INTEGRATION OF GEOGRAPHICAL INFORMATION AND EXPERT SYSTEMS FOR EIA IN URBAN TRANSPORTATION PLANNING*

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This paper presents a decision support system, CALTEAS developed by the authors for demonstrating the integrated approach for EIA which identifies the different levels in urban transportation planning and the interaction among Landuse, Transport and Environment. The framework has three major characteristics to analyze the policies for improving the urban environment: multi-level Geographical Information System (GIS), models for analyzing the impacts of policies based on the LU-T-E interaction and an expert system for evaluation.

1. INTRODUCTION

Urban environmental problems

The urban dwellers experience a continuously degrading environment with all the economic and other privileges. Transportation sources make up a large percentage of environmental pollution generated by human activities in the urban areas. On a national basis about 60% of all CO emissions, and a less proportion of NO_x come from the transport sector, and mainly from road traffic(Table 1). More than 30% of total population in Japan are exposed to noise levels in excess of 65 dB(A) from road traffic noise alone. Land consumption by transport infrastructures may result in loss of green spaces or conflict with other land uses and also influence access and property values. Accident risks, consumption of energy resources and solid waste problems are some of the other major consequences of transport. Such impacts depend very much on the production, operation and maintenance of transport infrastructure, and the different modes (for example, air, rail, road) and technologies used. Then, in the planning and implementation of improvements in urban transportation, it is essential to carefully consider the conservation of environmental quality against the other economic benefits.

2. AN INTEGRATED APPROACH FOR ENVIRONMENTAL IMPACT ASSESSMENT(EIA)

The necessity for an integrated approach for EIA in urban transportation planning originates from two major reasons namely, i) the multi-level nature of the urban transportation planning process and ii) the interaction among the three elements Landuse, Transport & Environment.

2.1 Elements in Urban Transportation Planning

Multi-level aspects: In any urban region, the transportation planning and design are carried out at a number of levels of detail and decision making.

Table 1 AIR POLLUTION FROM TRANSPORT 1980-1987

	% of total man-made emissions (Transport Emissions in 1000 tonnes/year,1980)					
	1980			1987		
	NOx	CO	HC	NOx	CO	HC
USA	45% (9135)	70% (52500)	40% (8920)	44%	69%	33%
GERMANY	53% (1581)	65% (5623)	38% (646)	61%	73%	51%
UK	41% (946)	89% (7220)	16% (536)	46%	85%	23%

Source: OECD Environmental Data,1989.

Also, the urban transportation planning is not a unique task but a set of sub tasks of different scales and scopes. Table 2 shows the different analyses and decisions required at the different levels of planning. There is also much interaction among the levels, at all stages, before, after and during each project plan and detailed design sub task, consisted in the entire master plan cycle being implemented. While the project decisions flow top-down, the posterior impacts flow bottom-up between the levels.

Interaction among the urban elements: The understanding and analyses of the interaction among the Landuse, Transport and Environment (LU-T-E) as shown in Figure 1 are very important to effectively evaluate the impacts of improvements in urban transportation, especially at the master plan and project plan levels. The importance of each link based on the levels are described elsewhere (Seetharam, et.al.,1989).

2.2 Problems of Present Approaches for EIA

Present approaches for EIA in urban transportation planning deal with mainly the detailed design level, where only the direct environmental impacts such as noise and air pollution from road traffic are considered. The policies that can be tested at this level are limited in number and effectivity. So, in order to conserve the environment

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more effectively, it is necessary to do the EIA at the project plan and master plan levels too. Then, in the environmental impact analysis at these levels which must be done at a much macroscopic level with estimates made over a longer period, not only direct but also the indirect impacts such as from changes in landuse must be included. But existing approaches lay a larger emphasis on the Landuse-Transport interaction (ISGLUTI, 1988), which is behavioral, than the pollution and policy links. Finally, the uncertainties at higher levels in the realization and location of the project and the alternatives which result in inaccuracies and arbitrariness in those evaluations should be explicitly considered.

