Computers in city planning: the simulation of urban development

Jörg Meise and
Michael Wegener
Battelle Institut e.V.,
Frankfurt/Main,
Germany

Summary The simulation model presented in this article has been designed to aid decisions for the long-range planning of the spatial urban development. The model allows the study of the physical, economic, and social consequences of various planning policies in the field of land use and transportation, and their interactions over time.

Keywords systems simulation, goal setting, deviation of needs, social and behavioral sciences, transportation, communication

Categories 8.6, 8.1, 3.3, 3.57

1. Urban development planning

Urban development can be defined as the long-range changes in the social, economic and physical environment of an urban area. The changes are the outcome of autonomous processes as well as processes which are induced and controlled by public actions. Urban development planning is concerned with the long-range planning of those actions. It includes spatial as well as a-spatial aspects. Spatial urban development planning deals with all those social, economic, and physical aspects that directly or indirectly affect distributions over space.

Cities are continuously faced with important decisions concerning the spatial development of their area: Where should a new housing project be located? Should more money be invested into streets? Or should subway construction be accelerated? Or parking garages in the city center be increased? Should more high-rise office buildings be permitted in the center? Today, many cities have recognized the weight of these decisions; they value space as a scarce resource which needs careful management; they see that the spatial arrangement of activities and efficient spatial interaction patterns do have strong implications for economic health, social welfare, and the quality of urban life.

This has led planners and politicians to conceive and publicly discuss schemes for the future spatial development of their cities. However, the discussion about such schemes, their comparison and evaluation on the basis of rational criteria is impeded not only by conflicting interests but more so, because social, economic, physical, and financial implications of the schemes are largely unknown. As a consequence, important decisions are paralyzed or, even worse, plans are adopted without prior careful analysis. It is this information gap the POLIS-Model is designed to fill.

2. The polis project

2.1 Objectives

Since 1969, Battelle Institute has been developing a model to support decisions for urban development planning. The model consists of three interrelated submodels, the functions of which are, respectively [Fig. 1]
– to forecast the growth of population and economic activity for the city as a whole [Forecasting Model]
– to show the consequences of alternative physical development plans for the urban area [Simulation Model]
– to increase the capacity for rational decisions between these alternatives [Evaluation Model].

Biography

Jörg Meise [born 1940] is a staff member of the Economics Department of the Battelle Institut e.V., Frankfurt. After receiving a degree in Architecture from the Univ. of Technology, Vienna [Dipl. Ing., 1963] and working in architectural offices, he studied City and Regional Planning [MCP, 1969] and Transportation Planning [Ph.D. cand., 1970] at the Univ. of California, Berkeley.

Michael Wegener [born 1938] holds a degree in Architecture of the Technical University of Berlin. After three years of teaching at the university's architectural school, he joined the Economics Department of the Battelle Institut e.V., Frankfurt in 1969.

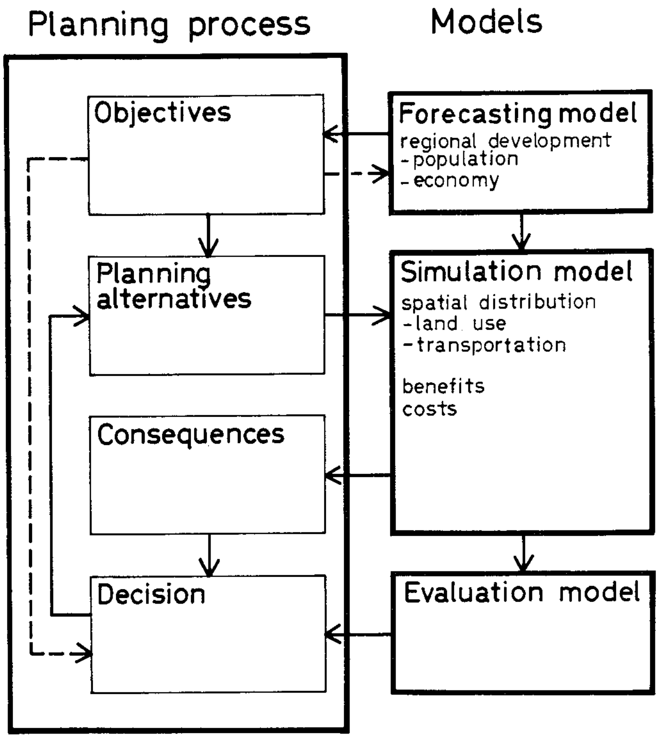


Fig. 1. Planning process and models

Presently, the simulation model POLIS is available for application. This model is designed to aid decisions for the long-range planning of the physical development of the urban area. It is designed to make explicit the interdependent consequences of alternative policy combinations for land use and transportation planning and to provide basic information for the long- and middle-range planning of the city budget.

