

Web-based FOSS Environment Decision Support Systems for Odense River Basin in Denmark

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Abstract: Complicated model structure and time consuming simulations increase the use of models in decision making process when the stakeholders are not familiar with the tools. Therefore, the user interface (UI) design for decision support system (DSS) should not only maintain the scientific model structure but also simplify the interaction with models and the need for easy access. Nowadays, web-based techniques have been developed so fast and Web 2.0 brings the time when web-based systems challenge the desktop applications. This technology also needs to be taken into account in the DSS development for water resource management because the stakeholders are spatial distributed and the internet is the most commonly available resource. In this paper, we developed a WebDSS prototype named VisREACHER that is fully based on Free and Open Source Software (FOSS). It is a stand-alone web page with the decision model running behind which means it offers more than a visualization system of a prepared dataset. Map-based UI with AJAX techniques give the user more flexible using experience. A Bayesian Belief Network (BBN) model is chosen as the decision model to generate the probabilities of future scenarios is run at the client side. The advantages of using BBN are: its graphic structure can be coupled with the upstream-downstream topology very well, it is efficient and it can combine different measures at the same time. Layer structures and clickable items are the most important components in the interactive design which reduce the problem of jumping between different windows. Pure Javascript 3D popup has been built into the UI to facilitate the combinations of measures. The prototype is implemented in Chrome, Firefox and Safari browser with the stable performance. Furthermore, VisREACHER is also easy to be extended into the table touch screen environment for group decision making.

1 INTRODUCTION

A decision support system is a complex tool due to the mixture of technologies and social aspects. Making decisions is a process of making selections and meanwhile dealing with conflicting interests among stakeholders. To support this process, a platform which can easily access and generate scenarios is very handy. Dynamic webpage brings the chance to improve the usability of interaction with information and realizes the user-center concept that corresponds to the requirement for the decision support platform design principles. Here, a 2D map-based user interface for a water resource management decision support system has been designed. The innovation of this design is to take the Web 2.0 concept into concern that can

support the dynamic interaction between users and decision support system over the internet. Two parts are focused in this design: decision support model and web-based user interface. This paper focuses on the last part and gives a brief introduction of the first part. Although this DSS focuses on the remediation measures to the water quality problems, the general framework, state-of-art information visualization methods and the interaction styles can be extended into any spatial related DSS which plan to use a 2D map as the main representation of the solutions. Additionally, this visualization system takes touch screen device into consideration so that an innovation method has been created to combine the 2D and 3D applications into one web page.

2 USER REQUIRMENTS

The paper represents the results of Working Package 6 (WP6) in the EU project named AQUAREHAB. The objective of WP6 is to develop a collaborative decision support tool 'REACHER' that can be used by stakeholders, citizens or water managers to evaluate the ecological and economical effects of different remedial actions on water bodies. Before this decision support tool design, there was a research about the stakeholders and potential users of this tool. In the conclusion of this research, we find out that the potential users are at all levels included: national, subbasin and administrations. The purpose of this tool is to determine the suitable alternative for the future river basin management. There are several topics that cover what really the users need to know:

- Impact of measures on different water aspects (biological quality and links to physic-chemical quality and hydromorphology)
- Local vs. central reporting levels: handle different scales
- Upstream-downstream impacts
- Possibility for users to interact with the data and to insert data

Because of the difference in background among the users, a complicated model running is typically not what they need to obtain a clear picture of the system. . Therefore, the impacts and the states of the water bodies are the main components that we need to be visualise. Meanwhile, we need to find out an appropriate way to express the information and knowledge that can be accepted by the users. We believe that maps with spatial features are the important factors for representing the impacts and states.

3 SYSTEM DESIGN

The system is designed to be as flexible as possible for accepting different model results, e.g. water quality model, ecological model and also decision support models. Therefore, the visualization module needs to be abstracted so that it can be independent when connecting different (data/model) suppliers. Meanwhile, the data need to maintain the topological relationships between objects, e.g. upstream-downstream relationships, subbasin-groundwater-river reach relationships. It is important for the decision support model to explicitly represent those relationships over the interface. The response time is a main problem in this visualization system. Due to those problems, we decided to link the visualization interface only to the database rather than models. Also, we try to find a proper mathematic model to represent the relationship over the whole river basin in order to predict different future scenarios under different alternatives in a relative short-time response way. Figure 2 shows the information flow of the whole system.

