Geographic Information Systems as Platform for Highway Pavement Management Systems

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Although existing highway pavement management systems (HPMSs) have so far served their intended specific purposes, they still have limitations. Many of these limitations come from the rigid mode of use of these systems, inefficient coordination between subelements of the system, and the lack of relevant information. Adaptation of geographic information systems (GISs) into this area, however, can help tackle many of these limitations. This is particularly true because of the realistic representation of real-world entities, the organized data structure, and the powerful analysis and presentation capabilities provided by GISs. A prototype HPMS is coupled with a GIS containing a land base of a selected study region. The resulting system is composed of (a) a spatial data base, (b) an attribute data base, (c) a general and a specific analysis module, and (d) an output generation module. Possible applications of such a system are then investigated. Several outputs representing different analysis stages and techniques mainly related to maintenance decision making are also presented. It is shown how this system provides a flexible tool for interactive analysis of policy tradeoffs, clear display of results, and coordination between related activities. The system can also improve data availability by spatially relating relevant information and facilitating data exchange between different administrative offices.

Highway management is a process, with several highway-related activities involving planning, design, construction, operation, maintenance, and research developments. Each of these activities requires frequent decision making to tackle various problems that are neither well structured nor unambiguous. Such problems are not unique, so a one-shot effort would be justified; neither do they recur frequently enough with sufficient similarity to subject them to rigid mathematical treatment. Moreover because of the mixture of uncertainty in the scientific aspects of these problems and the subjective and judgmental elements in their sociopolitical aspects, there is no wholly objective way of finding a best solution (*1,2*). Thus to effectively carry out the management process some sort of a decision support system (DSS) is essential (*1,3*). The functions of a DSS range from information retrieval and display, filtering and pattern recognition, extrapolation, inference, and logical comparison to complex modeling. Unlike information systems that are based on a sequential structure of analysis and decision support resulting in unique answers or at most scenario analysis, DSSs emphasize the importance of interactiveness and the direct involvement of the end user. This implies feedback between the different elements of the system. Under this definition many of the existing highway management systems would fall under the information system category (*2*). The use of DSSs can, however, vastly improve the decision-making quality and can move management toward achieving better use of limited highway resources.

One technology that is particularly promising for the highway management process is geographic information systems (GISs). These systems are gaining increasing importance and widespread acceptance as tools for decision support. GISs can assist in the preparation, analysis, display, and management of geographical data. It is in the analysis and display functions that GISs meet DSSs.

In this paper the applicability of GISs to the highway management process is discussed. A prototype GIS-based highway pavement management system (HPMS-GIS) was developed, with an emphasis placed on maintenance-related issues. This system couples highway performance evaluation and repair prediction models with GIS analysis and display capabilities. The results of a case study performed with this system are also presented to clarify some of the potential applications and advantages of implementing such a system.

WHY GIS FOR HIGHWAY MANAGEMENT?

Road networks are inherently geographic because they extend over wide areas and interact with various land topographies such as rivers, mountains, buildings, and other roads. Network components and events are also locational in nature. For example the extent and shape of a link, road intersections, accidents, and pavement condition cannot be completely defined unless the geographic location of the component or event is given. Thus spatial considerations in the analysis of different road activities are essential and can vastly improve the quality of the decision-making process (*4–8*). Analyses of such spatial considerations are difficult, inaccurate, and time-consuming without a GIS.

However highway management systems are usually based on a central data bank in which only descriptive data are handled. Moreover in most of these systems the data are not referenced to any geographic coordinate system, and thus diverse data types cannot be related in most cases. More advanced systems are also supported by computer-aided design and drafting (CADD) systems for generating maps. Neither of the two systems permits spatial operations on the data. GIS as a system with spatial analysis capabilities, besides having the attributes of the abovementioned systems, particularly matches the geographic nature of road networks.

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DEVELOPMENT OF PROTOTYPE HPMS-GIS

The application of an HPMS-GIS described here is not intended as a complete system but rather as an investigation of how to apply a system and the advantages of applying GIS to the highway management area. However the development procedure and elements of the described prototype system are equivalent to those required for a complete system.

The system described here was developed within the ARC/INFO environment (*9*) installed on a UNIX-based engineering workstation. This system integrates geographic analysis and modeling capabilities with a fully interactive system for the acquisition, management, and display of spatial and attribute data.

The Aichi Region in central Japan was selected as the geographic area of the prototype system. The city of Nagoya is located within this region and was selected for detailed representation in the system. An HPMS-GIS was then developed for this region. The system that was developed consists of several modules that interact with each other to carry out the required analyses and presentations. These modules are (Figure 1) (a) the data module for the spatial data base, (b) the data module for the attribute data base, (c) an analysis module, and (d) an output generation module. The contents of and the development procedure for each module are described in the following sections.

Spatial Data Base Module

The spatial data base module includes data describing the spatial distributions of geographic features in the study area. The basic features included are a selected road network and the region's boundaries. Other features were also included to represent a sample of the different land topographies that interact with the road network. Thus the final land base in the system contains the following features:

1. Borders of the Aichi Region,
2. Administrative boundaries within the Aichi Region,
3. National trunk roads within the region representing the study road network,
4. Other main roads located within Nagoya,
5. Land use in the area of Nagoya Port where two major trunk roads pass, and
6. Main water supply lines in the Nagoya Port area representing public utilities.

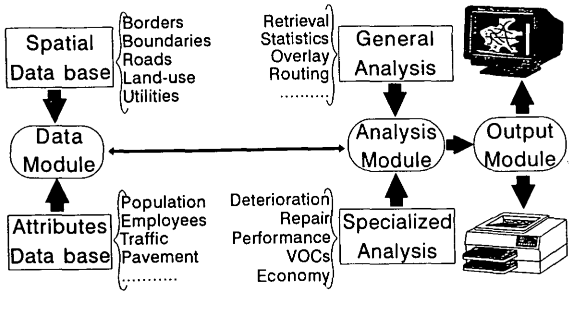


FIGURE 1 Modules of developed HPMS-GIS.

The only appropriate base maps that could be obtained were sets of paper maps; each provides a representation of one of the features to be included in the land base. These maps are originally produced by different authorities for different purposes and thus have different scales and geographic extents. Moreover some of these maps are not even referenced to any standard geographic referencing system, such as latitude-longitude. Thus to establish a common referencing system, common landmarks were selected and marked on each of the paper maps to be used later as reference ticks.

Each of the features was then digitized and stored in a separate coverage by using a suitable feature class (arcs or polygons). In the case of the national trunk roads in the city of Nagoya, each 1-km section was digitized as an arc connecting a beginning and an ending node. During digitization a unique identification (ID) number was assigned to each of the arcs representing highway sections, arcs representing utility lines, polygons representing administrative areas, and so on. The system was then run to generate topological relationships between the features in each coverage. During this step the length of each arc and the area of each polygon representing geographic features also were computed and stored. The reference ticks were used to transform all of the coverages so that all of them would have a similar extent and reference and thus could be perfectly overlaid. With this step done the land base is ready for the spatial analysis and display steps. Figure 2 shows a display of the road network within Nagoya as well as the boundaries and administrative borders. This display is obtained by overlaying different coverages by using location as a common key.