Thus, the model is an attempt to mold the usually fragmented views of urban development and planning into an interrelated and consistent approach within a quantitative framework.

Certainly, this attempt can only be a first step toward an integrated model encompassing all aspects of urban development. It cannot replace detailed investigations into specific [sectoral] aspects of development. But it is certainly a step necessary to guide decisions on urban development which cannot be delayed until a comprehensive set of detailed partial models and urban planning data banks will be available. In addition, it can provide a useful coordinating function for the very development of both partial models and data banks.

2.2 *The city as a system*

In the POLIS model the city is represented as a complex, dynamic, spatial-temporal system. A system is dynamic if its elements interact. The interactions may form feedback loops, which return information to their origin. Many of the interactions in a city are circular and can be interpreted as positive, i.e. growth-augmenting, or negative, i.e. stabilizing feedback loops.

The mathematical representation of a dynamic system requires two types of variables: State variables refer to the elements of the system describing its state [stocks] at one instant in time. Flow variables identify interactions between the elements describing changes of the system over time. The relations between the variables are expressed in form of differential or difference equations.

The subsystems land use and transportation and the relations between them form the spatial and temporal system city. The spatial dimension of the system is derived by subdividing the study area into a set of zones, the temporal dimension by representing its development over several successive time periods.

The relationship between land use and transportation is well known and constitutes a basic concept of transportation planning: Based on forecasts of zonal land use future traffic flows between all zones are estimated. Subsequently, the transportation system is designed so as to serve this demand. By far less investigated are the effects of the transport system – i.e. the transport supply – on land use. These very effects, however, are essential forces in shaping the spatial urban development. In the POLIS model the variable 'accessibility' is taken to account for these effects. 'Accessibility' measures the relative locational advantage of a zone with respect to the activities in all other zones and the transport system available. If transport services of a zone are improved, its attractiveness for development increases. As a consequence, traffic flows to and from

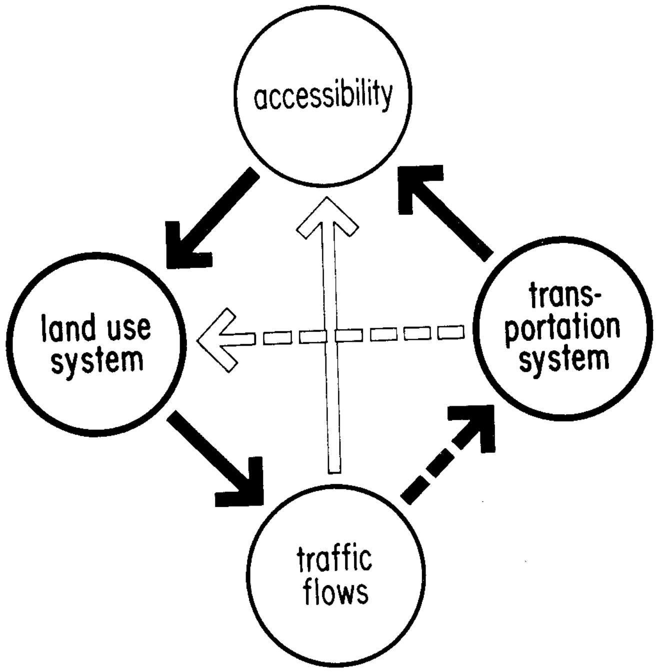


Fig. 2. Land use and transportation

this zone will rise, the transportation system has to be expanded, and so on . . .