2.3 Elements of the Integrated EIA

By combining the multi-level aspects and the LU-T-E interaction of the urban transportation planning in the EIA, it will be possible to meet some of the typical requirements for environmental analysis in urban transportation planning. The analyses explicitly consider the non-behavioral, pollution and policy links in the Transport-Environment and Landuse-Environment interactions, thus satisfactorily representing the planning process, described earlier in another paper by the authors (Seetharam, et.al. 1989). For example, at the detailed design level, only the direct environmental impacts from landuse and transport are considered in the EIA. Here, only immediate counter measures such as anti-noise walls can be tested.

At the project plan level, the environmental conservation policies include traffic control measures such as removing through traffic by route design, which are effective over a wider area. They can often be combined with schemes which improve the environment, like designating pedestrian-only areas or simply restricting the movement of heavy vehicles in *residential zones*. There are also other options such as road pricing, etc. All these in turn affect the road traffic and change the congestion levels, which affect the pollution in many related areas. To really test these policies, the environmental impacts must be simulated after the traffic assignment is done. Hence, here the Transport-Environment interaction will be the main focus.

At the *master plan* level, long term policies such as improving the network structure, not only change the travel demand, but also affect the location choice of firms and households. Similarly, zoning policies or taxing for pollution, affect the location of firms and households, which then affect the travel demands. So, the EIA at this level must focus on all the interactions.

Thus, the contents of the integrated *EIA* at the different levels of planning is different as shown in Table 3. The type of analyses required at the detailed design level are more microscopic, while at the master plan the macroscopic analyses are sufficient for evaluating the long term impacts of the alternatives.

Table 2 LEVELS IN URBAN TRANSPORTATION PLANNING

	MASTER PLAN	PROJECT PLAN	DETAILED DESIGN
Plan Coverage	Urban Scale	Local Scale	Design and *Implementation*
Plan Contents	*Network design *New Transport modes, etc.	*Traffic control over a large area, etc.	*Road design *Signal control *Noise wall,etc.
Plan Period	20 Years	10 Years	Based on proposal
Map scale	1:100000 or less	1:10000 ~ 25000	1:500 ~ 2500
Forecast of socio-economic situation	*Changes in population, employment,landuse & travel demand	*Changes in travel pattern, road traffic	*Hourly variation of traffic by mode
Policies for improving the Environment	*Wide area measures *Ring roads, *Mass Transit	*Route Improvement, *Area pricing	*Local measures, *Road alignment, *Bus lanes

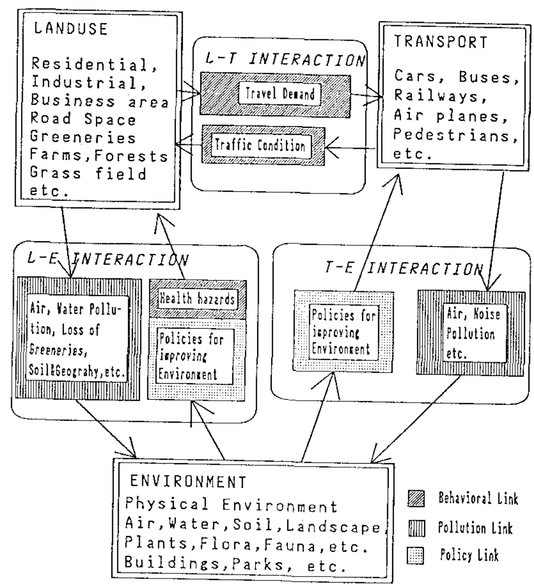


FIGURE 1 ENVIRONMENT-LANDUSE-TRANSPORT INTERACTION

2.4 Requirements for implementing the Integrated EIA

To support the aforementioned integrated EIA that addresses the multi-level process in the urban transportation planning and the interaction among the levels, there is much need for a wide variety and large volumes of data for the various analyses involved. A computer aided system will be indispensable to rationally support these requirements which can be summarized as follows:

Table 3 CONTENTS OF THE INTEGRATED EIA FOR THE DIFFERENT LEVELS

Steps in EIA	Levels in Urban Transportation Planning: Master Plan	Project Plan	Detailed Design
Scope of Project & Project Alternatives	*Network Planning, etc. *Mass transit, *Ring road, etc.	*Route Planning, etc. *Area pricing, *Rerouting, etc.	*Road Design, etc. *Anti-noise walls, etc.
Identification of Impacts	*Environmental damage for the entire area	*Environmental Problems in a local area	*Pollution in the immediate surroundings
Measurement & Prediction of Impacts	*Long term,direct& indirect impacts *Impacts from changes in landuse,etc.	*Short term,direct &indirect impacts *Impacts from changes in traffic volume,etc.	*Immediate & direct impacts *Effects of anti-noise walls, etc.
(Interactions of focus)	*Landuse-Transport-Environment Interaction	*Transport-Environment Interaction	*Impact of Transport on the Environment
Assessing the Significance of Impacts	*Consider total emission of pollutants in each zone,etc.	*Consider exposed population in each block to pollution,etc.	*Consider actual values of air pollution at each location,etc.
(Examples of Environmental Indices)	*Aggregated over all groups of population	*Aggregated for each group of population	*Impact on each index for each group
Communication	*Use Expert opinions	*Use Public hearings	*Use home interviews

Multi-level analysis & data management: The multi-level planning process supported by the integrated EIA requires the efficient management of geographical data of different geometric accuracies and details as shown in Table 4 and summarized as follows:

a) Geographical data at different levels, namely with different geometric accuracies, uncertainties and details, are required simultaneously.

b) Depending on the particular analysis, the geographical data (for example, for a trunk road represented by a line in the higher level and a polygon at the lower level) available at one level (probably, the traffic volume at the higher level) need to be manipulated and combined with those at another level as shown in Table 4, in which case the spatial correspondence between the features at different levels (the line and polygon) must be explicitly considered.

Such requirements can be rationally handled if a unified data structure is applied to assimilate the data of different levels. It is also efficient to provide a spatial interpretation for the data manipulation and reduce the redundancy in data. For this purpose, a multi-level GIS is proposed in this paper which will be discussed later.

Fuzziness in the integrated EIA: The integrated EIA also identifies the different types of uncertainties in the analysis arising from (i) the fuzziness in the spatial data: This arises from the ambiguities at the higher levels in the geographical data and the policy variables, for example, with a ring road plan - its location, capacity, etc.

(ii) fuzziness in the estimation: Existing approaches using quantitative modeling cannot support the wide variety of estimates, either due to insufficient knowledge for modeling, for example, methods for estimating the landuse changes at the detailed design level are not prominent while those for the higher levels (see Nakamura et.al., 1983; Miyamoto et.al., 1989) have been reported, or unavailability of sufficient information for calibrating quantitative models, for example, for the estimation of traffic situation at the detailed design level after a parking ban.

and (iii) fuzziness in the evaluation: The diverse priorities and opinions among the affected groups and decision-makers about the various impacts of a policy must be carefully considered in the EIA. Existing approaches cannot easily handle them rationally.

The uncertainties are assimilated into the data base development, the modeling and the evaluation processes using the fuzzy models and the expert system, explained later.

3.COMPUTER AIDED LANDUSE TRANSPORT ENVIRONMENT ANALYSIS SYSTEM(CALTEAS)

The computer aided decision support system developed by the authors to demonstrate the implementation of the

Table 4 MULTI-LEVEL DATA REQUIREMENTS IN THE INTEGRATED EIA

Data used in the EIA	Geographical levels of the data: Higher <******************************> Lower		
Data Characteristics			
Plan level	*Master plan	*Project plan	*Detailed design
Coverage	*Urban area	<<>>A few zones	<<>>A few blocks
Map Scale	1:100000 or less	1:10000 ~ 25000	1:500 ~ 2500
Spatial Unit	Municipality zones	Street blocks	Buildings
Fuzziness	High	Medium	Low
Examples of Typical Data			
Socio-economic information	*Zonal landuse, population, employment,etc.	<<>>Block landuse, population, employment,etc.	<<>>Building use, household size, no.of floors,etc.
Traffic data & road information	*Annual traffic demand. *Location of trunk roads & expressways	<-->Daily traffic volume by mode. <-->Structure & location of major roads	<-->Hourly traffic volume by mode. <-->Structure & location of all roads
Environmental information	*Annual average noise level. *Distribution of impact in each zone	<-->Daily average noise level. <<>>Distribution of impact in each block	<-->Hourly noise level. <<>>Distribution of impact in each location
Policy information	*Landuse zoning *Ring road plan	====Landuse zoning ====Road location	====Landuse control ====Road location