Attribute Data Base Module

The attribute data base module includes the representative nongeographic information associated with each administrative area, road section, land lot, and utility line. Each of these features is represented by the attributes described below.

Administrative Areas

Administrative areas are represented by area ID, area name, and road authority name. All of these attributes are entered and saved in one data base file.

Road Sections

Road sections are represented by section ID, route number, link number, road geometric data (such as kilometer post, number of lanes, lane width, and shoulder width), pavement data [such as pavement type, California bearing ratio, structural number, maintenance control index (MCI; an index describing pavement condition on a scale ranging from 10 to 0, with 10 for excellent condition and 0 for failed pavement), distress amounts, and last repair date and type], and traffic data (such as traffic volume, road capacity, percentage of trucks, directional distribution, and speed). These data sets are entered and stored in three separate data base files. Each record in any of these files contains one set of road data (geometric, pavement, or traffic) besides section ID, route number, and link number. These three variables are used as keys

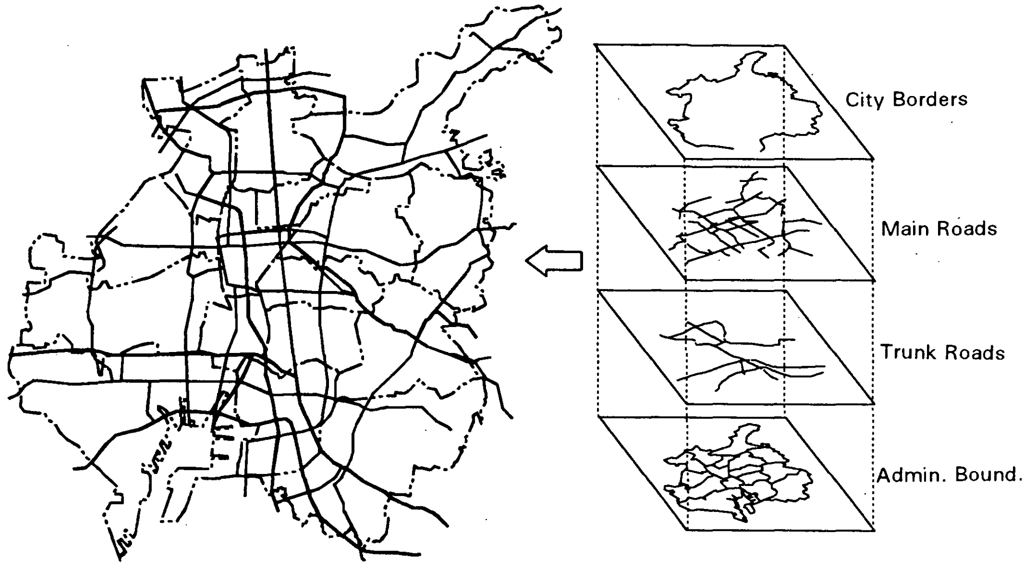


FIGURE 2 Overlay of road network and city borders.

for relating the records among these files (Figure 3). This separation is done to expedite the updating of data and to reduce the burden of maintaining and using files with large amounts of data. This can also reduce data redundancy in a well-structured data base.

Land Lots

Each land lot is represented by an ID number, land use type, and average land price. All of these attributes are stored in a single data base file.

Utility Lines

Each main water supply line is represented by an ID number, pipe diameter, the name of the authority responsible for its repair, and the year of planned future repair. One data base file is used.

Attribute Data Entry

Most of the attribute data were entered by using the conventional tabular format for data entry provided by the INFO data base manager (*10*). However some attribute data could be entered by first referring to a geographic feature on a screen displaying the corresponding coverage and then entering the attribute. For example the name of each administrative area could be entered by this technique (Figure 4). This allows for the direct use of thematic maps as the source of data without the need for coding. Therefore this technique reduces data preparation time and coding errors.

Special care was taken to ensure that the ID given to each data record in the attribute data base matched that given to the corresponding spatial feature. Once this match is accomplished the records in the attribute files can be linked to their spatial features, and thus to each other, by using location as a common key.

Besides the aforementioned attributes additional variables are included in some of the data files to accommodate output values from the analysis module. For example in the pavement data file, variables for expected future condition, repair type, costs, and after-repair condition are included.

Analysis Module

The analysis module consists of two categories of user-written programs. The first category is programs that run fixed sequences of standard ARC/INFO commands on user-selected coverage(s) or attribute data. This includes several programs written in ARC Micro Language (AML) (*11*) and INFO programing language (*10*). These programs help avoid the tedious work required for the step-by-step processing that must routinely be followed to perform a certain type of analysis or display, such as map composition, overlays, queries, data entry, update and retrieval, and general statistics. An example of this group is programs used to generate thematic maps with standard formats, attribute data, colors, titles, legends, and so on.

Besides the category mentioned earlier, for a GIS to be a useful tool like a DSS user-defined procedures in the form of specialized simulation and optimization models must be represented in the system (*3*). This can be accomplished by using the general-purpose programing language supplied within or outside of the GIS environment to represent these procedures. Therefore the second category of programs provides a specialized analysis related to highway management. This category includes programs for condition analysis, prediction of future deterioration of highway pavements, and the selection and simulation of repair alternatives under different budgets and scenarios. Programs for performance evaluation regarding the surface and service conditions of the highway system and changes in vehicle operating costs are also provided. All of these programs are written in FORTRAN 77 and can be called from within the GIS environment by the procedures written in AML.

Geometric Data

ID	Route	Link	KM	No. of lanes	Lane width	....	No. of lanes	Median	....
1	19	37	21	4	3.75	....	4	1.5	....
2	19	37	22	4	3.75	....	4	1.5	....
3	19	38	23	4	3.75	....	4	1.5	....
.	.	..	..	..	....	....	.	...	....
.	.	..	..	..	....	....	.	...	....

Pavement Data

ID	Route	Link	MCI	Pavement Type	SN	....	MCI	Repair type	....
.	..	..	...	..	.	....	...	.	....
1	19	37	7.8	AS	6	....	7.2	1	....
2	19	37	7.2	AS	6	....	7.0	1	....
3	19	38	6.5	AS	6	....	6.0	1	....
.	..	..	...	..	.	....	...	.	....

Traffic Data

ID	Route	Link	Volume	Speed	% Trucks	....	Volume	Capacity	....
.	..	..	.....	..	..	....	.....	.....	....
.	..	..	.....	..	..	....	.....	.....	....
1	19	37	20378	40	11	....	21765	24000	....
2	19	37	20378	40	11	....	21768	24000	....
3	19	38	18875	43	13	....	19666	24000	....

← Current Condition → ← Prediction →

FIGURE 3 Relational structure of attribute data base of road network.