This spiraling path of 'urban development' is halted when technological possibilities, resources or the willingness to utilize them are exhausted. Many large cities already have reached this limit: Traffic flows exceed the capacity of vital traffic arteries; zones with the heaviest traffic loads experience marked reductions in accessibility even if investments in the transport system are increased. At the same time, these investments consummate more and more of the scarce urban land [Fig.2].

2.3 The model

In its formal structure the POLIS model is a multi-stage digital simulation model of the complex, dynamic, spatial-temporal urban system. The modelling technique employed, mathematical simulation, has important advantages which make it especially suited for the purpose of this project. In contrast to analytical techniques it allows to represent large systems with a great number of linear or non-linear relationships in a simple and straightforward manner. As opposed to optimization techniques it does not require an objective function to be formulated from the beginning: Due to its experimental character, simulation adapts easily to the iterative problem-solving approach specific to socio-economic planning marked by conflicting interests, multi-dimensional goals and political issues.

The logical framework of the model consists of the subsystems and their relationships discussed above. In the model the status of the urban area is represented by a set of inventory data: The zones of the planning area [internal zones] are described by such data as 'population by age', 'employment by industry and size', 'buildings [dweling units] by age and condition', 'areas by land-use'; zones outside the study area [external zones] are represented by population and employment data. The transportation networks, i.e. public transit and road network connecting the zones are represented by their links. Link data contain, among others, information on type and length of the link, travel time, capacity, transit lines and train or bus frequency.

The base year inventory data provide the input at the outset of the simulation. They are subsequently subject to various changes: families expand, people move, grow older and die; employment increases or decreases, its distribution between the different industries varies with structural changes in the economy; dwelling units are built or remodelled, demolished or converted into office space; land uses are changed; streets or transit lines are constructed or improved, transport-service on other lines is expanded, reduced or discontinued. At the end of the simulation period all inventory data have obtained new values. The next period starts.

This process continues over a series of time periods until the planning horizon is reached. Sequence and magnitude of changes characterizing this process are controlled by assumptions which may be differently chosen for each simulation run. The assumptions comprise statements about the development of various technical and planning parameters as well as planning standards, cost and financial data and parameters that empirically describe different functional relationships. Total population and employment projections of the urban area – eventually the output of the Forecasting Model – are also external inputs to the model.

The most important of assumptions are the planning measures: The model accepts, besides institutional and administrative measures such as zoning regulations, some 60 different kinds of time-sequenced programs from the fields of housing, industrial development, education and social programs, recreation, retail, transportation, parking, public utilities, urban renewal and land reserve.

2.4 The computer program

The program for the POLIS model consists of two independent programs each containing several subprograms. The first program POLIS 1 contains the subprograms for the network analysis of a transport plan alternative [Fig. 3]. It produces a tape containing all necessary data about the transport networks as proposed in a planning alternative. With this tape as input POLIS 2 performs the actual simulation of the urban development.

The network analysis POLIS 1 employs familiar techniques of transportation planning: The network to be analyzed is updated from a base network and any network alterations [NETZV]; the 'network description' [NETZB] serves as the basis for determining both, the 'shortest path trees' from all internal to all internal and external zones as well as the travel times of the paths [BAUM, WEGE]. The procedure is repeated for both networks differing only in as much as in the transit network transfer times are taken into account while on the street network the time required for parking is added to the travel times.

POLIS 2 starts simulating urban development by computing accessibilities [ZUG]: Based on the distribution of land uses on a function of the travel times between the zones, accessibilities with respect to different activities are determined for all zones.

The spatial distribution of population and employment growth – the land use simulation – is performed by the subprogram ZUW. Population growth in a zone consists of two components: natural growth and migration. In the POLIS model zonal population growth is predicted by forecasting zonal housing construction. This is not only because of methodological problems in directly predicting intra-urban migration flows, but for theoretical reasons: The urban housing market is a tight one and will remain a seller's market for some time to come.

Given the various accessibilities and other characteristics describing the 'attractiveness' of a zone and the land available for development, the spatial distribution of housing construction and population is simulated.

Similarily, total industrial and service employment growth is distributed over the zones. Then, the gross floor area to be constructed, the building sites and the land to be developed for community facilities for the infra-structure and for public parks are determined. If excess demand for land occurs within a zone, adjusting actions will be initiated.

