December 2004

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ABSTRACT

Various governmental agencies use spatial decision support systems (SDSS) for not only long range planning activities but also running day-to-day operations. For example, many cities and counties use computer applications for managing snow removal assets in order to keep the roads cleared and the transportation network functioning. Prior research has reported a number of systems that provide limited support for mapping and route generation for snow removal operations. However, these systems are primarily stand alone, single user systems, constructed with a non-technical user in mind. This paper focuses on designing and implementing a web-based winter maintenance decision support system that improves the ability to evaluate different procedures for optimally managing snow removal assets. We discuss the architecture of such a system that integrates intelligent agents, web technologies and geo-spatial analytical techniques.

Keywords

Spatial Decision Support System, Snow Removal Assets Management, Intelligent Agents, Geographic Information System.

INTRODUCTION

Winter maintenance, particularly snow removal and the stress of snow-removal materials on public structures, is an enormous budgetary burden on municipalities and non-governmental maintenance organizations in cold climates (Anonymous, 1999; Anonymous, 1998; Black, 1997). Lately, geo-spatial technologies such as Geographical Information Systems (GIS) and spatial decision support tools are providing a valuable tool for planning snow removal operations (Farkas et al., 1998). The applications chiefly involve using GIS as a mapping and route-generation tool for snow-removal equipment. The Hennepin County Department of Public Works (DPW), Minnesota, developed an automated snowplow routing application using TransCAD GIS software (Caliper Corporation, 1999). The Indiana Department of Transportation is using a GIS spatial database program called CASPER (Computer-Aided System for Planning Efficient Routes) for optimizing route planning strategy for snow removal equipment (Pittman, 1996). The article referenced predicts that the implementation of automatic GIS-based route planning will have a significant economic benefit to the state, "Based upon an extrapolation of pilot test results, INDOT expects to achieve $8 million to $10 million savings in winter maintenance costs, a significant improvement in snow removal and ice control activities, and an extensive involvement of highway personnel in the modeling and analysis of route design activities" (Pittman, 1996). Researchers have also explored the possible use of decision-science tools for optimizing asset management of snow removal resources (Campbell et al., 1995), for example the Snow Removal Asset Management System (SRAMS) developed as an analytical tool to support improved resource allocation in Iowa using GIS and Artificial Intelligence techniques (Salim, et al., 2002).

Most of these winter maintenance tools, while having the potential to address some of these information needs, are not typically placed in the hands of planners and other interested stakeholders. Several issues have precluded this. Most tools are not constructed with a non-technical user in mind and lack an accessible, easily understood interface. Recently, agent technology has been considered as an important approach for handling this issue. Development of intelligent agents to assist users of GIS and SDSS applications is actively being pursued. Intelligent agents are employed to improve usability of GIS software as well as access to geo-spatial data and services available through the Internet. These agents know users' interests and preferences and can act autonomously on their behalf and monitor events and perform tasks to meet users' goals. In addition, these agents act as intelligent interfaces to multifaceted systems and mask the complexities of the system by reducing the cognitive load on the naïve end users.

The objective of this paper is to design and implement a web-based intelligent winter maintenance decision support system using the agent technology that improves the ability to evaluate different procedures for optimally managing the assets for snow removal.

BACKGROUND

GIS for Asset Management

A considerable amount of literature on transportation asset management has emerged. Recent publications have outlined the general case for applying asset management tools in the transportation construction and infrastructure maintenance industries (Federal Highway Administration, 1997, 1999; Gray-Fisher, 1999; Nemmers, 1997; Vanier, 2000). Ruben and Jacobs (1999) and Spalding (1998) have approached asset management problems in transportation from a more applied perspective by exploring the use of asset management for the supply of construction materials. Iraqi et al. (1998) have described the implementation of computer resources for construction-site management and applied real-time site-based sensors for monitoring potential construction logistics problems. A substantial amount of research on the integration of databases and expert systems, the application of GIS in transportation asset management, and basic principles of applying optimization techniques is available. In the area of expert system development, recent papers include the work of Begur et al. (1997), who integrated GIS information in the optimization of routing for visiting nurses, and Weigel and Cao (1999), who optimized the routing of Sears service vans using operations research methods combined with GIS to save $42 million per year. In the area of municipal public works projects, Tsai and Frost (1999) have integrated a GIS database with a knowledge base for toxin remediation, and Kamler and Beckel (1999) have illustrated the integration of GIS with other databases for public transport management.