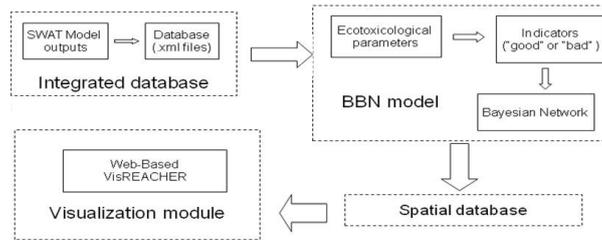


Figure 2 Flowchart of System Design

3.1 Bayesian Belief Network Design

A Bayesian Belief Network (BBN) is a graphical tool to aid reasoning and decision making under uncertainties. The network is a directed acyclic graph that using nodes to represent the variables and links to represent the cause dependency. Besides the graphic structure, another important concept is the conditional probability table (CPT). Each node has the table to establish the relationship between itself and its parents' nodes. The parameters inside the table can be collected by classical statistic or the subjective statistic. The classical statistic can be obtained from the frequency of the events and the subjective probability is obtained from the human's beliefs or experience. Normally, the frequency of the events is not easy to have because they do not repeatably happen. However, the events can be simulated by using process-based simulation models so that the frequency of the events can be made manually. A Monte Carlo (MC) simulation is implemented on the SWAT model to generate the frequency of the events. Two statuses have been determined as the events in the statistic calculations, i.e. good and bad, because of the requirement to represent the impact of different measures clearly so that two categories are suitable. Then the value can be put into the CPTs. This classification is flexible for modification and it is implemented in MATLAB.(Zheng Xu 2011) Figure 3 (left) shows out the basic structure inside one subbasin that nitrogen flux and ground water influence the subbasin status and then the subbasin status influence the reacher's status. Remedial measures are implemented on the nitrogen flux. 'probs' in Figure 3 (right) is the CPT for node 6 represents the chance of the 'states' in different combinations between parents.

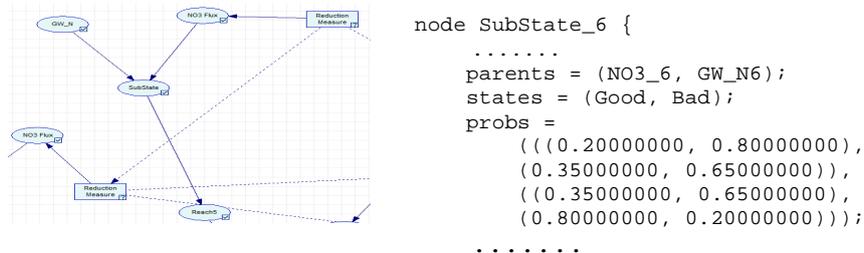


Figure 3 BBN in SMILE(left); CPT for node 6(right)

3.2 Spatial Database Design

Basically, there are three main kinds of features that can be stored in a spatial database as the table format: Point, Line and Polygon. With the coordination reference system, these features can be represented in their geometrical coordination values. The shapefile is the created geospatial vector data format which uses the primitives to represent the geometry of the objects. The spatial database can easily interact with the shapefile for getting spatial information and extent their attributes. In this implementation, the shapefile has been converted into the PostGIS database. Different data tables are linked by their spatial identity number which is considered as both primary key and foreign key. The CPTs maintain the spatial identity number for each feature so that these tables can link together by using SQL functions. Generally speaking, the table can tell 'what', 'where' and 'how'. 'What' is the type of the feature, 'where' is the location and 'how' is the parent nodes influent this node. After the tables are completed, they are

converted into the JSON file format for the requirement of internet data transformation.

3.3 VisREACHER Design

The VisREACHER is the visualization module of the REACHER tool and it is designed to be a single webpage. Its functionalities is to interact with the spatial database and restore the BBN computational inside the browser side program in order to execute the BBN model immediately based on the users input. Client/Server architecture is the main framework with the Browser as 'Client' side in this implementation. Several FOSS techniques have been selected to use:

Server part:

Apache: it is considered as the most popular open source HTTP server software. The primarily use of this software is to serve both static and dynamic web pages. It supports a variety of features and language interfaces, i.e. PHP, Perl and Python.

Mapserver: it can be considered as a graphic data rendering engine in the server side. In its most basic form, it is a CGI (common gate interface) program that sits inactive on your Web server. When a request is sent to MapServer, it uses information passed in the request URL and the Mapfile to create an image of the requested map. The request may also return images for legends, scale bars, reference maps, and values passed as CGI variables. The mapfile is the heart of the mapserver, it defines the relationships between different objects, points Mapserver to where data are located and defines how things are to be drawn. (<http://mapserver.org/introduction.html>) An advantage of 'Mapfile' is that it can link to the spatial database directly. In this project, we use mapfile to create our own static map layers about the whole area.

Client part:

Ajax: it is not a single technique but a group of techniques to enhance the internet users' experience. In the traditional web page, the users need to refresh the page very often to get the new data and these process wastes a lot of time in waiting for a data response. The Ajax technique is to use an asynchronous way to request parts of the data update in the server so that not the whole page will be refreshed. The direct feeling for the user is that they can get the new data very fast and need not to face the blank page all the time. The mature example of using Ajax is Google Map. The main techniques in Ajax includes: JavaScript, XMLHttpRequest, Cascading Style Sheet (CSS) and Document Object Mode (DOM).