At the end of the period, population, employment, dwelling units, land uses, and land available for development will have reached new levels due to construction activity, natural population growth, changes in space requirements, shifts in dwelling unit occupancy, demolitions of buildings, and so on.

Next, traffic flows between the zones are computed from zonal employment and population data [FAHRT]. Trips using the two transportation networks are determined according to a modal split function and, finally, assigned to the networks [UMLEG]. If links are overloaded, congestion occurs which causes traveltimes to be increased.

2.5 *Results of the simulation*

For each period, the results of the simulation are presented in tables and diagrams showing frequency distributions of travel times, modal split and link loads. Also, computer-printed maps can be called for which show the spatial distribution of various variables of interest. At the end of the simulation the development of land use and traffic is shown for the city as a whole.

In addition, broad categories of receipts and expenditures generated by the planning alternative are computed for the city and other groups [state and county agencies, transport authorities, users of the transport system, builders and developers, tenants]. Their cash flows are traced over the planning periods and subsequently balanced, discounted, accumulated, and compared with the respective balances of a hypothetical 'do-nothing' alternative. The 'do-nothing' alternative is a hypothetical alternative assuming no public planning actions; it serves as a neutral basis for comparison between alternatives.

Most important, for each planning alternative a set of

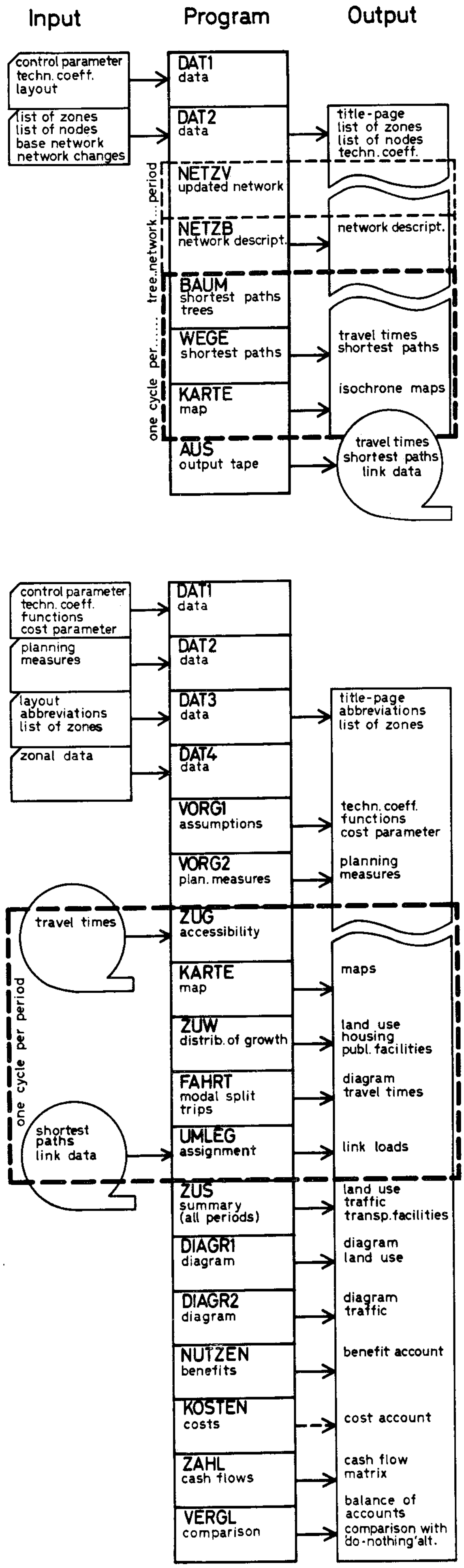


Fig. 3. The computer programs POLIS *1 and* POLIS *2*

BENEFIT ACCOUNT

System's Users

		OPNV	PKW	GESAMT
km/trip	[1]	15.78	13.06	13.69
	[2]	16.16	13.40	13.91
	[3]	16.50	13.69	14.14
	[4]	16.78	13.94	14.35
	[5]	17.01	14.12	14.52
travel time/	[1]	0.91	0.56	0.64
trip	[2]	0.93	0.57	0.64
	[3]	0.94	0.58	0.64
	[4]	0.96	0.59	0.64
	[5]	0.97	0.59	0.64
km/hour	[1]	17.39	23.12	21.24
	[2]	17.46	23.37	21.77
	[3]	17.51	23.58	22.16
	[4]	17.54	23.76	22.40
	[5]	17.54	23.91	22.57
waiting time/	[1]	0.13	–	0.13
trip	[2]	0.13	–	0.13
	[3]	0.14	–	0.14
	[4]	0.14	–	0.14
	[5]	0.15	–	0.15
walking time/	[1]	1.99	0.34	0.72
trip	[2]	2.00	0.34	0.65
	[3]	2.01	0.34	0.60
	[4]	2.02	0.34	0.58
	[5]	2.03	0.33	0.57
congestion time/	[1]	–	0.07	0.07
trip	[2]	–	0.08	0.08
