WEB-BASED COLLABORATIVE DECISION SUPPORT SERVICES: CONCEPT, CHALLENGES AND APPLICATION

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ABSTRACT:

The complexity of spatial decision-making makes it difficult for individual organization to deal effectively with decision making. Difficulty in linking data, analysis tools and models across organization is one of the barriers to be overcome in developing integrated spatial decision-making. By facilitating an inter-organizational decision-making process through information exchange, knowledge and model sharing, collaboration can be used to resolve conflicts and reduce uncertainty. Web-based spatial decision support systems (SDSS) can increase public access and involvement in inter-organizational collaborative decision-making. However, most web-based SDSS are application-specific DSS consist of software, data, and model for a specific decision problem. Most of these systems utilize different types of Internet technologies and framework, and cannot share their data and model with each other. There are no generic tools that would accept user data online, supporting data, software and model sharing and hence act as a web-based decision support service. Therefore, it is required to develop a standardized framework for Web-based Collaborative Decision Support Services (WCDSS), supporting information exchange and knowledge, software and model sharing from different organizations on the web. Such a WCDSS supply both metadata services, geodata services and geoprocessing services to help collaborative decision-making, not only support distributed data sharing and services, but also support distributed software sharing and model sharing. This WCDSS can play an important role to establish a collaborative mechanism across organizational boundaries for spatial decision-making support. This paper will give a detail literature review analysis of WCDSS, concluding the historical route towards WCDSS and its research progress and challenges. Then using web-based weights of evidence model for flowing well prediction as a case study, a conceptual framework of WCDSS will be proposed. Based on this conceptual framework, a prototype system will be designed to support the information exchange and knowledge, software and model sharing from different organizations on the web.

1. INTRODUCTION

The complexity of spatial decision-making makes it difficult for individual organization to deal effectively with decision making. Difficulty in linking data, analysis tools and models across organization is one of the barriers to be overcome in developing integrated spatial decision-making. Many researchers have been working on development of various models and decision support tools to address complexity in spatial decision-making. Many sources in the literature, including Decision Support System (DSS), Spatial Decision Support System (SDSS), Web-based SDSS (WebSDSS), Collaborative Spatial Decision-Making (CSDM) and Geographic Information Services (GIServices) demonstrate that considerable progress was made in the recent decades. However, there still exists some challenges for spatial decision-making and a growing number of researchers have realized that a new approach is needed to emphasize the benefits from a more open and collaborative decision-making process. This paper will give a brief literature review analysis of Web-based Collaborative Decision Support Services (WCDSS), concluding the historical route towards WCDSS and its research progress and challenges. Then using web-based weights of evidence model for flowing well prediction as a case study, a conceptual framework of WCDSS will be proposed. Based on this conceptual framework, a prototype system will be designed to support the information exchange and knowledge, software and model sharing from different organizations on the web.

2. HISTORICAL ROUTE TOWARDS WCDSS

2.1 Problem Statement for Spatial Decision-Making

Spatial information is used to satisfy many needs. Member of government, business, and the general public depend on spatial information for management, public service, decision making and decision operations. Spatial problems are typically of a multidisciplinary nature, requiring the analyst to examine data from several sources and to apply computation and assessment tools distributed in different organizations. Spatial decision-making usually involves various management organizations, but no single organization can collect and maintain all the diverse and distributed data sources. The various parties to a spatial controversy bring different positions, interests, and values to the problem. These ideals are often incompatible and make problem resolution complex. Increasingly, uncertainty and conflicts characterize many spatial decision-making situations. The complexity of spatial decision-making makes it difficult for individual or organization to deal effectively with decision making. The decision-making process may involve clarifying, refining, and resolving a problem situation through information exchange, discussion and negotiation among stakeholders. It may also involve the use of statistical and spatial analysis and modelling. A major barrier to sound decisions is a lack of information to adequately inform the decision-making process. Difficulty in linking data, analysis tools and model is one of the barriers to be overcome in developing integrated spatial decision-making techniques.

Many researchers have been working on development of various models and decision support tools to address complexity in integrating models and tools for spatial decision making. Many sources in the literature, including Decision Support System (DSS), Spatial Decision Support System (SDSS), Web-based SDSS (WebSDSS), Collaborative Spatial Decision-Making (CSDM) and Geographic Information Services (GIServices) demonstrate that considerable progress was made in the recent decades. However, there still exists some challenges for spatial decision-making and information services and a growing number of researchers have realized that a new approach is needed to emphasize the benefits from a more open and collaborative decision-making process.