Types of data manipulation across the levels: <<>> spatial aggregation & disaggregation, <--> sampling or statistical indicator, ==== transfer without change.

proposed integrated EIA is called Computer Aided Landuse Transport Environment Analysis System(CALTEAS). CALTEAS has been developed on the SUN workstation and applies ARC/INFO (1989) for managing the data base. The overall framework of CALTEAS is shown in Figure 2. There are three major subsystems namely, i) Multi-level GIS, ii) simulation subsystem for estimating impacts, and iii) Expert system based on comprehensive indices for evaluation of policies. The main features of each subsystem are discussed in the following sections.

4. MULTI-LEVEL GIS

4.1 Conventional GIS & its application in CALTEAS:

To efficiently handle a variety of spatial information in an organized manner, a Geographical Information System (GIS) is indispensable. For example, the distance from a building to the nearest road can be automatically estimated, to be used to forecast the noise levels or so on. A GIS can maintain different types of spatial informations as layers. The topology consisting of the geometric features such as points, lines and polygons sufficiently represents all two dimensional map features on a vector image. Raster images such as grid data can be also stored in the GIS. Then, for the same map, population, landuse, etc., can be stored as attributes of the features in the vector or raster images.

Conventional GIS approaches cannot efficiently address all of the requirements for multi-level data management shown in Table 4. The problems can be summarized as follows:

a) Basically geographical data of the different levels must be stored in separate layers since the differences in the geometric uncertainties at the different levels cannot be explicitly considered in the data structure. This increases data volume and redundancy.

b) To maintain consistency between the geographical data of different levels, the data corresponding to one level must be manipulated and combined with those of another level easily, for which the spatial correspondence between the levels is indispensable. In the conventional GIS, the spatial correspondence is established, by coding, that is, an attribute information relating each building and the block containing it, which is laborious. Also, its errors cannot be detected easily, because the spatial reality of the correspondence is not expressed graphically.

4.2 Data Structure and Special Functions

CALTEAS consists of a multi-level GIS database sub system based on ARC/INFO (1989). The data structure can assimilate map and attribute information of different scales and geometric uncertainties, supporting complicated spatial queries required in the analysis.

Data Structure: The data required for the analyses are obtained at different scales and details corresponding to the levels of planning. So, the data structure of the multi-level GIS has additional information, other than those required for representing topological relationships in a conventional GIS for the geometric features (point, line, polygon), as described below:

(i)Level Reference: First, the level at which each piece of geometric information was originally input is identified along with its geometric ambiguity through a fuzzy function. This concept is called the Level Reference. So, using this information we can generate the buffers representing the possible spatial extent of each feature as shown in Figure 3.

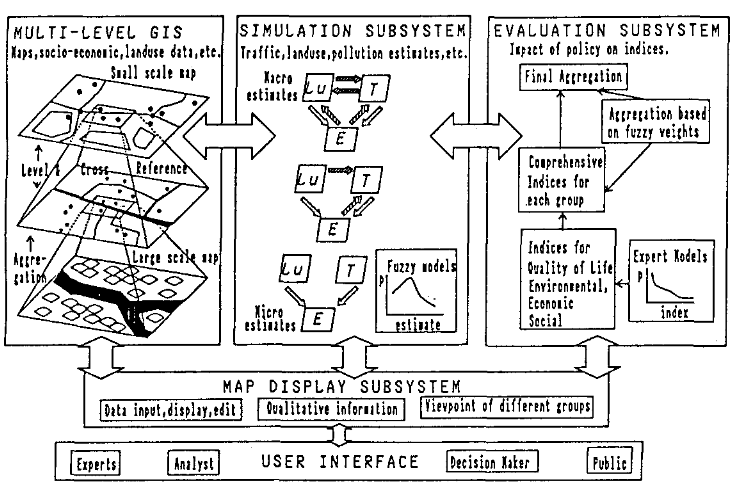


FIGURE 2 OVERALL FRAMEWORK OF CALTEAS

(ii)Cross Reference: The Cross Reference identifies corresponding geometric features at the other levels. For example, the buildings at the detailed design level belong to some block at the project plan level and a municipality at the master plan level. As shown in Figure 3, a line representing a road in the higher level may correspond to a set of small lanes, or a wide road, represented by a polygon at the lower level, and so on. This cross reference links both the geometric as well as attribute information of the corresponded features. For example, if a block at the higher level represents set of buildings at the lower level, the population attribute for the block will be the sum of all the populations in the buildings it represents.

