawn attention to the need for planners to take full account of the important land-use/transport interaction in policy formulation. It has identified problems and deficiencies with the models used in the study and has shown how, with suitable care, substantial improvements can be made. It has given guidance on the type of model which is most suited to particular tasks and the impacts which can be expected from implementing particular urban policies.

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APPENDIX Brief Descriptions of ISGLUTI Models

AMERSFOORT (A) This is a relatively undetailed model concentrating on housing location and development policies rather than transport. It uses a Lowry-type mechanism to allocate homes to different zones of the study area in relation to their accessibility to employment, which is located exogenously in the model. The allocation is based on entropy maximisation rather than the original gravity model. Accessibility is measured in a somewhat simplistic way since there is no transport network and no representation of modal split. Population is disaggregated into three income groups with a different mechanism for allocating housing to each group. It distinguishes between housing and population. The model has been applied to Amersfoort (population 150 000).

CALUTAS (C) This model operates at two levels of detail to suit its application to Tokyo, a metropolitan area of 28 million people. Large-scale basic industries are located exogenously but other work places are allocated on the basis of accessibility to suppliers and markets and attractiveness of the area. There is a link between location of retail employment and non-retail service employment. Population is allocated to housing according to a "locational surplus" function based on the value of living in the locality (accessibility and other attributes) and the price of land. While housing and population are modelled separately they are linked together so that housing does not provide a constraint to population movement. The model incorporates a fairly conventional transport model and predicts travel times and costs, locational utility and land prices.

DORTMUND (D) The model, which is applied to Dortmund (a city of a million people) and its neighbouring communities, is the middle stage of a 3-stage hierarchy of spatial allocation models. It simulates the locational decisions of industry, residential developers and households in a highly disaggregate way. It can cope with decline as well as growth. Development of residential and commercial sites is made dependent on accessibility, attractiveness and the price of land, which is set against estimated profits. Housing rents are also predicted by the model. On the transport side many purposes, modes (including walk) and income groups are represented and car ownership is predicted using a household money budget. The high level of detail in the model makes large demands on data, computer storage and operating time and limits the model's transferability.

ITLUP (I) By taking exogenous regional forecasts of total employment, population and activity rates at each time point, the model predicts the spatial location of households and employment and the pattern of trips by two purposes and two modes. The Lowry-type residential location model allocates different types of households to zones according to an accessibility-attractiveness function, while employment is located mainly on the basis of accessibility to population using an entropy-type distribution function. ITLUP has meagre data requirements, is easily transferable and has been applied to a number of cities, mainly in the USA.

LILT (L) This model links together a locational Lowry-type model with a fairly conventional transport model. It allocates exogenous forecasts of the total net change in population, new housing and jobs for the whole area to the individual zones according to an accessibility/attractiveness function, using an entropy-maximising technique. Different behavioural rules are used for allocating the various sectors of employment and the different population groups to the individual zones. The model can handle demolition, overcrowding and vacancies. On the transport side, car ownership is predicted within the model and, unlike most of the other models, the modal split includes walking. LILT has been applied mainly to Leeds, a city of half a million population.

MEP (M)/MEPLAN (M*) MEP is the middle stage of a 3-model hierarchy. Originally, it represented Bilbao, a city of nearly a million population. It follows the Lowry tradition in that basic employment (the totals of which are provided exogenously) generates population, which in turn generates other employment and more population, and so on, but the mechanism for doing this relies on input-output relationships to determine the strengths of the interactions between the various activities and the population. Spatial location is based on general utility functions which depend on measures of attractiveness and accessibility. Competition for floor space between different income groups and firms is governed by price. The transport model is fairly conventional but with no walk mode. The model provides a detailed economic evaluation of benefits to producers and consumers. MEP has now been superceded by MEPLAN (M*) which is a comprehensive modelling framework with the capability of incorporating many different mechanisms within the various submodels. The implementation of MEPLAN for the Phase 2 work was similar in structure to the MEP model with the addition of the walk mode and the disaggregation of trip purposes as the most significant improvements.

OSAKA (O) Like CALUTAS, this 2-stage model represents a very extensive area with a large population (15 million in Osaka). It is focussed mainly on land use rather than transport although the accessibility indicators which govern activity location are based on detailed travel characteristics : the model does not explicitly represent travel flows at all. The model works in a similar way to the Lowry-like allocation model of ITLUP by sequentially relating population to employment, service employment to population, and so on, but it uses linear regression rather than an entropy-based function. Equilibrium between demand and supply is achieved by calculating a locational surplus over the estimated land price and allocating land to the highest bidder.

SALOC (S) SALOC is an optimising model which does not explicitly represent travel patterns, although land-use allocations are dependent on calculated accessibilities (it can be coupled to a transport model if necessary). Given the pattern of employment location and travel characteristics, it allocates a single category of population to the zones of the study area in a way which satisfies a set of welfare goals based on accessibility, neighbourhood size, housing density and the cost of providing the necessary services. The model maps out a broad range of "good" residential locations which can be chosen to be reasonably robust against future uncertainties, if need be. It was originally developed for Stockholm but has been used in other cities also.

TOPAZ (T) This is a general spatial allocation model which allocates activities to the individual zones in an optimising way. In the ISGLUTI application the model determines the distribution of both employment and housing in the Melbourne region (population 2.7 millions) to minimise a weighted sum of the costs of the urban infrastructure and the incurred transport costs. The transport model is entropy-maximising and represents individual behaviour. It predicts the travel pattern which would result from the optimised land-use pattern so, unlike SALOC, TOPAZ can be used for most of the standard ISGLUTI tests, though its interpretation is somewhat different from that of the predictive models because of the way land is assumed to be released and taken up by developers. The model's main features are simplicity, efficient solution and modest computer requirements.

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