2.2 Spatial Decision Support Systems (SDSS)

Spatial Decision Support Systems (SDSS) are ‘‘explicitly designed to provide the user with a decision-making environment that enables the analysis of geographical information to be carried out in a flexible manner’’ (Densham, 1991). SDSS extend DSS to provide a rational and objective approach to spatial decision analysis and enable the decision-maker to assess the implications of the trade-offs between alternatives. Through closely coupling analytical models SDSS overcome the GIS limitations for tackling complex, ill-defined, spatial decision problems (Densham and Goodchild, 1989). The field has now grown to the point that it is made up of many threads with different, but related names, such as Multi-criteria SDSS, environmental DSS, web-based SDSS and collaborative SDSS.

2.3 Collaborative Spatial Decision-Making

Since spatial decision-making usually involves multiple organizations, collaboration is needed to facilitate an interactive decision-making process. By facilitating an inter-organizational decision-making process through information exchange and knowledge, software and model sharing, collaboration can be used to resolve conflicts and reduce uncertainty in spatial decision-making. In recent years, there is a growing interest in the distributed access to geospatial information and services to decision makers and planners to promote Collaborative Spatial Decision Making (CSDM) (Sikder, 2002). This surge of interest in CSDM stems from the growing realization that effective solutions to pervasive spatial decision problems require collaboration and consensus building among people representing diverse areas of competence, political agendas, and social interests, which has been spurred not only by the trend in business organizations but foremost by the realization that effective solutions to spatial problems require collaboration and consensus building (Jankowski et al., 1997). In recent years, a few CSDM support systems have been developed to help decision makers in spatial decision-making. Much attention has been given to the use of rational decision-making modelling techniques to support decision making, such as multi-criteria analysis. Normally such an approach attempts to develop a DSS to support problem identification, alternatives identification, and implementation of an appropriate alternative through use of various mathematical models. However, most of these systems usually support interactive decision making within only one organization and lack the capability for distributing information and modelling through web, most of these systems usually use knowledge-driven models for decision support, little attention has been given to web-based data-driven prediction model such as weights of evidence for spatial decision support, little attention has been given to using the strategic decision-making process of collaborative spatial decision-making, especially in terms of the exchange of information and knowledge, software and model sharing among different organizations. Few studies have been completed regarding the development of decision support system for inter-organization collaboration, which emphasizes information exchange and knowledge, software and model sharing among different organizations through web technology.

2.4 Web-Based SDSS

In recent years GIS have begun to appear on the World-Wide Web (WWW) ranging from simple demonstrations and references to more complex online GIS and spatial decision support systems (Carver and Peckham, 1999). Because of advantages such as platform independency, reductions in distribution costs and maintenance problems, ease of use, ubiquitous access and sharing of information by the worldwide user community (Peng and Tsou, 2003), this has resulted in research studies demonstrating the suitability of the Web as a medium for implementation of spatial decision-making. Internet-based decision support systems can increase public access and involvement in decision-making. There is now increased interest in pursuing the development of SDSS on the web to support better decision-making. Rinner and Jankowski (2002) describe technical foundations and applications of WebSDSS. Rinner (2003) gave a detail literature review about web-based SDSS. However, most web-based SDSS are application-specific DSS consist of software, data, and model for a specific decision problem. Most of these systems utilize different types of Internet technologies and framework, and cannot share their data and model with each other. There are no generic tools that would accept user data online, supporting data, software and model sharing and hence act as a web-based decision support service.

2.5 Geographic Information Services

Due to the high cost of production, potential for widespread reuse, value in spatial-analytical overlays, and complex in structure, there is a huge requirement for geographic information sharing and services. Assuming that all the information is at the same scale and has been formatted according to the same standards, users can potentially overlay spatial information which is originally collected and maintained by a separate organization to examine how the layers interrelate. Geographic information sharing and services are vital to avoiding duplication of efforts and waste of resources invested in databases developed by many government and private sector organizations.

Also, the development of the Internet and information technique ought to make geographic information sharing and services possible, convenient, and powerful. Advances in computer hardware, networking technologies and software, such as the change from centralized configurations to distributed client/server architectures, the increased presence of World Wide Web as a means for accessing spatial data, and in particular, the advanced network techniques such as Java language, ActiveX controls, Common Object Request Broker Architecture(CORBA), Distributed Component Object Model(DCOM) and Java Beans, has substantially enhanced the potential value of GIS because now it is possible to locate and harness data from many disparate GIS databases to develop very rich analytical information on almost any topic that is associated with physical locations. Data that were once collected and used only for a single purpose could now have much broader applications.

