COLLABORATIVE PLANNING OF ROAD NETWORKS CONSIDERING BRIDGES AND TUNNELS

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1. INTRODUCTION

The planning and design of a road network are usually multi-disciplinary projects that involve the cooperation of city planners, transportation engineers and road engineers. In addition, a road network usually includes a number of bridges and tunnels to cross over or under a natural or an artificial feature. Therefore, bridge engineers and tunnel engineers should participate in the design of the road network. Each of the previous engineering fields contains a number of specialized branches. For instance, a bridge engineer may be specialized in the superstructure design or substructure design. Another aspect of specialization is related to the phase of the lifecycle of the road, the bridge or the tunnel. The lifecycle has in general the following phases: 1) planning, 2) design, 3) fabrication and construction, 4) service, monitoring, and maintenance, and 5) replacement.

The authors have discussed the relation between road network alignment and bridge type selection in a previous paper [3]. They have suggested coupling the Geographic Information System (GIS) approach for representing and processing the geographical data of the road network with the expert system approach for representing and processing the knowledge of expert designers. The previous research suggested loose coupling of three expert systems for the preliminary design of the roads, bridges and tunnels included in the road network. The data exchange between the GIS and the expert systems was done using intermediate data files.

A better and more realistic scenario is to have the GIS and the expert systems running concurrently on different machines by different designers and planners. In this case, the changes that may happen in any sub-system should be shared by other sub-systems to maintain the consistency of the knowledge and to insure a perfect coordination between the different agents.

The target of this paper is to make a task analysis of the processes related to road network lifecycle engineering and to investigate the different communication levels needed between these processes in a GIS and expert systems environment.

2. GIS AND EXPERT SYSTEM APPROACH TO ROAD NETWORK PLANNING

GIS can represent different geographical features of the real world by related data layers. Many applications of GIS have been suggested for transportation planning and highway infrastructure management [1]. GIS can also play a key role in integrating the information management among the expert systems for the design and planning of roads, bridges and tunnels of the road network. The benefits of this integration are: (1) Organizing the flow of the data between the central database of the GIS and the different expert systems; (2) Considering the interactions between the roads, bridges and tunnels on the level of the whole road network; and (3) The resulting data of the design can be used after the planning and design stages for managing the road network through the GIS.

A prototype system that can be used to select and compare different road alignments is under development. The GIS module is developed using ARC/INFO [5] on a Sun workstation. Figure 1 shows a conceptual case where a new road is planned. The road crosses over a river and through a mountain and therefore, it includes a bridge and a tunnel. The topography of the land, road network, a river, buildings around the river, the soil types, and the pipe network of underground utilities are represented by several overlays. GIS facilitates this task by providing a spatial database, an attribute database, the ability to perform spatial and attribute analysis, and a graphical user interface.