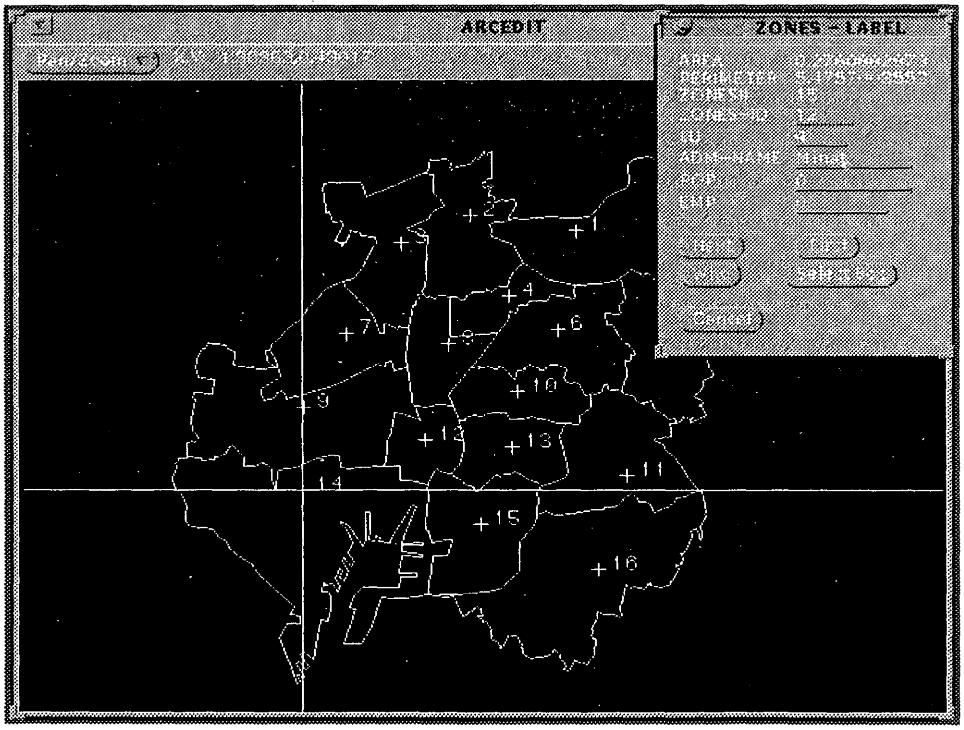


FIGURE 4 Interactive entry of attribute data.

The merit of running these specialized applications from within the GIS environment was realized through another set of programs that take advantage of the spatial analysis capabilities of the GIS. The outputs of these programs are passed to the specialized analysis programs automatically or by the user. Possible spatial manipulations that can be carried out by these programs involve (*12*):

1. Determination of patterns of data associated with locations and the manipulation of location-related data to derive new information from existing data, for example, the analysis of clusters of certain pavement deficiencies by the determination of patterns that indicate nonrandom occurrences and therefore require investigation for other relationships to understand the reasons for the clustering. The result of such an analysis can be fed back to the condition analysis program for example; and
2. Manipulation of data such as overlays, address matching, and routing topologically to create new information from the relationships among the data and the topological structures related to them. An example is finding the best detour path between two nodes on a network to avoid maintenance work on a certain link or overlay land use and road network coverages to get information on the land required for widening a certain route. Almost all of the specialized analysis procedures can benefit from the results of this type of spatial manipulation of the data.

Other required analyses that are not supported by any of the programs described earlier must be carried out interactively. This requires a certain level of skills with GIS. The development of a user interface can vastly facilitate this task. However the developed prototype system does not provide such an interface at the current stage. Nevertheless the ARC/INFO general-purpose menu interface built in to the system, known as ARCSHELL (*13*), can provide an easy pathway for accomplishing many such tasks.

Output Generation Module

The main function of the output generation module is to produce screen displays or hard copies of data and information generated by the analysis module. These outputs are usually on a thematic map or in tabular formats or data files. In general output generation can be done by using one or more of the analysis programs, textual queries, or direct geographic queries (by pointing at a feature on a screen map by using a mouse for example).

POSSIBLE APPLICATIONS AND ADVANTAGES OF SYSTEM

The prototype system that was developed can benefit the different activities within the maintenance management process as well as other highway-related activities. Some of the possible applications and merits of implementing the system are discussed below.

The way in which the data are captured and stored in the system can vastly improve data quality and their availability. Data inconsistency, data redundancy, and coding effort can be minimized. The data held within the system can easily be accessed by staff scattered in different places within and outside the local authority maintaining the system. If mutual data access is achieved the benefits from the wider availability of the data will also be reflected in the effort expended to ensure that the data are up-to-date and that their quality is maintained. There is no doubt that improved data quality and availability will positively affect the quality of decisions made on the basis of those data.

Automated cartography can replace the routine process of manually transferring some of the tabular information on road conditions to a base map as a step in understanding the data. With the powerful cartographic capabilities of GISs, this step can be done more extensively, accurately, and even more cheaply. On the other hand summary reports on conditions, problems, policies, impacts, and achievements that are typically presented in tabular and graphical formats can be supported or even replaced by thematic maps generated by the system. A picture or a map is easier to comprehend than a report. Such an understanding is the basis for more sensible judgment and decision making. Showing information in a map format is most suitable for clearly presenting abstract information to high-level decision makers, politicians, and groups of citizens. Without a GIS it is impractical and time-consuming to extensively show information by manual cartography.

The spatial analysis capabilities of the system can help to revolutionize many of the activities carried out within the highway management system. Spatial integration of the data and pattern determination capabilities can help in the development of sophisticated deterioration models that take into consideration a diversity of factors that may affect deterioration rates. These capabilities would also make it possible to enrich the decision-making process by incorporating other types of data that cannot easily be brought into the process without the ability to spatially relate the data. For example repair decisions that take into account accident analysis, the features of the land surrounding the road such as land use and price (for road widening), and the repair and the timing of installation of utilities embedded in the roadbed can be realized. This can vastly improve the cooperation and coordination between the different local authorities within and outside the highway administration, leading to greater efficiency. Even within the maintenance administration better interaction between offices with different tasks can be achieved because all staff can easily access the same data source.

Topological manipulation capabilities can be employed in developing a realistic simulation of traffic flows under different network conditions. This may help to assign traffic to the best detour routes during the repair of certain links of a road network. The capability of performing geographic queries directly from the display of outputs on the computer screen can also help in the interactive examination and evaluation of problems, policies, and consequences. This would achieve much of the interactiveness between the system and its user that is so strongly required.

Another possible application that could not be added to the prototype system because of time and software limitations is the dynamic segmentation of road networks. In this application each road-related attribute is stored in its own representation of the network, separate from the spatial configuration of the network. Segment boundaries in each thematic network would be defined by the variability of each attribute used in a map. Such a construct would minimize data redundancy while capturing data at any desired level of detail (*4,14*). This also eliminates the need for prior road segmentation.

APPLICATION OF DEVELOPED SYSTEM

The following sections present a sample application of the HPMS-GIS that was developed. The objective of the application is to show how this system can help in the decision-making process by showing various outputs and analysis results produced interactively.

The developed system was used to examine the performance and repair needs of the study road network by assuming different budget levels and repair policies. Several maps representing different stages and types of analysis were produced throughout the application. In general the outputs can be classified into three categories: data retrieval, data analysis, and data integration maps.

Data Retrieval Maps

Data retrieval maps are the counterparts of summary reports generated directly by querying a data base containing raw road data. Two examples of data retrieval maps are shown in Figures 5 and 6. Figure 5 shows the current road (pavement) condition in terms of MCI. Each road segment is highlighted by using different colors or patterns according to the category of its MCI. Summary statistics are also shown on the map. Such maps are routinely produced manually as a preliminary analysis step. The developed system can efficiently perform such tedious work.