Several agencies' efforts in implementing transportation asset management systems have been documented recently (DeLaurentis, 2001; Novak et al., 1998). In the area of integration of GIS in asset management for public works, relevant works include that of Chang, Lu, and Wei (1997) in municipal solid waste removal, Yeh and Tram (1997) in electric power delivery, and Taher and Labadie (1996) in municipal water distribution. The Federal Highway Administration of the United States Department of Transportation (1997) has conducted research to develop programs that are capable of integrating urban planning travel models and GIS packages such as ArcView, AtlasGIS, MapInfo, and Maptitude. Loomis (2000) has developed a computerized asset management system integrated with GIS. A paper in this area is that of O'Neil (1991), who described the use of GPS in municipal transportation planning.

Intelligent Agents and SDSS

As an artificial intelligence tool, expert systems have been used by several researchers in transportation. For example, Ljunberg (2000) has developed an expert system for the selection of deicing material for winter road maintenance. Hung and Jan (2000), and Jia (2000) implemented knowledge-based techniques for construction problems, and Melhem et al. (1996) applied such systems to steel bridge construction. With all the literature existing related to transportation asset management and optimization, the use of GIS for planning snowplow routes, expert systems for transportation infrastructure maintenance, the importance of and interest in these topics is evident. Researchers have also discussed the possible use of decision-science tools for optimizing asset management (Bowerman et al., 1995; Chang et al., 1991). Recently, there is growing interest in using intelligent agent technology to provide decision support capabilities for solving unstructured problems with significant spatial components.

Modern intelligent systems contain agents (intelligent computerized assistants) that are capable of acting autonomously, cooperatively, and collaboratively to achieve a collective goal. Intelligent agents can act on behalf of humans and assist them in executing complex tasks. They can be integrated into Knowledge-driven Web Based SDSS environments to shield the complexities of spatial modeling and analyses and help novice users tackle unstructured problems with spatial components. For example, a group of intelligent agents can cooperatively work together to solve the complex spatial optimization problem encountered in the search for the least environmental impact area in a certain region (Ferrend, 1996). Some agents would be responsible for model formulation and refinement where as some other agents may access various data sources and gather the necessary data to solve the problem. These agents have the capability to communicate and coordinate the various tasks that need to be executed in order to solve the problem. Communication covers the exchange of information between cooperating agents. An agent by itself may not have sufficient information or expertise to solve an entire problem; hence mutual sharing of information and expertise is necessary to allow a group of agents to produce a solution to a problem. Collaboration involves joint work by a group of agents on a common task or sub-task. Finally, coordination means the integration and adjustment of the individual group member's work towards the common goal.

Development of multi-agent systems is increasing (He and Jennings, 2003; Wang et al., 2002; Hendler, 2001). Specifically, several research efforts have been reported that use agent technology in addressing spatial decision making problems (Sugumaran, 1998; Manson, 2000; Sengupta et al., 2003). Sengupta and Bennett (2003) provide an agent-oriented modeling framework to overcome some of the limitations of traditional SDSS. Their SDSS (DIGME) evaluates the ecological and economic impacts of agricultural policies. Papadias and Egenhofer (1995) report on using agents in Qualitative Collaborative Planning. Agents represent topological, direction and distance constraints that are applied to a spatial planning problem. Rodrigues et al. (1997) describe a multi-agent system called MA-MEGGOT, used for modeling geographic elements for environmental analysis in land use management. It is aimed at establishing methodologies for evaluation and standard simulation in environmental quality description scenarios. Agent technology can be incorporated in WBSDSS to create enhanced systems.