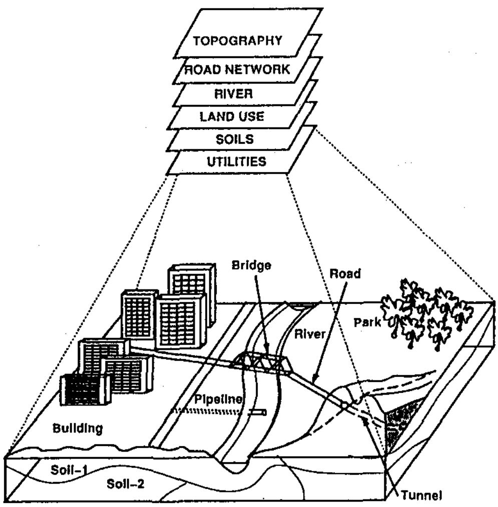


Figure 1: Representation of the Real World Using Coverage

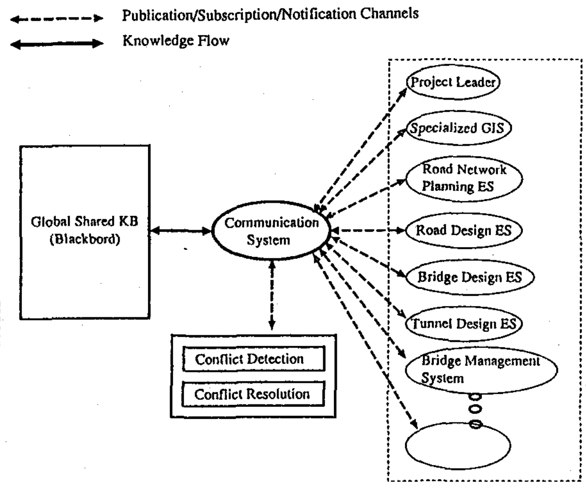


Figure 2: Structure of the Collaborative System

In the old prototype system, the GIS database is used as a repository database for the road network design [3]. The system has a GIS module and three expert systems modules for the design of roads, bridges and tunnels. The road network planner can start by trying a road alignment interactively using the GIS. The bridges and tunnels locations along the road are found and the characteristic data of these locations are extracted from the computerized maps using the spatial analysis capability of the GIS. These data are handed to the specific design expert system.

3. TASK ANALYSIS AND COMMUNICATION AMONG PARTICIPANTS IN THE ROAD NETWORK LIFECYCLE ENGINEERING

As mentioned earlier, the project of a large road network is usually divided into sub-projects that can be handled with the minimum interaction. This kind of division closely follows the physical configuration of the object to be considered. Roads, bridges and tunnels are considered sub-projects of the road network project. The boundaries of each of these sub-projects are decided just after the overall road network planning stage which is done by city planners and in which the alignment of the road network is chosen. The interaction between these sub-projects is limited to the dimensions and locations of the interface sections. Similarly, the design of a bridge is divided to the design of the superstructures and substructures. Here, the interaction between the two parts of the bridge is more significant.

The following three stages can be noticed in the project lifecycle from the point of view of design data changes:

1) Planning and preliminary design stage: In this stage, several alternative routes and types of the structures should be compared. The commitment level to any of these alternatives is very low and any partial or total change in the design is possible. Consequently, this change should be shared by all the participants in the project that may be effected. For instance, investigation for a tunnel should be a continuing activity throughout its planning, design and construction. As each item of information is utilized, new and more detailed problems appear and further investigation becomes necessary [4]. Even at quite a late stage a substantial change of level or line may be found advantageous.

2) Detailed design and construction stage: A strong commitment to a specific route and structures types has to be made at the beginning of this stage. However, some minor partial changes can

occur in different parts of the road network because of the emergence of new problems. These problems should also be shared by other participants.

3) Management stage: After the project is fully constructed, the management stage starts. Many changes may occur because of the malfunction of a part of the road network, the expansion of the network, or some changes of the traffic flow in the network. Examples are the failure of a bridge or the closure of a road for maintenance purposes. These kinds of changes should be communicated to the management systems to adjust their plans for the collective management of the facilities in the road network.

Figure 2 shows the structure of the suggested system. This is a network-based open-architecture system that is flexible and extensible. All participants in the road network lifecycle engineering can link to the system only by having the ability to translate their tool-specific knowledge representation into a standard knowledge interchange language such as KIF [2]. A participant can be a human such as the project leader, a specialized GIS, an expert system for bridge design, or a bridge management system. *Agent* is a general term to describe any participant (human or computer system). Knowledge sharing can be done by satisfying the following requirements:

1) The knowledge representation of the shared knowledge should have a standard syntax and a basic domain vocabulary and it should be accessible by all the participating engineering agents in the framework. The resulting global shared knowledge base is a kind of black-board system.

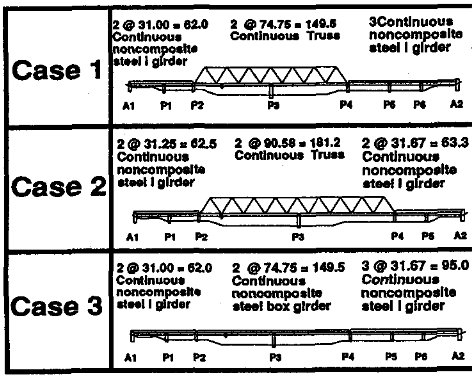
2) Knowledge is exported from the GIS and the expert systems into the shared environment via a *communication* system that fulfills the following tasks: (1) *Publication* of new information by transforming agent-specific items into a form that is in conformance with the common knowledge representation of the shared knowledge base; (2) *Subscription* of interested participants for receiving specific items of the shared knowledge base; and (3) *Notification* to those interested participants about any changes in the shared knowledge base concerning the items they have subscribed for.