Driving by both above factors, GIS is shifting into a new direction, geographic information services (GIServices). The need for global access and decentralized management of geographic information is pushing the GIS to distribute mapping services on the Internet (Peng and Tsou, 2003). Traditional GIS are no longer appropriate for modern distributed, heterogeneous network environments. With the popularity of the Internet and Intranet technologies, dynamic and distributed GIServices will replace centralized GIS (Tsou, 2001) GISservices focus on open, distributed services will broaden the usage of geographic information into a wide range of on-line geographic applications and services, including digital libraries (NSF, 1994), digital governments (NSF, 1998), digital earth and data clearinghouse etc. On-line geographic information services have become more and more and many on-line GIServices research projects ware focus on how to provide distributed geographic information services to the public and researchers. For example, GIServices provide digital library resources to dispersed populations (Goodchild, 1997). The Alexandria Digital Library Project (Buttenfield and Goodchild, 1996) adopted Java to implement GIServices such as spatial queries, map browsing, and metadata indexing. Since one of the main goals for distributed GIServices on the Internet is to encourage people and organizations to use geographic information and to make better decision, GIServices can generate new information value by sharing geographic information, spatial analysis methods, users' experiences and knowledge (Tsou, 2001). By adopting modularized, real-time based GIServices, geographers and spatial scientists can build more realistic models to solve research problems and can utilize geographic information and share research results and models more efficiently (Peng and Tsou, 2003). The OpenGIS Consortium (OGC) and ISO TC211 have jointly developed an international standard for geospatial service architecture. ISO 19119 "Geographic Information – Services" has been adopted as part of the OGC Abstract Specification, Topic 12 "OGC Architecture." ISO 19119 has also been used in the development of the CeoNET architecture in Canada, by CNES in France, and in the EOSDIS ClearingHOuse (ECHO) by NASA.

However, it should be noted that most existing GIS service systems focus on providing geodata services than groprocessing services and offer limited geoprocessing functions. It still lacks Web-based spatial and model analytic capabilities. Therefore, it is required to develop a standardized framework of the Web-based Collaborative Decision Support Services (WCDSS), supporting web-based information exchange and knowledge, software and model sharing.

3. WEB-BASED DECISION SUPPORT SERVICES

In order to solve above problems, a growing number of researchers have realized that a new approach is needed to emphasize the benefits from a more open and collaborative decision-making process. New approach to spatial decision-making support should attempts to provide effective, efficient decision-making support among various organizations. The idea of web-based decision support system as services has been explored by various researchers and involves the concept of "offering decision computation technologies as services on the web" and "using the web as computer" (Bhargava, 2001). Based on an analogy between Peng and Tsou's (2003) classification of web mapping technology into four classes: (1) static map publishing, (2) static Web mapping, (3) interactive Web mapping, and (4) distributed geographic information services, Rinner (2003) consider a total of four WebSDSS categories: (1) data-driven web SDSS, (2) server-side web SDSS, (3) client-side web SDSS, and (4) distributed spatial decision support services. Rinner advocate for Web-based decision services as the building blocks for future WebSDSS. He believes that complex geo-processing services, such as distributed spatial decision support services, are the highest level of SDSS. Web-based decision services can support information exchange and knowledge, software and model sharing from different organizations through web. Bhargava and Krishnan (1998) discussed the role of a series of enabling technologies in the context of model-driven DSS, covering technologies that enable the use of the web for communication of decision information and computation, technologies that enable the remote and platform-independence access of DSS, and technologies that allow DSS components to be distributed over the web, which include COBRA, DCOM, Java RMI and Java Beans et al. Bhrgava (2001) mentioned that the big leap forward in the WebSDSS is to develop off-the shelf products that could generate web-enabled application-specific DSS, and she also introduced that very few vendors allows developers to produce web-enabled DSS application. The emerging web-based collaborative decision support services (WCDSS) are driven by practical necessity rather than by abstract theory.