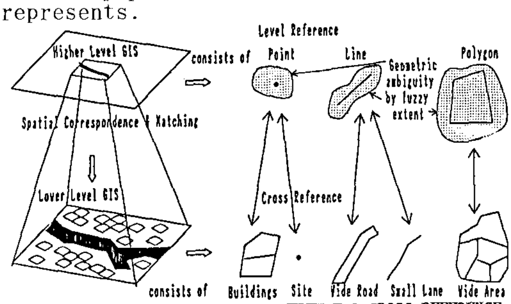
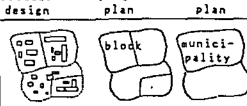
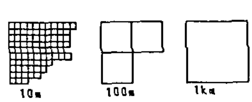
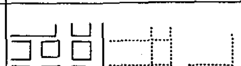
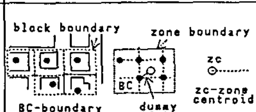
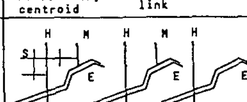


FIGURE 3 CONCEPT OF LEVEL REFERENCE & CROSS REFERENCE

Some of the typical approaches for establishing the level reference, cross reference and attribute aggregation as shown in Table 5 are based on: official designation of the area, requirements in the modeling & the map resolution. The cross references for the classifications based on official designation or modeling can be manually coded which is prevalent in the conventional GIS, although it is a very laborious task.

Special Functions of Multi-level GIS:
(i) The semi-automation of cross references between elements in two levels is possible by identifying the spatial correspondence between the two levels. For example, with area features representing the buildings at the lower level and at the higher level, the boundary of the block represented by an area feature, first a buffer is generated representing the probable extent of the block considering geometric ambiguity in its location. By overlaying the maps at the two levels, the possible buildings belonging to the block can be pre-selected automatically using a "polygon-in-polygon analysis" and displayed. Finally, from this selection, the desired buildings can be reselected interactively to represent the cross reference as shown in Figure 4. Such a pre-selection, interactive edit and reselection enhances the process of developing cross references very much. Once the cross references are established manipulation of attribute information such as, aggregation, disaggregation and transfer can be automated easily. With this function, cross references developed manually elsewhere can be displayed and their errors can be edited, if any.
(ii) The same feature can be used for spatial query among the different levels, such as the location in the lower level of a point belonging to the higher level.

TABLE 5 APPROACHES FOR AGGREGATING GEOGRAPHICAL DATA

data type	Basic principle for Level Reference, Cross Reference	examples: detailed design	examples: project plan	examples: master plan	(Aggregation Procedure), Commands in GIS
Map data Polygon info. e.g. buildings parks	Official Designation - buildings - blocks - municipalities - .		block	munici-pality	(boundary aggregation) DISSOLVE, GENERALIZE in ARC/INFO. (Preparata, 1988)
	Grid size 10m grid - 100m grid - 1km grid	 10m	100m	1km	(occupancy in a grid>50% of area) FREQUENCY in ARC/INFO.
Line info. e.g. roads, railway lines, etc.	Map resolution_ no explicit level/cross references represent roads, tracks by center line, omit narrow, short links at higher levels				(use tolerance to reduce intersecting arcs, simplify lines) CLEAN in ARC/INFO.
	Application Modeling_ streets, roads - network in traffic assignment - network in models at higher level	 block boundary; BC-boundary centroid	zone boundary; BC; dummy link	zc; zc-zone centroid	(network at each level is digitized independently) networks can be matched spatially with IDENTIFY in ARC/INFO.
	Official Designation_ small roads(S), major roads(M), national highways(H), expressways(E), etc.	 H M S E	H M E	H E	(Filter H,E at higher levels) Only the large scale, detailed map is necessary Spatial correspondence for S,M aggregated into nearest H roads.