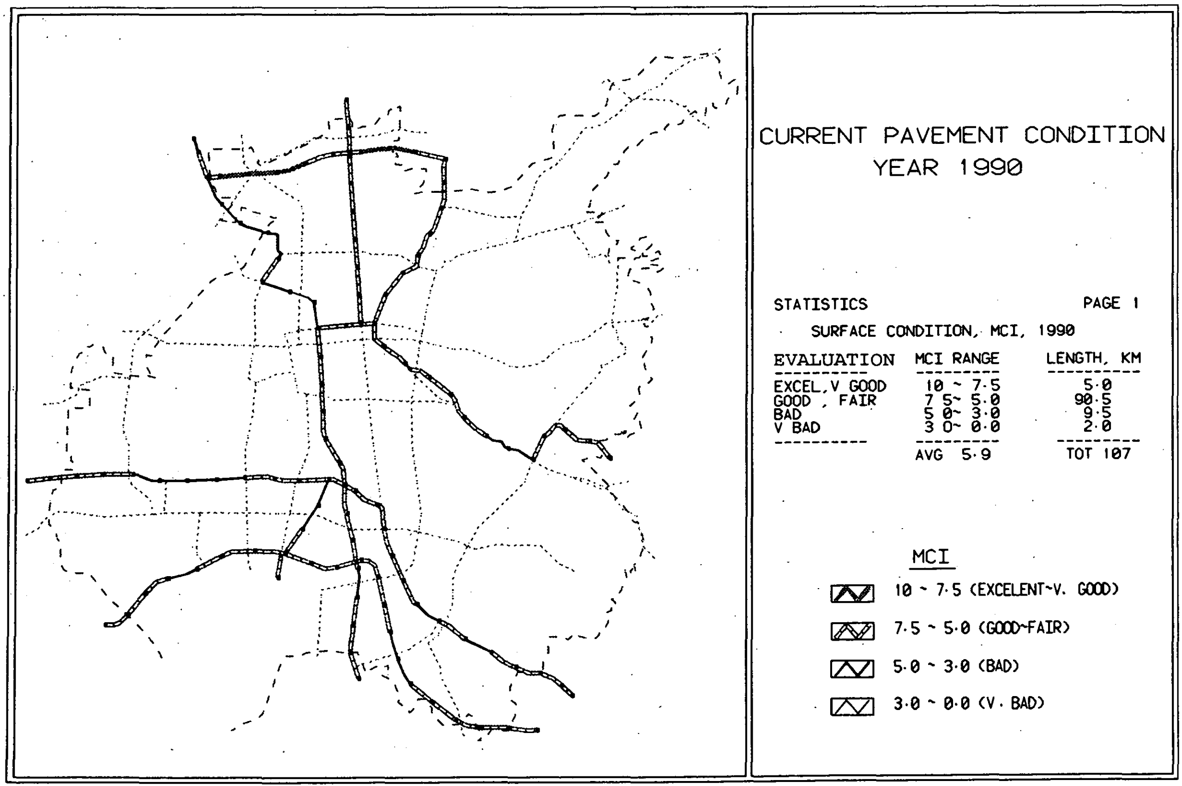
Figure 6 shows the current traffic condition in terms of the volume-to-capacity (v/c) ratio. A different technique is used to display segment attributes in Figure 6, in which the buffer width around the road center is used. The buffer width varies according to the v/c ratio, with wider buffers for higher v/c values. By using such a map it is easy to discover locations with low service levels that need widening or improvements. Also the nature of the traffic distribution throughout the network can be understood and better traffic management alternatives can be suggested.

An unlimited number of similar maps can readily be generated by using different data items or a combination of items from the road data base. Three-dimensional maps and overlays would also have been possible if the elevation of features were given related to a fixed datum.

The advantages of this category of maps are that they are clear, are easy to comprehend, can be intensively produced, and can facilitate data consistency checks.

Data Analysis Maps

Data analysis maps can be divided into two types. The first is conceptually similar to and has the same advantages as data retrieval maps, but data analysis maps use information resulting from the analysis module. Figures 7, 8, and 9 show examples of this type. Figure 7 shows the results of a maintenance needs assessment and project selection in which a limited repair budget equals 80 percent of full needs. Two data items are displayed for each segment: the type of required maintenance assessed at the end of year 1991 (shown numerically) and the segment if it is selected for maintenance in 1992 or is deferred (shown as a pattern). The evaluation of such maps by the end user can give good feedback from the system, leading to a fairer and more logical budget allocation. Figure 8 shows a comparison of the predicted surface condition over time if two budgeting scenarios are considered. A higher average MCI is predicted in the case of a decreasing allocation of the available limited budget over the budgeting period (front-loaded investment). Visual comparison of the maps shows that only those segments with high traffic volumes



STATISTICS PAGE 1

SURFACE CONDITION, MCI, 1990

EVALUATION	MCI RANGE	LENGTH, KM
EXCEL,V GOOD	10 ~ 7.5	5.0
GOOD , FAIR	7 5~ 5.0	90.5
BAD	5 0~ 3.0	9.5
V BAD	3 0~ 0.0	2.0
	AVG 5.9	TOT 107

FIGURE 5 Current pavement condition.