WCDSS not only support distributed data sharing and services, but also support software sharing and distributed model sharing. In such a case not only data is distributed in different organization, software and model are also distributed in different organization, they can collaborate to serve for decision making. A typical application scenario for WCDSS is that the clients want to combine data from several different places and want to "rent" some web based decision-making support software and tools available in the network to process them, such as database management, input/output, visualization, modeling and data analysis. Users without data, software and mode on their local computers can use such a WCDSS to help decision-making. This WCDSS can play an important role in assisting decision makers to establish a collaborative mechanism across organizational boundaries for spatial decision-making.

From technical perspective, WCDSS supply three levels decision support and services: metadata services, geodata services and geoprocessing services. The first level is metadata services. Users use the metadata services as a front end to learn about all the types of data available in the system, as well as the types of models that can be used for analysis. Using metadata services, users can understand what data and model are available, how they have been collected, and who is responsible for managing and distributing the data and model.

Using geodata services include Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Services (WCS) and filter Encoding etc al, users are shielded from the inconvenience of worrying about a variety of data sources, multiple data formats and data maintenance and update of the available distributed data because WCDSS detects and automatically resolve data heterogeneities in the underlying datasets, supplying data services and web mapping services for public. The decisions can be made faster and better when the decision-makers are provided with the most up-to-date, complete and correct information relevant to decisions for the problem they confront. By utilizing the Internet, on-line, distributed geographic information services will offer many opportunities to better serve the public, make government more efficient, and reduce costs.

The third level of decision support and services is geoprocessing services. It has been realized that, in GIS servicers, distributed geoprocessing is very critical to help users in geodata manipulation, modeling and analysis. From an information service perspective, GIServices is value-adding processors, which add meaning value to data. In addition, methods and tools are likely to be of interest to a much larger collection of users than a given item of data. Effective sharing of methods and tools has potentially much higher return than sharing of data. A typical application scenario for geoprocessing services is that the clients has his own geodata sets and only want to "rent" some GIS processing tools to process them, such as data format conversion, reference system transformation, data editing, data analysis and modeling. Expanding this use cause to a more complicated scenario, the client may combine geodata from several different places and process them by using geoprocessing tools available in the network and save the results in the local site. A typical geodata publishing system cannot solve this problem. To tackle this problem, different technologies should be applied such as distributed object technologies.

Yet it's unusual to see spatial information sharing and services among different organizations. Exchanging data and model analysis between, and sometimes within, the same organizations is recognized as a problematic endeavour. Obstacles exist for the implementation of WCDSS. Those obstacles can be part technical, and part non-technical. Bhargava (2001) talked about the difficulties including technological challenges, economic challenges and social and behavioral challenges. The most significant impediments to sharing and services are institutional, organizational, standard and technical. Appropriate organizational motivation, attitudes, structure, policy, management mechanism and standard are required for geographic data sharing and services to happen. Improvements in technical capabilities can drive much of the desire to access and share and serving geographic information. Among these improvements are networked infrastructures, standardizing software interface, developing spatial data transfer standards, dynamic web mapping, web-based distributed computation, information integration and model analysis etc. There are, a lot of institutional, organizational, standard difficulties associated with institutional, organizational, and standard. However, these issues fall outside the scope of this paper. This paper is mainly focus on the solution to technical difficulties.

4. CASE STUDY: WEB-BASED WEIGHTS OF EVIDENCE MODEL FOR FLOWING WELLS PREDICTION

The Oak Ridges Moraine (ORM) in the Greater Toronto Area (GTA), Canada is recognized as a major aquifer complex within Ontario. It is one of the most heavily used ground water sources in Canada. To understand the ground water system and its interaction to the surface water system may provide scientific evidences for decision makers in assessment of water resources and development planning in the area (Cheng, 2004). If we can statistically test the potential spatial association of the locations of flowing wells and other geological and topographical features and generate a potential map showing the zone with high probability of having flowing wells, it may provide scientific evidences for decision makers in assessment of water resources and development planning in ORM. To develop a practical system for prediction of flowing wells relies on several innovations including sophisticated models, Spatial Decision Support System (SDSS) and efficient on-line system to provide public information service and decision-making support.