A Web-based Winter Maintenance Decision Support System (WMDSS).

The WMDSS include development of Web-based interactive GIS tools and implementation of SRAMS using ESRI's Internet Map Server technology. The WMDSS design uses the Internet platform for developing GIS tools and decision support systems, which has several advantages. Web technologies, for the most part, are platform independent; they can be developed once and be used everywhere. Also, end-users are largely already knowledgeable about navigating websites and using Web-based tools (Peng and Nebert, 1997; Sugumaran et al., 2000). This has resulted in research studies demonstrating the suitability of the Web as medium for implementation of planning tools. For example, several researchers demonstrated the use of Internet and GIS for improved decision-making (Sugumaran et al., 2000; Dragicevic et al., 2000) and environmental modeling (Carver, 1991). Although there has been significant progress in the use of the Web as a medium for environmental data sharing and data visualization (Sugumaran et al., 2000; Dragicevic et al., 2000), few studies have focused on developing a Web-based planning tool using Spatial Decision Support Systems (SDSS). There is now increased interest in pursuing the development of SDSS on the Web to support better decision-making and policy formulation. Lately, a few planning systems such as a Web-based Activation Information Management (AIM) by the US DOT (Puzzanghera, 2002) and the Evacuation Decision Support Solution by Tennessee DOT were initiated in this direction. In our current research, we focus on developing a Web-based GIS tool and SDSS that facilitate access to existing data, the editing of local spatial and attribute data using remote sensing information and local expertise, and the incorporation of such data into procedures developed to optimally manage assets for snow removal. The following section presents the architecture of our proposed asset management system.

ARCHITECTURE OF AGENT-BASED WMDSS

Providing consistent snow removal services requires informed decision making at many levels. It involves automatic generation of routes, intelligent assignment of vehicles (snow plows) to routes, assignment of drivers to vehicles and integrated inventory system for resource allocation and control. This is generally referred to as "asset management". The allocation of resources at each level of the asset management process entails unique considerations, but common issues emerge throughout all levels. Decision making for snowplowing problems needs to be agile in its response to unpredictable circumstances such as weather. Most importantly, snowplowing problems involve a large numbers of variables, constraints, and complex interactions. Hence, in addition to conventional mathematical optimization and AI techniques, state-of-the-art technologies such as intelligent agents, knowledge management, XML and data mining are needed for appropriate model selection, execution, refinement and interpretation of results. An intelligent agent can help the user reason about the various options the optimization algorithms generate based on past knowledge, patterns and heuristics.

The architecture of the proposed agent-based winter maintenance decision support system is shown in Figure 1. The WMDSS architecture follows the traditional client-server architecture. The client side is a basic web browser using which a user interacts with the winter management decision support system. The client side user interface could be developed using JavaScript or VBScript, HTML, and applets to dynamically create "user-friendly" HTML pages that present the spatial and non-spatial information to the user. The communication between the client side and the server side is accomplished through HTTP and XML. The server side primarily consists of three components: a) Web Server, b) Winter Maintenance Module, and c) GIS Components Module. These components are briefly described below.