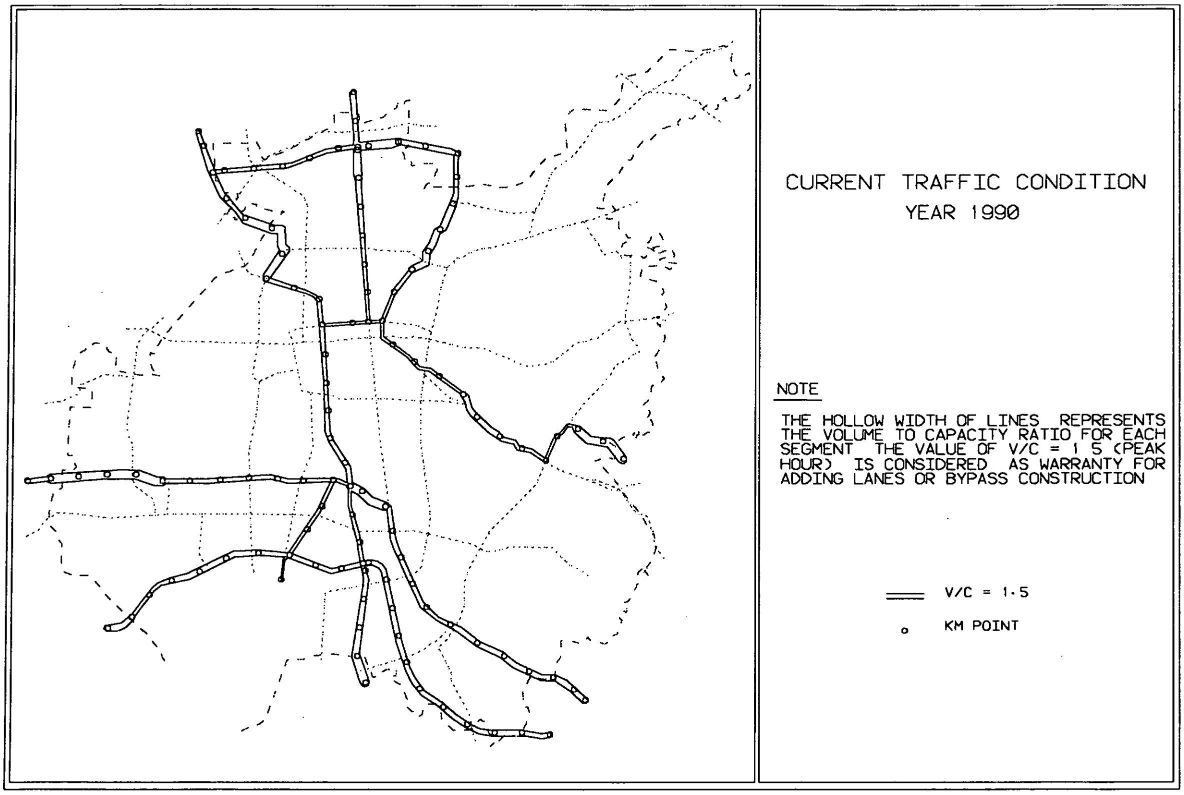


FIGURE 6 Current traffic condition.

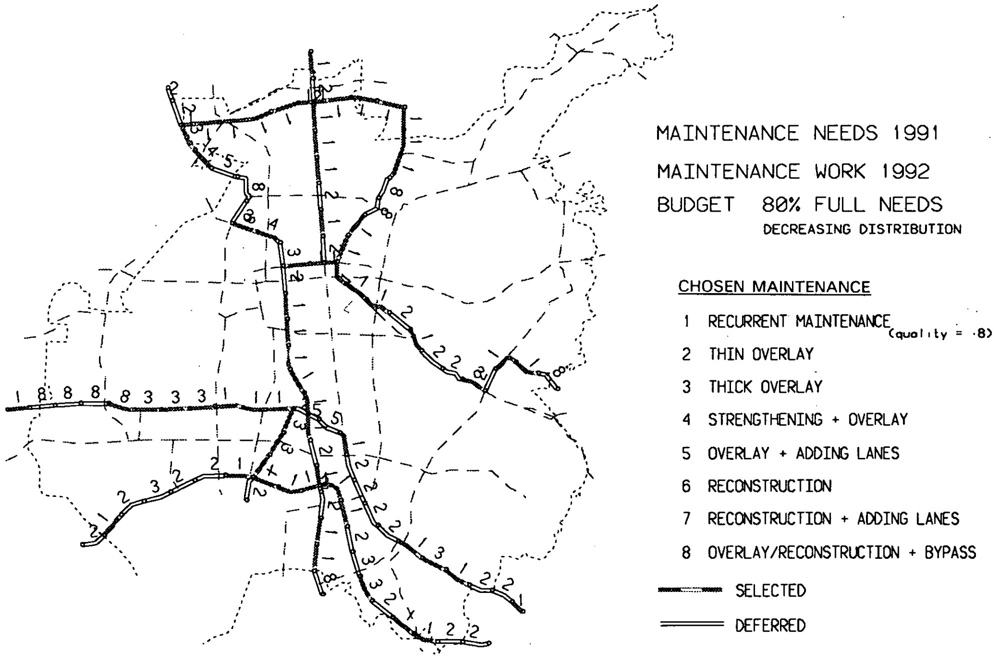


FIGURE 7 Display of predicted repair needs and selection.