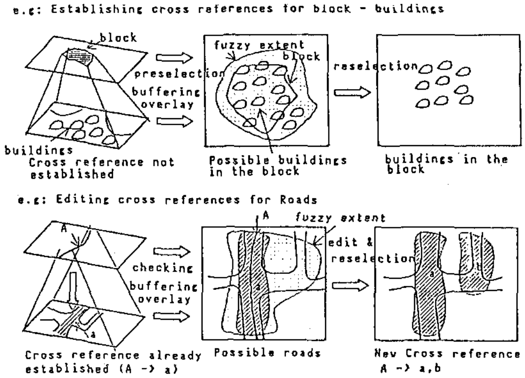


FIGURE 4 SPECIAL FUNCTIONS OF MULTI-LEVEL GIS

(iii) It is also possible to represent the spatial relationship(e.g. distance to nearest road) considering the geometric ambiguities in the features.
(iv) By applying boundary aggregation techniques as referred in Table 5, the geometric features at higher levels can be automatically generated.

4.3 Advantages of the Multi-level GIS: The advantages can be quickly summarized as follows:
a) Spatial correspondence is established using buffering and other matching techniques to maintain the consistency and links between those maps, with much less errors and data redundancy.
b) Simultaneously maps are available at different levels along with the socio-economic and other attribute informations.
c) Map data with different geometric details and uncertainties are created as are required in the application since some of the features for higher levels can be automatically created.

5. FUZZY MODELS AND EXPERT SYSTEM

5.1 Fuzzy Modeling in the Simulation Subsystem

A wide variety of estimates are required in the integrated EIA. In some situations statistically reliable quantitative estimates may not be possible due to insufficiencies either in the data or knowledge for modeling. For example, to evaluate the impacts of a "ban on trucks" on a quantitative index like "noise pollution" with a pollution forecasting model, the traffic volumes must be estimated. Such traffic assignment models for estimating traffic volumes mainly at the higher levels are prevalent. Although some models exist for the estimations at the detailed design level, the required data to calibrate them are not easily available. Whereas, the estimates for the changes in traffic volume can be obtained from experts in a qualitative manner as shown in Figure 5. Using fuzzy inferences, the knowledge from experts can be utilized along with other information, such as the distance to the nearest road, share of heavy trucks, etc., and the noise pollution near a building can be qualitatively estimated.

Other Advantages of fuzzy modeling
1) The effect of the uncertainties in the estimates on the EIA can be evaluated since the fuzzy modeling approach explicitly considers these uncertainties.
2) The spatial ambiguities in the geographic data and planning variables at higher levels, such as the location of a planned road, used in the analyses can be easily accommodated in the fuzzy modeling approach, since they are represented by fuzzy extents in the level references for corresponding features in the Multi-level GIS.

5.2 Expert Models in the Evaluation Subsystem

The Evaluation subsystem of CALTEAS consists of expert models for evaluating the policies and decision analysis using comprehensive indices developed with fuzzy inferences. Its overall framework is shown in Figure 6.

To comprehensively evaluate the policies it is important to consider their impacts on a wide variety of indices representing the "Quality of Life" that fall into three broad categories

a) Bio-physical Environmental Aspects - Noise & air pollution, Greenery, etc.
b) Social Aspects - Accidents, Emergency Services, Accessibility, Landscape, etc.
c) Economic Aspects - Household Expenses,