The Web Server facilitates the communication and transfer of data between the client side (Web browser) and the spatial (GIS Components Module) and non-spatial (Winter Maintenance Module) components of the system. The Application Server interfaces the web server and the GIS components and provides access to the various winter models stored in the model base as well as the relevant spatial and non-spatial data. The Winter Model Database contains different routing and optimization models that is used for analyzing specific scenarios in terms of allocating assets to different areas depending upon weather conditions. The Spatial/Non Spatial Data component supports the Winter Maintenance Module by providing the required roadway data needed for the allocation of routes, drivers, and other resources. For this, typically, a GIS database of all roads along with traffic volumes, roadway inventory information, and other data is created. The Winter Maintenance Module consists of three agents: a) Knowledge Agent, b) Data Mining Agent, and c) Transportation Asset Agent. The Knowledge Agent incorporates the key concepts, rules, and operational knowledge needed to generate optimal routes and assigning assets to these routes. Some of the factors that need to be considered in optimizing the allocation of snow removal assets are (1) annual average daily traffic (AADT), (2) route prioritization, (3) number of lanes, (4) operation time for each vehicle, (5) pavement type (concrete or bituminous), (6) availability of vehicles and drivers, (7) treatment of roads with salt/sand, and (8) minimum snowfall thresholds to mobilize equipment. The Data Mining Agent sifts through historical operational and weather data and tries to find common patterns and hidden nuggets of knowledge that could be used to reason about various options generated by the Knowledge Agent. The Transportation Asset Agent provides information about the various assets that are utilized in snow removal activities such as characteristics of snowplows, capacity, mileage for equipment maintenance, Odometer reading prior to assignment of the machine, details of the materials available at the central storage for snow removal, available quantity, unit cost of the material, reorder point, assignment of the operator to preferred machines, etc.

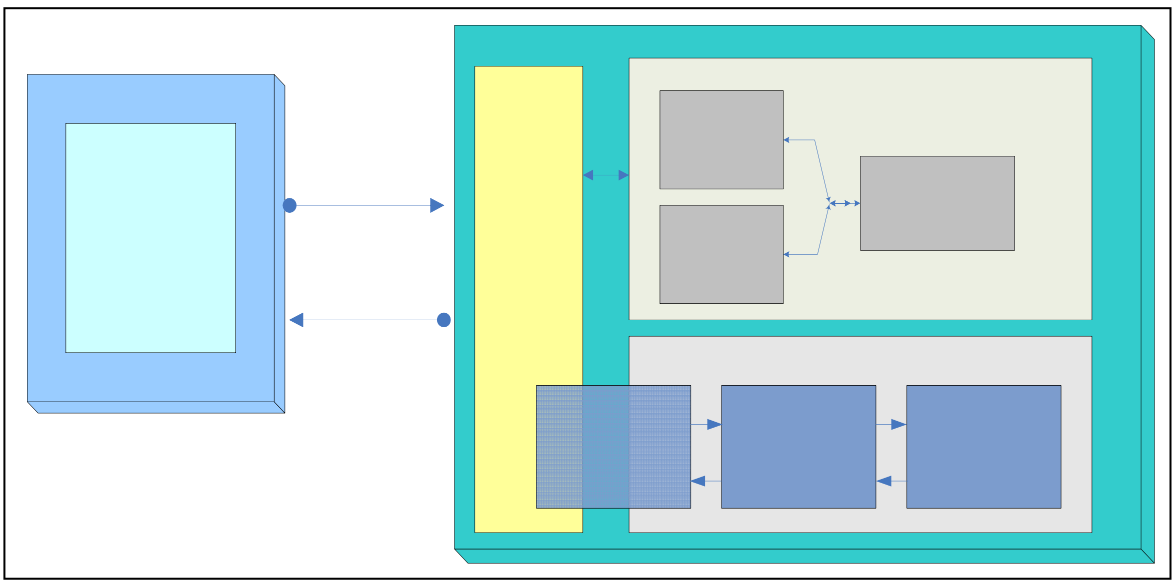

Figure 1. Architecture of Agent-Based Winter Maintenance Decision Support System

IMPLEMENTATION

The proposed intelligent winter maintenance system environment will be implemented as a web-based application using client-server architecture. The proposed framework will use ESRI's ArcIMS 4 and JAVA for the prototype development. ArcIMS 4.0.1 will run on Microsoft Windows 2000 Server with Tomcat 4.1.12 using Java 1.4.0 and IIS 5.0. ArcIMS, developed by ESRI, is currently one of the most popular Internet Map Servers and provides a common platform for the exchange of Web-enabled GIS data and services and for distributing GIS capabilities via the Internet (Tsou, 2002).