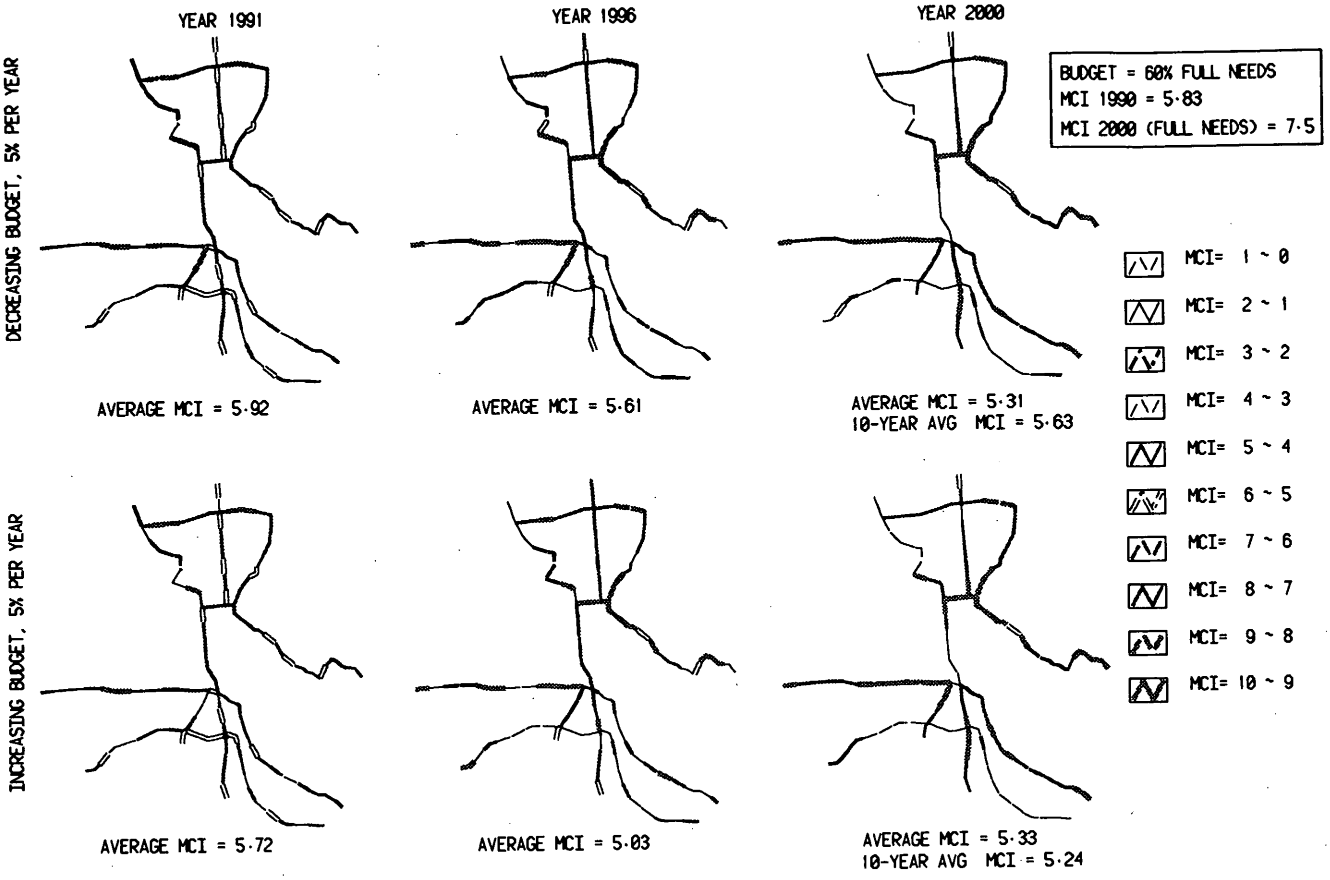
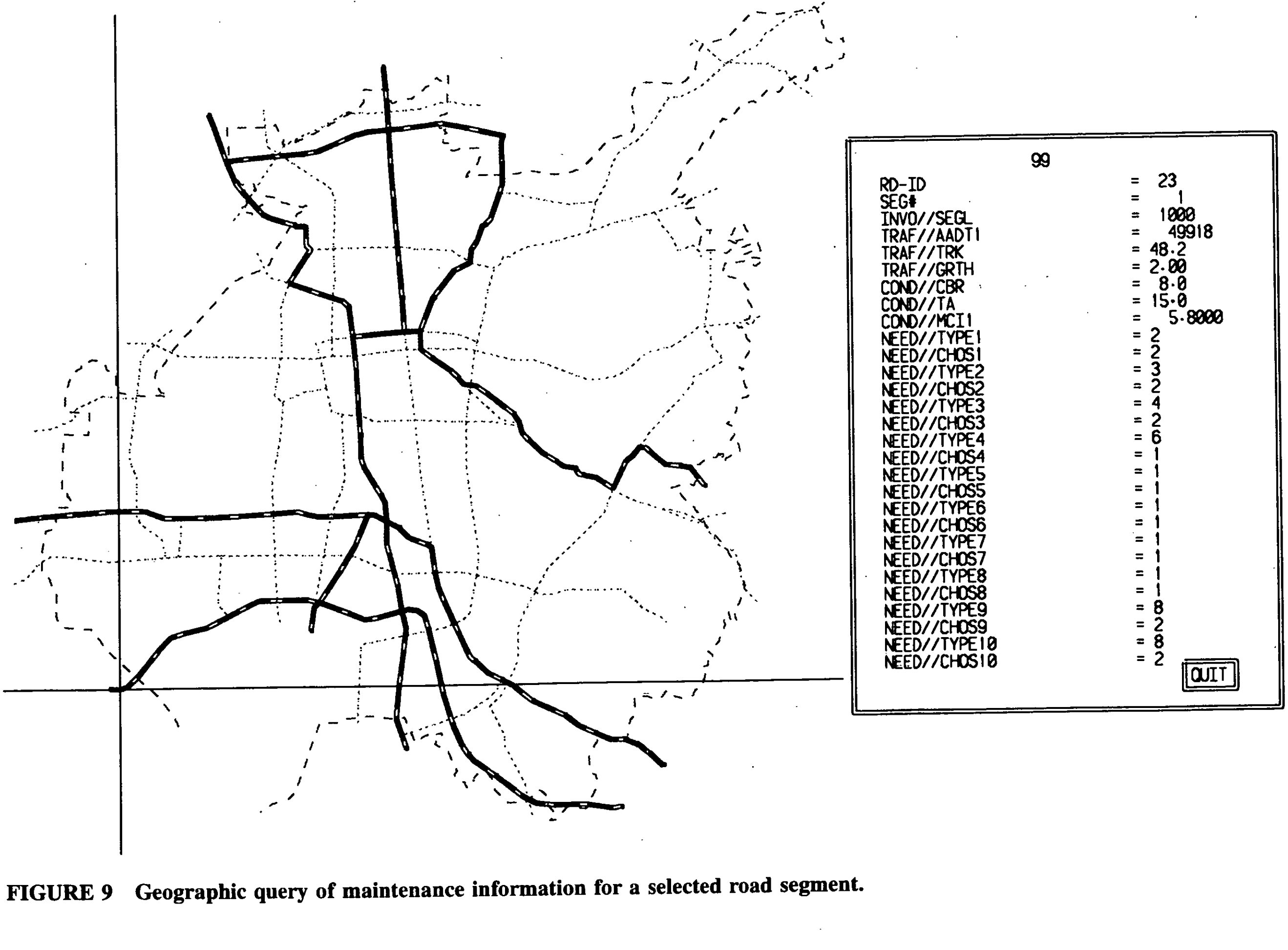


FIGURE 8 Comparison of predicted pavement condition under two different budgeting scenarios over time.



```
                 99
RD-ID                   = 23
SEG#                    =   1
INVO//SEGL              =  1000
TRAF//AADT1             =   49918
TRAF//TRK               = 48·2
TRAF//GRTH              = 2·00
COND//CBR               =  8·0
COND//TA                = 15·0
COND//MCI1              =    5·8000
NEED//TYPE1             = 2
NEED//CHOS1             = 2
NEED//TYPE2             = 3
NEED//CHOS2             = 2
NEED//TYPE3             = 4
NEED//CHOS3             = 2
NEED//TYPE4             = 6
NEED//CHOS4             = 1
NEED//TYPE5             = 1
NEED//CHOS5             = 1
NEED//TYPE6             = 1
NEED//CHOS6             = 1
NEED//TYPE7             = 1
NEED//CHOS7             = 1
NEED//TYPE8             = 1
NEED//CHOS8             = 1
NEED//TYPE9             = 8
NEED//CHOS9             = 2
NEED//TYPE10            = 8
NEED//CHOS10            = 2
```

FIGURE 9 Geographic query of maintenance information for a selected road segment.