4.1 Weights of Evidence Model for Flowing Wells Prediction

A problem of flowing wells prediction system is that they can be costly and time consuming, especially in areas such as ORM where there still have many unidentified, unmapped and unevaluated flowing wells. Recent advances in remote sensing and Geographic Information Systems (GIS) make the identification and mapping of flowing wells more efficient and cost-effective than before. Remote sensing can identify flowing wells and GIS are used for storing, manipulating, visualizing, and analyzing. However, since the potential spatial association of the locations of flowing wells with other geological and topographical features is complex, the potential spatial association can be called as 'wicked' or difficult because they contain intangibles that cannot be easily quantified and modeled. Through closely coupling analytical models, such as weights of evidence model, SDSS can overcome the GIS limitations for tackling complex, ill defined, decision problems and help to flowing wells prediction.

Weights of evidence model is used to predict a hypothesis about occurrence of an event based on combining known evidence in a study area where sufficient data are available to estimate the relative importance of each evidence by statistical methods. Weights of evidence model is a data-driven predictive model (Bonham–Carter, 1994) that differs from other predictive map models that are either knowledge driven and/or prescriptive in nature. The distinction between a data-driven model and a knowledge-driven model is apparent in that the weight of evidence model relies on objective assessment of input data to "estimate the relative importance of evidence by statistical means" (Bonham-Carter, 1994). Rather than employing knowledge driven subjectivity in populating other similar map models, weights of evidence model uses the training data layer to make suitable adjustments to the mechanics of the model itself. The ultimate goal of this form of map modeling is to predict the likelihood of the occurrence of a particular phenomenon within a certain study area based on one or more layers of evidence. Cheng (2004) developed a SDSS using weights of evidence model for assessment of flowing wells in the ORM. The model demonstrated the excellent potential for the use of GIS and weights of evidence method to assess flowing wells.

4.2 New Challenges for Flowing Wells Prediction Model

However, there are still three challenges associated with using GIS and weights of evidence model for flowing wells prediction in the ORM. Difficulty in linking data, analysis tools and models is the main barrier to be overcome in integrated flowing wells prediction with weights of evidence model. The first challenge lies in that flowing wells prediction with weights of evidence model require collaboration due to the data is distributed and managed by different organizations. Since flowing wells prediction requires diverse information that includes geological map, DEM and water well database and several geological and topographical databases, which usually involves multiple organizations, no single organization can collect and maintain all the multidisciplinary, diverse and distributed data. The extensive data requirements have long been an obstacle to the timely and cost-effective use of complex weights of evidence model, which is facilitating an increasing realism to distributed collaborative weights of evidence modeling, support the information exchange and knowledge sharing among different organizations through web.

Second, weights of evidence model has been implemented in ArcView GIS (Arc-Wofe), ArcSDM (Kemp et al., 1999 and 2001) and GeoDAS (Cheng, 2000). However, in such three software packages, ArcView, ArcGIS and GeoDAS are required for the implementation of weights of evidence model. Users need to download and install Arc-Wofe or ArcSDM or GeoDAS software packages on their local desktop computers and learn how to operate the models and ArcView or ArcGIS. In addition, by now there is no web-based Weights of Evidence Model has been developed. There is a great need to develop dynamic weights of evidence model running on the web, supporting software sharing among different organizations through web.

Third, development of models is always an expansive and tedious process for a single person or a group of people. While many hydrological modelling software packages are currently available, few are well integrated within GIS and are capable of non-expert implementation. The models require considerable professional training in model application because of the types of data required and the interactive nature of their application. So the last challenge is that if it is possible to develop web-based weights of evidence model services, not only software services but also model services, to decision maker and public in the ORM. Users who do not have data and knowledge about how to predict flowing wells in the ORM can use such web-based weights of evidence model services to predict flowing wells.

So we need to develop a new SDSS that provides a comprehensive environment for flowing wells prediction, support the information exchange and knowledge, software and model sharing among different organizations on the web. WCDSS are a significant potential solution as they resolve many of the limitations currently hindering the adoption of geospatial technologies by decision-makers. Web-based weights of evidence model for flowing wells prediction services system can provides a comprehensive environment for weights of evidence model for flowing wells prediction, supporting information exchange and knowledge, software and model sharing on the web.

4.3 Web-based Weights of Evidence Model for Flowing Wells Prediction Services Prototype System

With the construction of Canadian Geospatial Data Infrastructure (CGDI), a lot of spatial data and information can be accessed in real-time from distributed sources over the Internet to facilitate Canadians' need for information sharing in support of decision-making. CGDI can provide user with access to integrated and timely data and services, such as Web Map Service (WMS), Web Feature Service (WFS), Filter Encoding, Geodata Discovery Service, etc for decision-making support. However, only WMS, WFS and Filter Encoding cannot meet the requirements for web-based weights of evidence model for flowing well prediction, new application are still needed to integrate WMS,WFS, statistical analysis, modeling and spatial analysis together for decision making support. Although weights of evidence models have been developed and demonstrated applicable and effective for predicting flowing wells in ORM (Cheng, 2004), online application still need integration of various types of web-based GIS technologies so that these models can be executed online with required data accessed remotely.