	[3]	–	0.08	0.08
	[4]	–	0.08	0.08
	[5]	–	0.09	0.09
perc. seats	[1]	86.18	–	86.18
available	[2]	99.16	–	99.16
	[3]	107.52	–	107.52
	[4]	108.54	–	108.54
	[5]	106.10	–	106.10
vehicles/	[1]	0.67	76.92	58.13
100 persons	[2]	0.77	80.00	64.28
	[3]	0.84	83.33	69.33
	[4]	0.84	85.47	72.23
	[5]	0.83	86.96	74.09

Population, Industry

accessibility of . . .		OPNV	PKW	GESAMT
population	[1]	30.30	100.24	83.95
to pop.	[2]	30.86	101.27	88.12
	[3]	34.41	103.61	92.59
	[4]	40.09	107.23	97.41
	[5]	44.24	111.54	102.18
pop. [old]	[1]	30.59	–	30.59
to pop.	[2]	32.44	–	32.44
	[3]	41.74	–	41.74
	[4]	52.44	–	52.44
	[5]	53.21	–	53.21
pop. to	[1]	33.68	101.42	85.64
work places	[2]	34.04	104.66	91.47
	[3]	36.03	109.03	97.40
	[4]	39.47	114.76	103.75
	[5]	42.92	121.89	110.90
pop. [old]	[1]	32.10	–	32.10
to jobs	[2]	32.33	–	32.33
	[3]	34.86	–	34.86
	[4]	40.72	–	40.72
	[5]	46.44	–	46.44
pop. to	[1]	34.83	102.27	86.57
services	[2]	35.64	107.36	93.96
	[3]	38.02	113.81	101.74
	[4]	41.63	121.86	110.13
	[5]	45.22	131.57	119.56
pop. to	[1]	29.41	101.63	84.81
recreation	[2]	32.93	105.00	91.54
	[3]	38.21	108.37	97.19
	[4]	44.33	111.57	101.73
	[5]	48.39	114.09	104.95
business	[1]	33.55	100.25	84.71
to pop.	[2]	33.17	101.07	88.39
	[3]	34.16	102.78	91.85
	[4]	36.24	105.48	95.35
	[5]	38.15	109.05	99.19
services	[1]	60.97	101.70	92.22
to services	[2]	59.53	105.61	97.00
	[3]	58.94	110.56	102.34
	[4]	59.00	116.68	108.24
	[5]	59.38	124.09	115.09

Environment

		OPNV	PKW	GESAMT
fatal	[1]	0.04	1.18	1.22
accidents/	[2]	0.04	1.31	1.35
mio pop/day	[3]	0.03	1.43	1.46
	[4]	0.03	1.51	1.55
	[5]	0.03	1.59	1.62
injuries/	[1]	1.09	29.71	30.80
mio pop/day	[2]	0.94	34.00	34.95
	[3]	0.86	37.85	38.71
	[4]	0.85	41.24	42.09
	[5]	0.87	44.46	45.32
property	[1]	0.06	3.14	3.20
damages/	[2]	0.05	3.56	3.61
mio pop/day	[3]	0.04	3.91	3.95
	[4]	0.04	4.18	4.22
	[5]	0.04	4.42	4.46
air pollution:	[1]	0.09	29.25	29.34
CO in tons/ha	[2]	0.09	34.82	34.91
	[3]	0.09	40.37	40.46
	[4]	0.09	45.12	45.21
	[5]	0.09	49.48	49.57
air pollution:	[1]	0.02	5.12	5.13
NOX in tons/ha	[2]	0.02	6.09	6.11
	[3]	0.02	7.07	7.08
	[4]	0.02	7.90	7.91
	[5]	0.02	8.66	8.68
noise in DB[A]	[1]	55.18	65.18	65.68
*	[2]	54.18	66.18	66.56
	[3]	53.60	66.98	67.27
	[4]	53.53	67.61	67.87
	[5]	53.70	68.17	68.40
intrusion	[1]	89.93	107.17	107.14
**	[2]	89.93	127.58	127.52
	[3]	89.93	147.92	147.85
	[4]	89.93	165.31	165.22
	[5]	89.93	181.29	181.19
space	[1]	0.00	0.00	0.00
requirement	[2]	0.00	0.00	0.00
	[3]	0.00	0.00	0.00
	[4]	0.00	0.00	0.00
	[5]	0.00	0.00	0.00