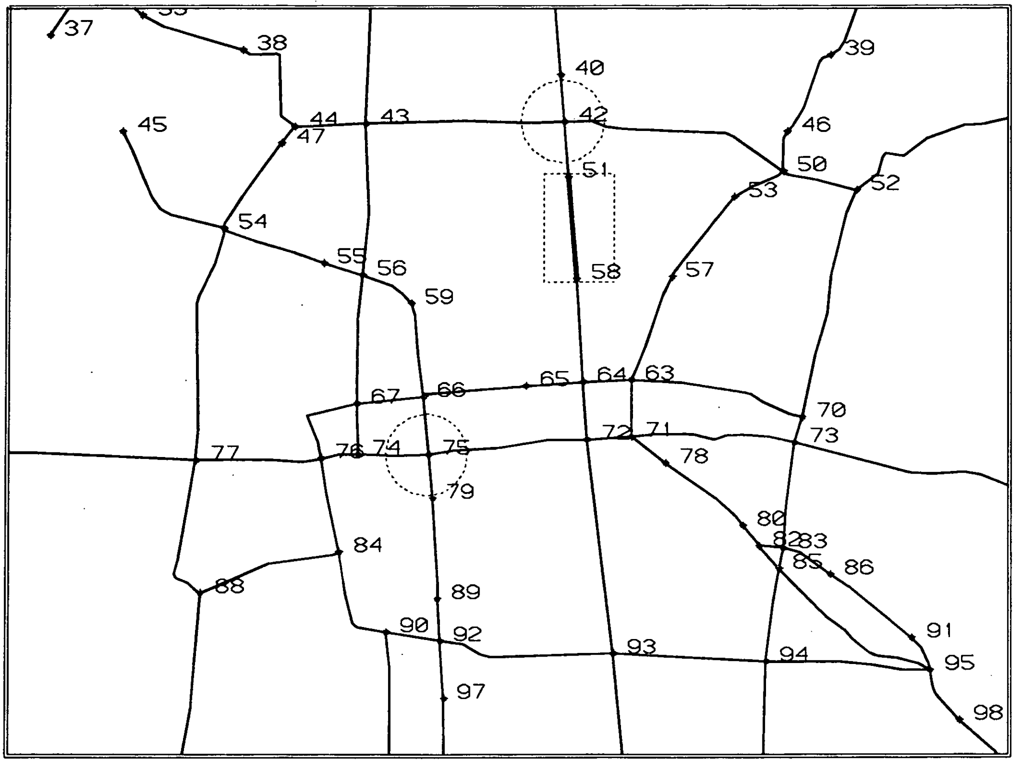
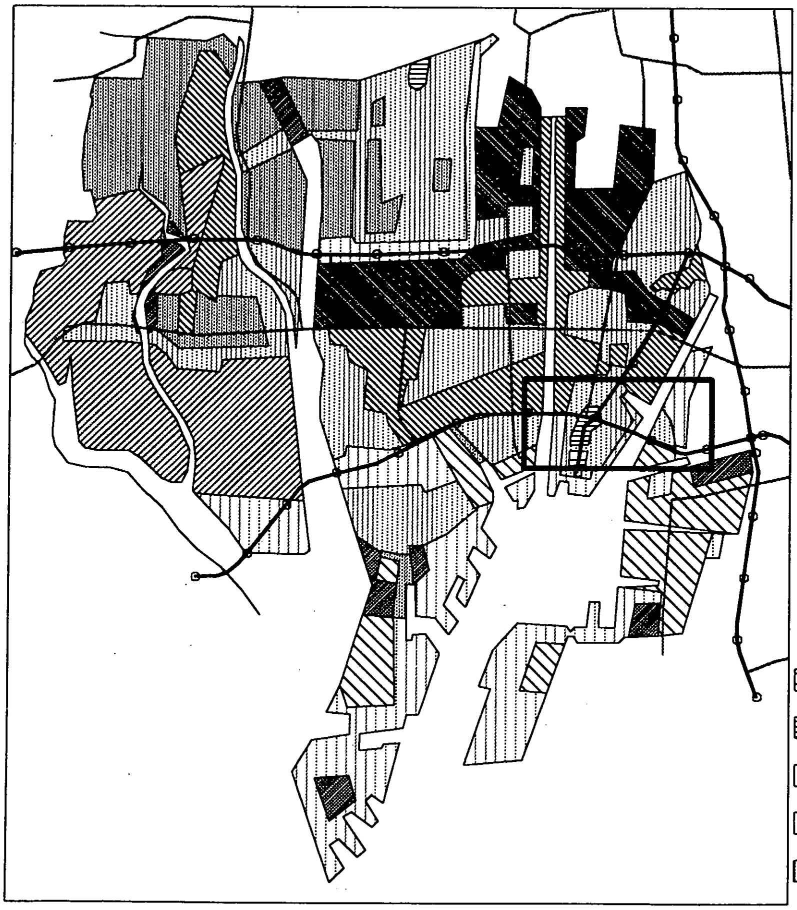


FIGURE 10 Search for best detour route during repair of a link.



LAND ACQUISITION COST IN THOUSAND YEN

RD-ID	SEG#	RD-LENGTH	LU-CODE	COST/M2	TOTAL COST
23	7	281·48	10	200·00	450377·6
23	7	226·84	10	200·00	362950·4
23	7	209·24	7	181·50	303819·4
23	7	198·09	4	330·00	522976·1
23	8	107·50	4	330·00	283807·9
23	8	453·31	7	181·50	658211·9
23	8	100·53	6	194·70	156588·6
23	8	77·29	7	181·50	112238·1
23	9	280·13	7	181·50	406758·9
23	9	108·09	9	116·30	100568·8
		---------			----------
		2042·55			3358297·7

▭	ORDINARY COMMERCIAL	▧	COASTAL INDUSTRIAL
▤	DISTRICT CEN COMMERCIAL	▧	INLAND INDUSTRIAL
▥	RESIDENTIAL - INDUSTRIAL	▩	DISTRIBUTION SERVICES
▥	ORDINARY RESIDENTIAL	▨	AGRICULTURAL
▦	EXCLUSIVE RESIDENTIAL	▩	PARKS AND GREENS

FIGURE 11 Land acquisition requirement for road widening.

have different MCI under each scenario. Figure 9 shows a different type of data query. A road segment is geographically selected on a map on a screen by simply pointing at the segment. A preselected set of information describing road ID, traffic characteristics, pavement design, and maintenance assessment and selection over the analysis period are displayed on the screen as a response to the query. Such a query technique can easily help in clarifying interrelated facts.

The second type of map under this category is that which uses an analysis based on the topologic features maintained by the spatial data base. A possible application is finding and evaluating alternative routes during the shutdown of a road segment for rehabilitation. This application utilizes information on link connectivity, network resources, and turning impedance between links to represent possible routes, directions, and traffic condition on each link. Figure 10 shows an example of this application when the end user is interacting with the system to search for the best detour routes for traffic between nodes 42 and 75 during the application of a planned repair on link 51–58.

Data Integration Maps

In data integration maps several coverages containing diverse types of data are overlaid, and attribute data are integrated by using location as a common key. The result of the overlay is a new coverage containing all spatial features and attributes originally contained in the overlaid coverages. Such an overlay can be useful for both theoretical analyses as well as practical considerations of the features surrounding the road.

An example of possible practical considerations is shown in Figure 11, which shows an overlay of land use and road coverages. The user is analyzing land use, area, and cost of the land area to be acquired along a road section to which a lane is planned to be added where the right-of-way was assessed and was found to be insufficient for the required widening. Figure 12 shows a map used for an analysis for land acquisition for bypass construction as an alternative to the addition of a lane. Figure 12 displays a three-dimensional map of land value in the proposed construction area. The minimum land acquisition cost can be then searched for by analyzing the profile of the land value along several possible routes.

Figure 13 shows an enlarged part of an overlay of roads and the main water supply network. The purpose of this analysis is better coordination between the timing of road repairs and planned installations and the repair of utility lines embedded under the roadbed. The results of this analysis can be fed back to the system as constraints on repair timing or used for communication with other public authorities.