Due to most of web-based GIS software do not support raster-based spatial analysis, which is a problem for web-based weights of evidence model implementation. Environmental Systems Research Institute (ESRI) ArcGIS Server Spatial Extension can help to solve above problem, it provides a broad range of powerful spatial modeling and analysis features that allow developers to create and analyze cell-based raster data, per-form integrated vector–raster analysis, and derive information about their data (ESRI, 2004).

System Architecture: Web-based weights of evidence model for flowing wells prediction services system will supply metadata services, geodata services and geoprocessing services to public information services and decision-making support. The most important benefits to users are that this system provides comprehensive support for distributed information retrieval, analysis and modeling.

This system has a multitier architecture consisting of presentation, business logic, and data tiers. The Figure 1 below provides an overview of the system architecture. The presentation tier includes the system client viewers for accessing, viewing, and analyzing geographic data. The components in the business logic tier, including web server, application server, metadata server, geodata server and spatial analysis and model analysis server, are used for handling requests and modelling analysis. The data tier includes all distributed data sources available for use with this system.

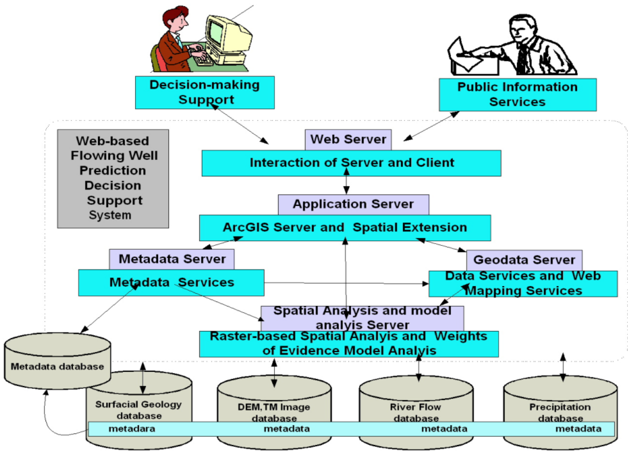

Figure 1. System Architecture

System Function: Such a Web-based Decision Support Services System (WDSS) will meet the challenges of current desktop-based flowing wells prediction system. Such a WDSS can supply web-based weights of evidence model services, integrating information management, information retrieval, spatial analysis and weights of evidence model analysis together, supporting information exchange and knowledge, software and model sharing from different organizations on the web.

Metadata services as a front end to learn about all the types of data available in the system, as well as the types of models that can be used for analysis. Data services and web mapping services detects and automatically resolve data heterogeneities. Geoprocessing services, such as weights of evidence model analysis and other raster-based spatial analysis, can accept user data online, supporting data, software and model sharing and hence act as a WCDSS to generate a potential map showing the zone with high probability of having flowing wells. It is capable of non-expert implementation and permits users to perform flowing wells and test "what-if" scenarios without being mathematics or hydrological experts. The intricacies of the mathematical models and the necessary data processing are hidden from the users and extensive visualization facilities are provided so that end users can immediately see the results in maps.

System Prototype Implementation: A prototype system is developing using Visual Studio.net and ArcGIS Server and Spatial Extension to implement web-based weights of evidence model for flowing wells prediction. The prototype does not currently implement all the functions and components in this paper.

5. CONCLUSION

This paper gives a detail literature review analysis of Web-based Decision Support Services System (WCDSS), concluding the historical route towards WCDSS and its progress and challenges. Then using web-based weights of evidence model for flowing well prediction as a case study, a conceptual framework of WCDSS prototype system is designed to support the information exchange and knowledge, model and software sharing on the web. WCDSS supply metadata service, geodata services and geoprocessing services to help collaborative decision-making, not only support distributed data sharing and services, but also support distributed software and distributed model sharing. Users only require a simple web browser to access data, software and perform model analysis without the requirements of installing GIS and modeling processing software packages. This WCDSS can play an important role in assisting decision makers to establish a collaborative mechanism across organizational boundaries for spatial decision-making.

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