OPNV = Public transit PKW = Private car GESAMT = Total [average of OPNV and PKW] PKW [1968] = 100 * 1968 = 55 [OPNV], 65 [PKW] ** 1968 = 100

Fig. 4. Benefit account [transportation system] 1968–1993: system's users [left]; population, institutions, industry [middle]; environment [right]

benefit accounts is developed to assist in evaluating and comparing the plan alternatives. Because of the central importance of evaluation within the simulation, it will be discussed in more detail below.

2.6 Evaluation

The purpose of evaluation is comparison among alternatives to identify that bundle of planning measures which best serves the objectives of a community given the recources available. Evaluations occur implicitly in all phases of the planning process, from the first conceptualisation of alternatives, their selection for further testing and development to their analysis and final comparison.

The POLIS model is to provide the information necessary for these evaluations. Experimentation with the simulation model is a means to initiate a learning process about the mechanism of urban development and the implications and interactions of planning measures and, thus, iteratively improve the basis for developing effective solutions. Within this process evaluation is a continuous activity employing logical, consistent, and reproducible procedures.

The benefit accounts provide a major basis for the comparative evaluation of the plan alternatives. In these accounts the consequences of the alternatives are expressed by a set of quantitative performance measures or indicators and observed in their development over time. The presentation of a multitude of quantitative indicators draws a detailed picture of the physical, social, economic, and environmental aspects of the consequences. As an example, the benefit account of the transportation system is designed to show the consequences of a transportation alternative for different groups: the users of the system; the population, institutions, and business; and the environment [Fig. 4]. From the user's viewpoint, the quality of a transport system is characterized by service performance data: speed, reliability, safety, comfort, flexibility, seating, time spent riding, waiting, and walking, or lost in congestions. For the population, the institutions and the business, the quality of the transport system is expressed by the access to activities offered by the system: such as work places, people, retail, recreation or cultural facilities. In addition, an analysis of public transit accessibilities for minorities [the young, the old, the poor] with respect to various urban opportunities, illuminates specific aspects of social justice. Third, the quality of a transport system is quantified by its external consequences for the environment, air and noise pollution, safety hazards, impedance, space requirements, intrusion, destruction of urban neighborhoods, and selected aesthetic impacts.

The financial implications of the planning alternatives provide an additional basis for evaluation; cost accounts express the financial feasibility of alternatives, the relation between input and output and – in tracing the incidence of costs for different groups – distributional effects and aspects of equity.

The evaluation model which is being designed will, in its first implementation phase, systematically organize, present, and make comparable the many multidimensional consequences of the alternatives; in a later stage more sophisticated evaluation techniques may be employed with the ultimate aim to rank the alternatives according to some composite measure of utility.

3. Progress report

Development of the POLIS project was financed by the Battelle Institut, while the city of Cologne served as a test city. Development of the project is now being carried on with a research contract from the West-German Ministry of Town Planning and Housing.

As an example of the model's present state of development, Fig. 5 shows part of the output produced by a simulation run for Cologne. The model simulates the 'do-nothing alternative' mentioned above. Simulation begins in 1968 running in five periods of five years each up to 1993.