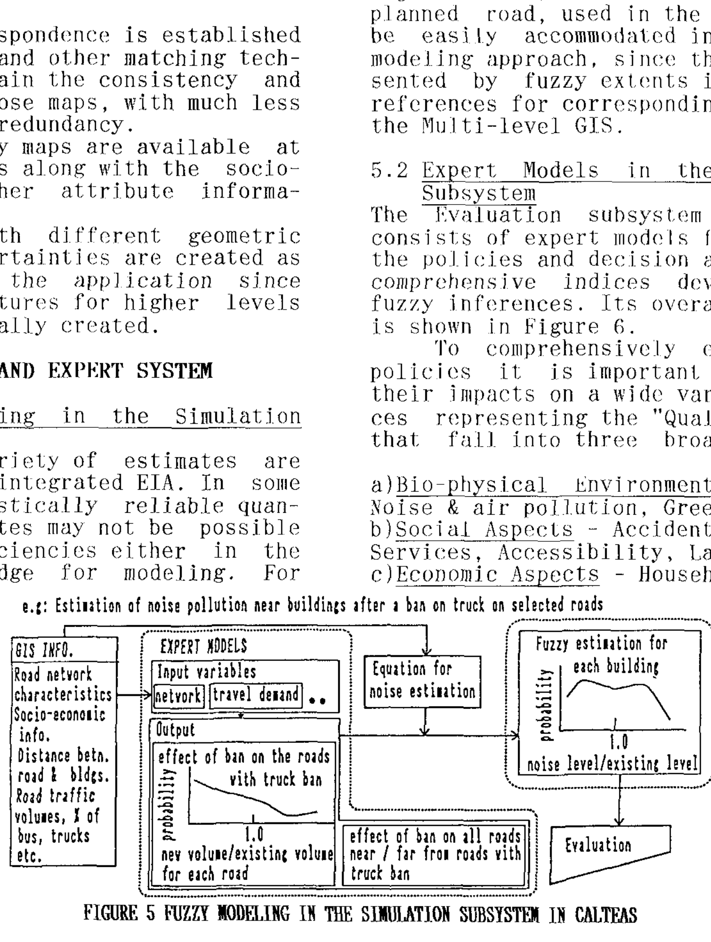


FIGURE 5 FUZZY MODELING IN THE SIMULATION SUBSYSTEM IN CALTEAS

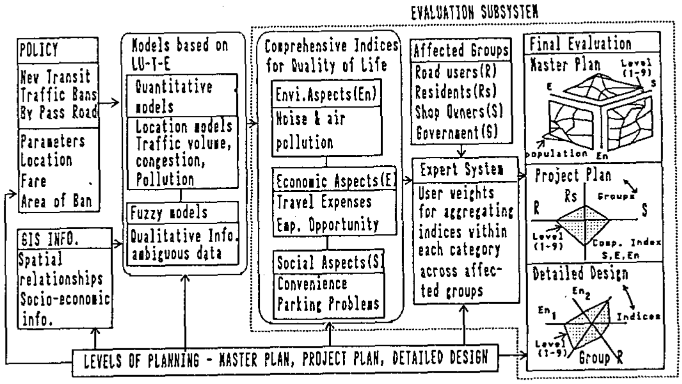


FIGURE 6 EXPERT SYSTEM IN THE EVALUATION SUBSYSTEM IN CALTEAS

House rent, Travel Expenses, etc.

These indices are estimated from the quantitative and fuzzy models based on the LU-T-E interaction in the simulation subsystem. The types of impacts to be considered and the statistical nature of the indices to representing them for evaluation vary with the level of planning. Generally at lower levels the detailed spatial distribution of the actual values of the indices representing the direct impacts will suffice, while at higher levels the indirect impacts will also have to be considered and the long term trends for the statistically representative values of the indices over a large area will be necessary.

The impacts are evaluated variably by each person in the affected population falling into one of four main groups: Road / Transport Users, Residents, Shop Owners (Business, Industries) and Transport Operators (Government).

To facilitate the aggregation of impacts on the different types of indices, quantitative and qualitative, also considering the fuzziness in the estimation, the severity of impact on each index is represented on a non-dimensional scale using an expert model. For example, the noise pollution estimated in dB(A) in the area is shown on a simple scale 1 through 9, where 9 represents the best situation of noise pollution, probably, 20 dB(A). A value 1 represents the worst situation of noise pollution, probably 90 dB(A). The expert model for representing the severity of impact on each index depends on the affected group (residents, shop owners, etc.) in the study area. Then, the "severities" for the indices can be aggregated for one affected group over the area to yield the distribution of population of that group exposed to different levels of severity 1 through 9 for each index.

Evaluation of policies

The objective of the final evaluation is to present graphical displays of the overall impact of the polices than some numerical values. The decision maker can interpret the results and make the final decision.

At the detailed design level, the final evaluation can be performed by inspecting the average and peak level of severity for each index, for each population group, as shown in Figure 6, before and after each policy.