3) In order to avoid inconsistency in the shared knowledge base, any conflict should be detected and resolved. The detection and resolving of conflicts can be done by a human expert or an expert system that has a knowledge base of domain-independent and domain-dependent knowledge about conflicts. This kind of knowledge base can be established gradually by capturing and organizing conflicts during the run-time of the collaborative system.

4. COMMUNICATION SCENARIO

As an example of communication between the different agents, the interaction between the GIS and the bridge design expert system will be explained. In this case, the data needed by the expert system include (1) the topography of the river cross section, (2) the river width, the bridge length and the overall bridge width, (3) the skew angle of the bridge, (4) the average water depth extracted from the river coverage, and (5) N-values and the soil bearing capacity of the low river bed and high river bed. The bridge design expert system will subscribe for these data to the communication system. The GIS will be asked to provide these information and the results will be notified to the bridge design expert system. The types of the bridge superstructure and substructure are selected using the bridge design expert system. This expert system selects the span arrangements and generates all the possible bridge type combinations. Each solution is evaluated by calculating its construction cost. In addition, a total assessment based on easiness of erection, maintenance, driving comfort and landscape is done and the best three bridge types for the specific location are found.

Figure 3 shows an example of the bridge types selected by the expert system with the evaluation results. Driving comfort is evaluated according to the vibration that drivers feel and the view



Case		Value	Scaled	Total Assessment
Case 1	Total cost	1306 million Yen	3.0	3.0x1.0+ 2.5x0.4+ 3.0x0.5= 5.5
	Driving Comfort	7.62	2.5	
	Landscape	5.05	3.0	
Case 2	Total cost	1429 million Yen	3.0	2.5x1.0+ 2.5x0.4+ 3.0x0.5= 5.0
	Driving Comfort	7.62	2.5	
	Landscape	5.05	3.0	
Case 3	Total cost	1310 million Yen	2.9	2.9x1.0+ 3.0x0.4+ 1.0x0.5= 4.6
	Driving Comfort	8.20	3.0	
	Landscape	0.47	1.0	

Figure 3: Example of the Bridge Types Selected by the Expert System

obstruction. As for the landscape evaluation, points are assigned to each bridge type according to the bridge type and its harmony with the environment. The evaluation values of the three cases are scaled, weighted and summed. The weights given for the cost, driving comfort and landscape evaluation are 1.0, 0.4 and 0.5, respectively. These weights are estimated by a number of bridge design experts and can be changed if necessary.

The results of the expert systems are made public to the shared knowledge base and they will be routed to the road network planning expert system so that their effects are considered in the total evaluation of the road network. This process should be repeated many times until the final road alignment is decided.

5. CONCLUSIONS

1) Effective communication between the different agents that participate in the planning, design, construction, and management of road networks is essential in order to accelerate and improve the quality of their performance.

2) Task analysis of the processes used in the road network lifecycle engineering is done. The interdependencies between these processes are used to specify the level of knowledge sharing and communication protocols that are necessary.

3) A shared knowledge base is suggested for the integration of the sub-systems and the communication between them. The changes in any knowledge entity are reflected in the knowledge base and notified to the interested agents.

REFERENCES

[1] Abkovitz, M. et al.: Adaptation of Geographic Information Systems to Highway Management, Journal of Transportation Engineering, ASCE, Vol. 116, No. 3, pp. 310–327, 1990.

[2] Geneserth, M. and Fikes, R.: Knowledge Interchange Format, Version 3.0 Reference Manual, Technical Report Logic-92-1, Stanford University Logic Group, 1992.

[3] Hammad, A., Itoh, Y. and Nishido, T.: Bridge Planning Using GIS and Expert System Approach, Journal of Computing in Civil Engineering, ASCE, Vol. 7, No. 4, June, pp. 278–295, 1993.

[4] Megaw, T.M. and Bartlett, J.V.: Tunnels Planning, Design and Construction, Ellis Horwood Limited, New York, 1981.

[5] *Understanding GIS, The ARC/INFO Method.* Environmental Systems Research Institute, Inc., 1989.