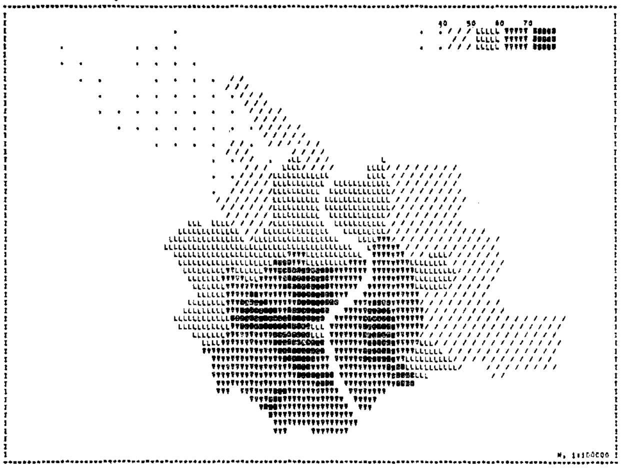
Presently, the main emphasis is given to the empirical task of calibrating the model on the basis of data for Cologne. At the end of this phase, several plan alternatives developed in co-operation with the department of city planning of the city of Cologne will be simulated. Upon completion the model will be attuned to some specific planning problems of the city. Together with the department of city planning, three problems have been defined:

- Comparison of different land use and transportation alternatives for the central business district with special respect to density restrictions imposed by traffic considerations.
- Investigation of possible density increases at rapid transit terminals.
- Comparison of alternative schemes for shopping facilities within the city limits under land use and transportation aspects.

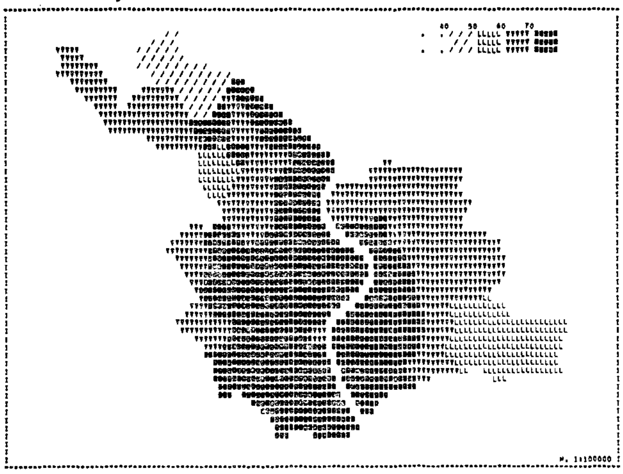
This will require the simulation model to be expanded to be sensitive to problems such as parking, retail location, land use succession, urban renewal. Work on these and other modifications of the model is in progress.

Fig. 5. Examples of a simulation output [Cologne]: accessibility; land available for development; net population density; travel times; 1968 [left] and 1993 [right]