The client machine and web browser will use the framework of ArcIMS's Java Viewer, which makes use of Java applets, JavaScript, and XML programming. The server side environment is where most of the actual functionality is implemented using ArcObjects, Visual Basic programming etc. The winter maintenance agent will be implemented using JADE, a FIPA-compliant agent framework (Bellifemine et al., 1999) and its reasoning capability will be implemented using Java Expert System Shell (JESS). Jess supports the development of rule-based systems, which can be tightly coupled with code written in Java (Friedman-Hill, 2004).

As an initial step, a standalone version of the system called Snow Removal Asset Management System (SRAMS) has been implemented to demonstrate some of the capabilities related to optimal route selection and asset allocation. SRAMS was implemented by integrating Visual Rule Studio Professional 2.2 running under Microsoft Windows, Visual Basic 6.0, and MapObjects 2.1. SRAMS was developed with a single user point of view, which requires a major effort to update its scheduling and assignment capabilities if an updated version is released or if specific knowledge bases are used. Although SRAMS is fully operational, it does not include the agent component present in WMDSS that allows learning capabilities, and demands more computing power on the client side than the web based counterpart. Some of the benefits on the proposed agent-based system compared to SRAMS are its simplified interface, the level of integration with its different components: web interface, enhanced GIS functionalities, data mining modules; and its flexibility to adapt to new knowledge.

A web-based approach is a user friendly and simplified interface which allows the snow removal planners and supervisors for easy access and use of the system. From an implementation point of view, the system does not require the installation of any additional software on the client computer. The agent based system also incorporates embedded learning capabilities, which allows the adoption of knowledge structures dynamically as new solutions for snow operations are accepted. It also uses data mining capabilities, which utilizes advanced statistical analysis to determine relationships among existing data. These characteristics allow the continuous revision of new knowledge using an agent component, as well as simplified modification of existing knowledge bases. This depends on local expertise used by human experts that affect a particular geographical area, or new relationships that are discovered by the system among existing data.

SAMPLE SCENARIO

Using the system, the user can specify the weather condition, priorities for various roads and generate different routes for the various snowplows. Each snowplow is deployed for two consecutive hours for the first time. A decision as to the assignment of the same snowplow for the second time depends on plowing needs and the availability of snowplows for the first time assignment. The system automatically generates different routes for various priorities and the user can select a particular route to get additional segment and route details. For example, let us assume that the user selects Route 2. Further information about that route is displayed, as shown in Figure 2. The system allows either activating or deactivating any route in the display area. The user can initiate the assignment of snowplows to different routes and the system would try to minimize the “deadhead” (distance traveled by the plow to get to the route before beginning to plow) while satisfying the priority, capacity, and other related constraints. The user can also perform “what if” analysis by modifying some of the assignments and examine the impact on the overall solution. The vehicle assignments for the various routes and the total cost are displayed to the user, as shown in Figure 3.