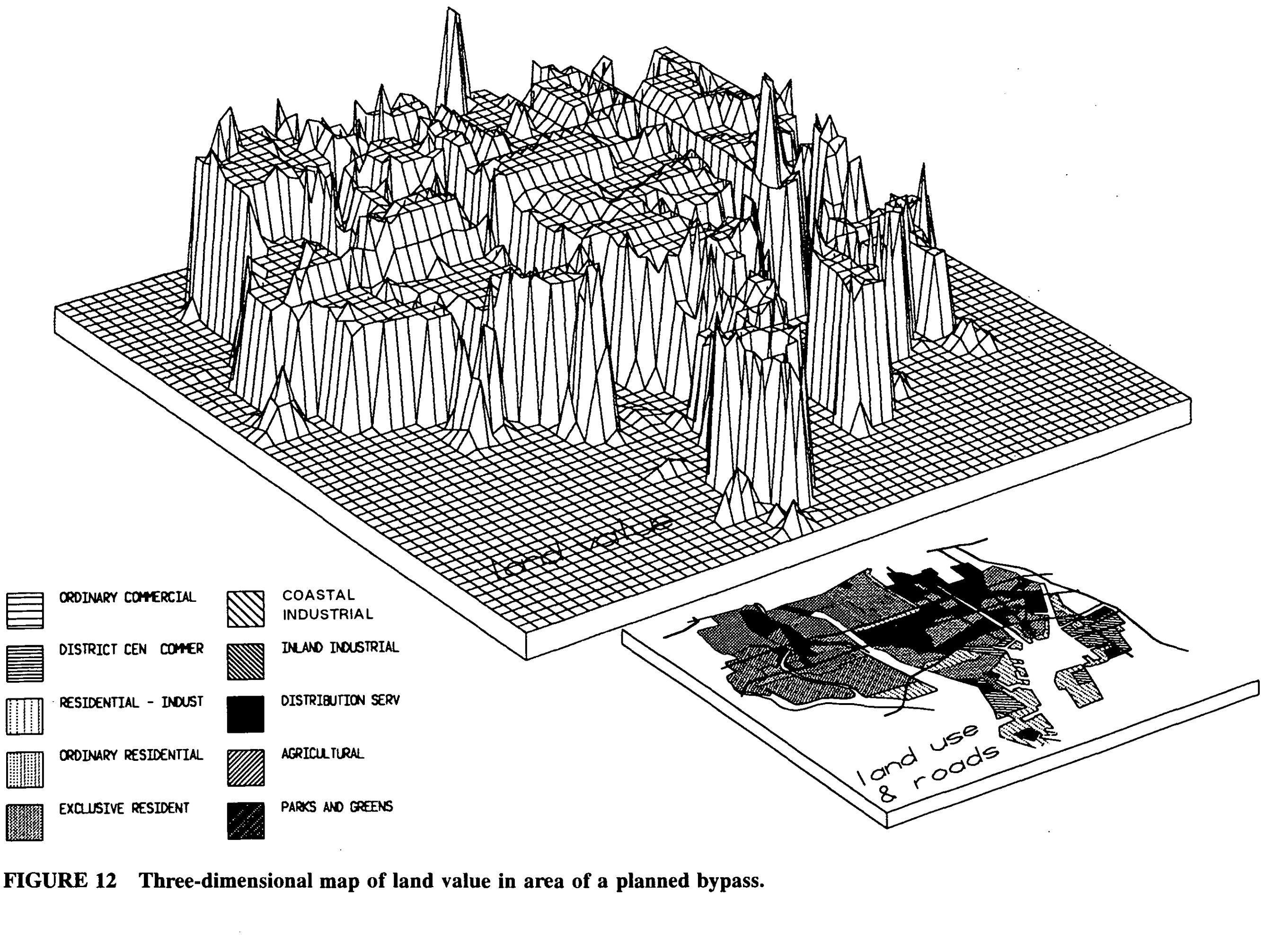
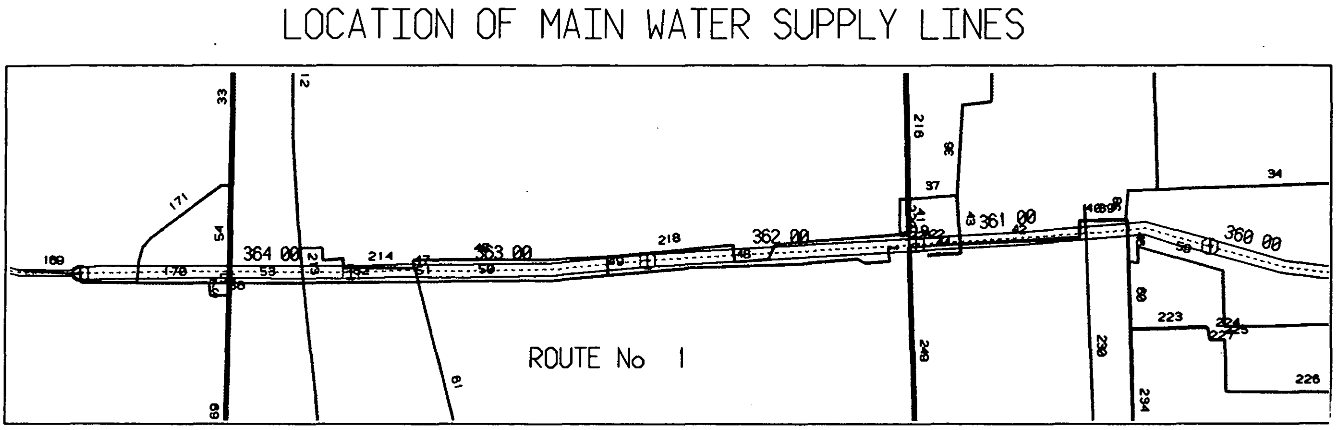


FIGURE 12 **Three-dimensional map of land value in area of a planned bypass.**



WATER-ID	DIAM(CM)	OVERLAP LENGTH(M)	REPAIR YEAR	AUTHORITY
46	60	45.11	199*	******
230	40	45·02	199*	******
42	60	455·52	199*	******
43	30	30·76	199*	******
222	30	181·39	199*	******
221	40	28·81	199*	******
44	60	14·23	199*	******
249	110	16·25	199*	******
48	30	57·79	199*	******
218	40	50·30	199*	******
218	40	45·00	199*	******
47	40	12·47	199*	******
214	40	248·04	199*	******
49	30	45·13	199*	******
51	40	34·30	199*	******
213	40	45·11	199*	******
171	40	45·15	199*	******
54	140	45·00	199*	******
169	30	225·21	199*	******

— DIAMETER 300 ~ 400 mm
— DIAMETER 500 ~ 800 mm
— DIAMETER 900 ~ 1400mm

FIGURE 13 Coordination between timing of road repair and utility repair and installations.

CONCLUSIONS

The adaptation of GIS in highway management is promising and may vastly improve the quality of the decision-making process. This is particularly true since the problem is inherently spatial. In this paper an HPMS was coupled with a GIS. The resulting prototype system (HPMS-GIS) consists of (a) a spatial data base module that contains several spatial features of a selected study area, (b) an attribute data base module in which representative descriptive data are stored, (c) an analysis module in the form of programs that perform general and specialized analyses, and (d) an output module that produces screen displays and hard copies of the results of the analysis. Possible applications and advantages of the prototype HPMS-GIS were then explored. Results of a case study were also provided.

The main advantages of the system can be summarized as follows;

1. The system can improve the quality and availability of relevant data that will positively affect the quality of the decisions based on them.
2. The system makes it possible to extensively produce automatically generated maps for use in the different stages of the management process, starting with the preliminary analysis and ending with the display of the results and the preparation of reports. Because maps are easier to comprehend, this can be a basis for more sensible judgments and decision making and will be a means of gaining better support from high-level decision makers.
3. The system's powerful spatial queries and its analysis and display capabilities allow for the interaction between the system and its end users for further analysis of outputs. This is a main requirement of an efficient DSS.
4. The spatial integration of data can help users to consider diverse types of data in the analysis, which can enlarge the scope of the decision-making process.
5. Consideration of more features surrounding the road can be given. This can result in better coordination between repair activities and other directly or indirectly related activities.

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