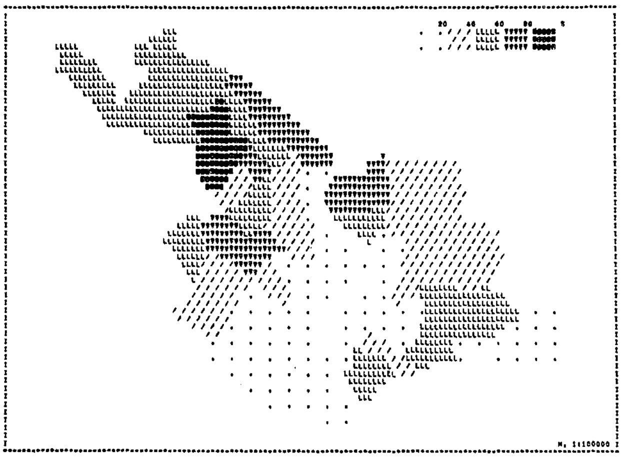
Accessibility 1968



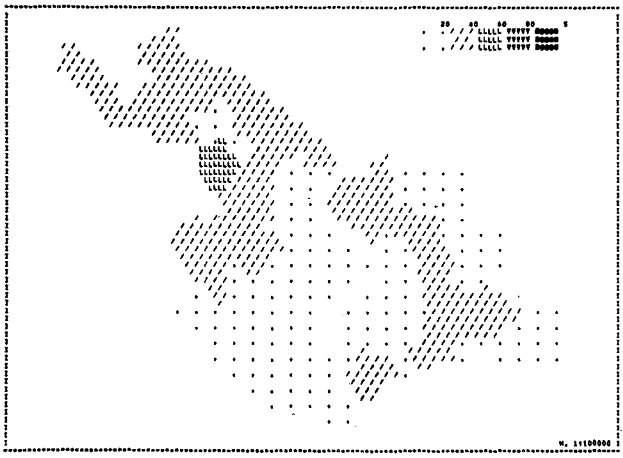
Accessibility 1993



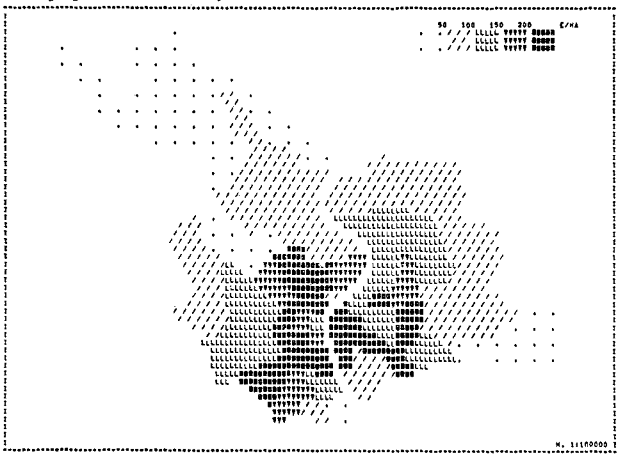
Land available for development 1968



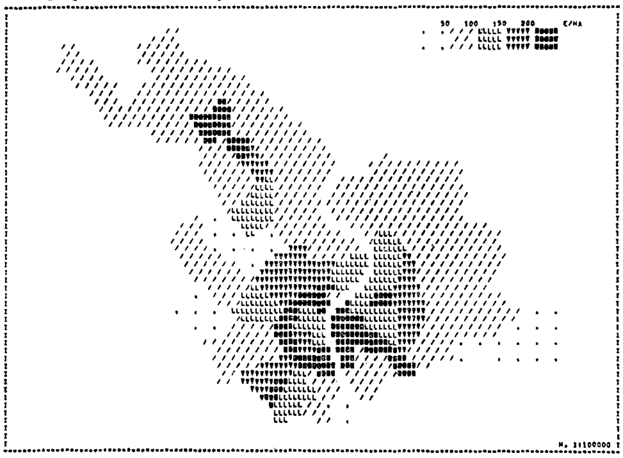
Land available for development 1993



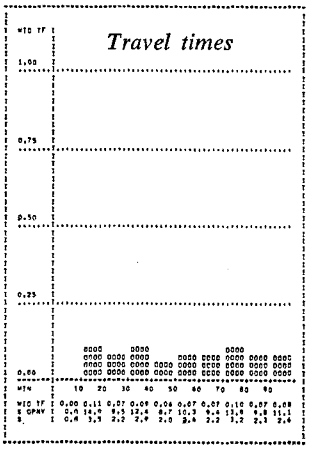
Net population density 1968



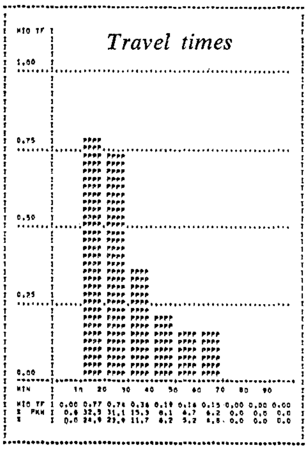
Net population density 1993



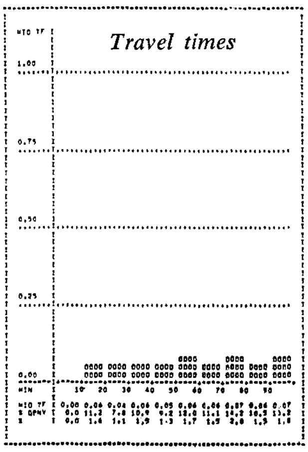
Public transit 1968–1973



Private car 1968–1973



Public transit 1988–1993



Private car 1988–1993