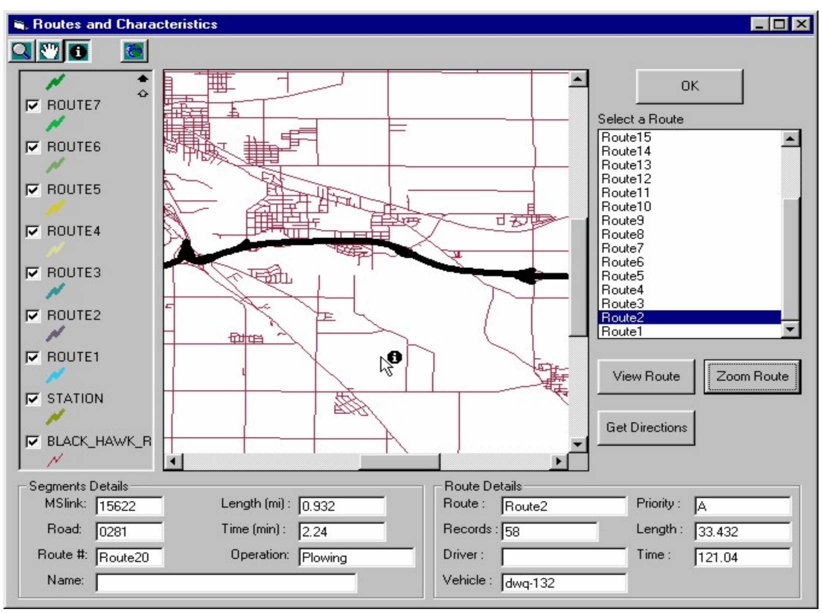

Figure 2. Suggested routing using standalone SRAMS

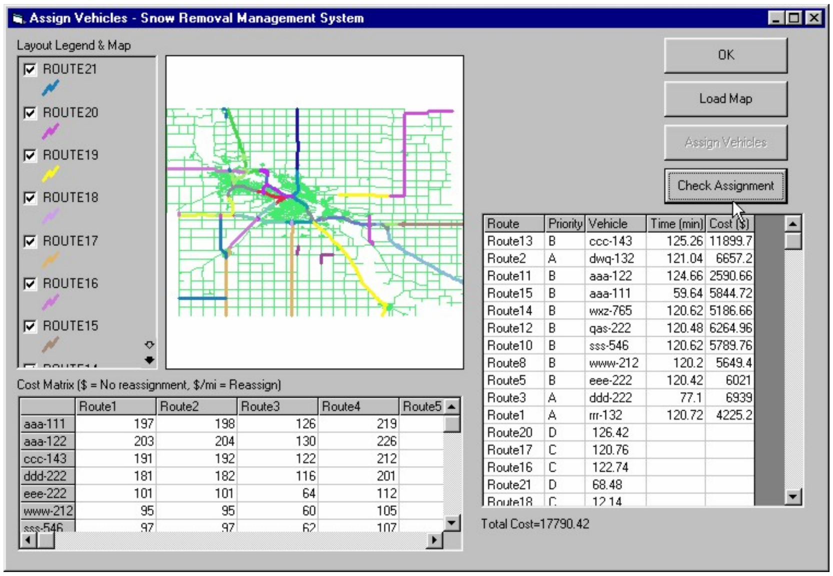

Figure 3. Assigning vehicles using standalone SRAMS

CONCLUSION

Snow-removal is a complex routing problem than any other vehicle-routing applications because it involves several factors including allocation of personnel resources (drivers, mechanics, supervisors), the distribution of materials (road salt, road sand, other ice/snow removal chemicals), the deployment of equipment (snowplows, dump trucks, supervisor trucks), meteorological data, and geographic information. We have presented an architecture for a web-based winter maintenance decision support system that improves the ability of stakeholders to evaluate different procedures to optimally manage assets for snow removal. This architecture integrates geo-spatial analytical techniques, intelligent agent technology, and spatial decision support systems. The implementation of this web-based WMDSS will provide a set of analytical tools for transportation asset management in the context of snow removal. This system would generate prioritized snowplowing routes in color-coded visual format and allow decision makers to manage the allocation of snow removal assets and resources. Since the system is web-based, the user interface is primarily browser driven and very intuitive. Also, the system would be accessible to geographically distributed users through the Internet. This system can efficiently be utilized to optimize allocation of assets for plowing snow, especially in the northern part of the United States. The system also has the ability to provide on-line information on the status of inventories and to warn users when materials are depleted beyond their re-order level. The use of intelligent agent in our system reduces the cognitive load on the user and provides a user-friendly interface even for a naïve user. Our future work includes completing the implementation of WBDSS and validating it through several case studies.

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