At the project plan level, comprehensive indices representing each of the three broad categories (environmental, social and economic aspects) are obtained by calculating the fuzzy weighted average of the indices in each category where the relative priorities for the indices for each group are obtained by community participation or expert knowledges. The decision can be made from the graphs showing the trends of the comprehensive indices as shown in Figure 6 for a few years with and without each policy.

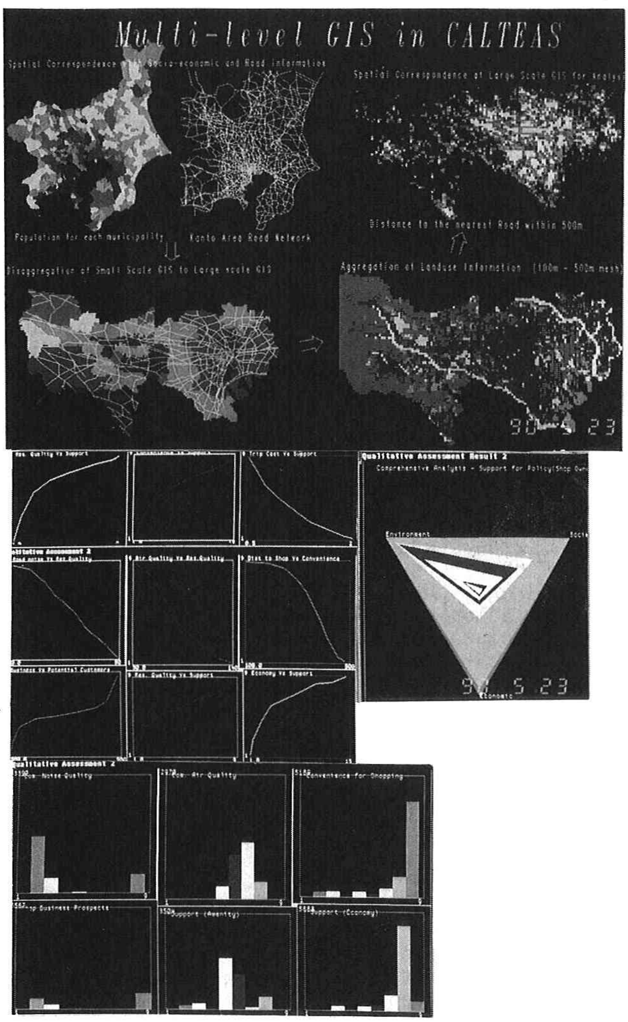
Finally at the master plan level, the weights for the opinion of different groups are decided by the decision maker or expert, and used in the further aggregation of the impacts across the population groups to estimate comprehensive values for all the levels of severity in each category as shown in Figure 6. Then, long term trends of these values for each policy can be used in the decision making. All these fuzzy weights can be modified interactively in CALTEAS.

6. APPLICATION

In order to demonstrate the capabilities of the multi-level GIS and the expert system in CALTEAS an environmental evaluation of banning trucks on selected roads at the master plan level was in the Tokyo Metropolitan Area.

First, as shown in Picture 1, the socio-economic, landuse, traffic and environmental database based on a 500m mesh was established using the multi-level GIS from data from different sources with varying geometric scales and accuracies. Originally, the population and other socio-economic data were based on the municipalities while the landuse data was based on a 100m mesh. The traffic volumes with and without ban on truck on selected roads, were estimated with conventional traffic assignment techniques.

Then, expert models were developed for evaluating the impacts of the policy on about 12 indices such as - noise, air pollution, convenience for travel, business potential, etc., for residents and shop owners. The impacts were aggregated across indices within each user group and across user groups. The results of the evaluation are shown in Picture 1.



PICTURE 1 EXAMPLES FROM THE APPLICATION OF CALTEAS

7. CONCLUSION

The integrated approach is essential for the comprehensive EIA in urban transportation planning. Multi-level GIS and fuzzy modeling approach in CALTEAS are imperative for supporting efficient and rational implementation of the integrated EIA. The user-friendly environment with the expert models in the evaluation subsystem is a major advantage to evaluate from the viewpoint of different sectors of community. The concept of multi-level GIS can also applied to other softwares while ARC/INFO has been used in this demonstration. Multi-level GIS and fuzzy modeling approach promise prolific applications not only in EIA or urban transportation planning but other general purpose planning and analyses.

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