Openlayers: it is a JavaScript library to help to generate the interactive user interface with maps and layers. Since November 2007 OpenLayers becomes an Open Source Geospatial Foundation project. (OSGeo) It is no-server side dependency so that it can support the mapserver to render the user defined maps.

Extjs: it is a cross-browser JavaScript library for building rich internet applications. Mainly, it adds more complex options tools over the user interface, e.g. menu, form, tab and so on . We use them for arranging the layout about VisREACHER.

WebKit: It is an open source web browser engine and it support CSS 3D transforms which we need to build the 3D Popup for the applications.

3.4 Interaction Design

Interaction Design is a relative new discipline since the 1980s when Bill Moggridge and Bill Verplank first coined this term. Its topic is as simple as how to satisfy the human side in the Human-Machine interactions so that the users will feel pleasure and the knowledge transform process can be enhanced. Regarding this research purpose, the methodologies are related to the cognitive research which focuses on the human's behavior and user experience analysis which can assist to generate the principles and regulations for the interaction design. A map-based system is familiar by the end users due to the prevalence of GIS, Google Map and Google Earth. From Google maps forum, the figure is about 1,000,000,000 worldwide and there are roughly 55 Million unique visitors each month in the US (Google map help forum, 2010) The essential reason why so many people like to use or at least have a try on Google maps products is that it is so easy to use. These successful user interface designs for the map-based system are all the resources for Vis-

REACHER to design. There is a survey on the interactive style for the map-based system and several points have been claimed:

- Layer control and Clickable Item

Using layers to construct different information into the map-based system is based on the Object-oriented user interface (OOUI) concept which explicitly represents the components with their applications. It abstracts different objects based on the attributes of the entities and capsules them into different layers. Clickable Item is considered as the most important characteristic in interactive map design phase because it naturally simulates the human behavior when using a map. It must be symbiotic with the layer control which constraints the range of information it represents. By clicking, users can understand and remember the spatial information related to the features they selected. Meanwhile, this activity gives an opportunity to modify the spatial items separately which is also important for studying up-stream and downstream relationship in water resource management area. Additionally, this operation can easily cooperate with the touch screen technique in order to support a kind of map-table system for group decision making activities.

- Tool bar

This element is related to the functionalities selection for different user activities. It is associated with the main window, always control the representation of the map, e.g. zoom in/out, pan, information item selections. Users need to be notified very well which tool is working on which layer in the web page. For example, if the measures are working on the rivers, the tool for select measures should be activated only when the rivers' layer is selected. However, the consequence after the river operations can be influent into the layers of subbasin, outlet and so on. In general, users should understand well what they are doing on the scenarios and this is guided by the user interface.

- Status representations

It can be considered as the history of implements and it has the effect to record the alternatives users made. Some commercial softwares have the windows for the status representations so that the user can clearly know what they have been done. Meanwhile, it is easier for them to modify the operations after they visualise the consequence scenarios. In decision support system, it is important to view the effect after alternatives and modify them appropriately. By the recording of those states, user can get familiar with the decision support model and see the sensitivities of the different features explicitly.

- Interactive Device

In the questionnaires survey, all the participants preferred the mouse as the method for manipulation. Another sense is that some of the participants also take gesture method into consideration very much. Nowadays, the table-like device becomes popular in different areas and should get more attention in the design of a decision support system for group decision making. Touch provides the natural way of interacting. Compare to the other interaction method, touch has the advantage of portable that the user can finish tasks without keyboard, mouse and touchpad. Meanwhile, it is silent that much less distracting than typing or clicking, especially in social situations such as meetings.(msdn.microsoft.com) However, the accuracy of picking up items will be reduced due to our fingers can not touch small things precisely. Especially in the water related research area, the reaches are represented by lines and increase the difficulty of selection from the touch screen environment. Therefore, the size of items needs to be identified clearly before the touch manipulation design.

Vis-REACHER uses the map as the main window and layers control the different information patterns. Clickable features with popup works for representing various measures and trigger to display the changes over the specific layer. However, if the number of the measures is large and users want to combine different measures, the size of the popup will become unpredictable and it will overlap the main windows. Extending the popup's dimension becomes the best choice for the measures combination activities. Therefore, different sides of the 3D popup can

display different information and measures. By rotating and translation, users can find the specific measures and make the options. All the modifications of the measures are explicitly displayed over the 3D popup. The methodology of drawing 3D popup depends on the support from the rendering layout engine for the web pages. WebKit is chosen to be the layout engine for the VisREACHER development which supports the Cascading Style Sheets 3D (CSS 3D) transformation. In CSS 3D, the 3D object has been divided into several elements which are represented in 2D and then project these elements into a three-dimensional space as a viewport with Z axis. Then, there are some functions that can be used to realize the 3D transformation over the 3D object, e.g. rotate, scale and translate. Here, six faces have been created to compose a 3D cube for the popup by specifying the size and position of each square. The contents for different faces are represented by HTML pages in order to link with the main map-based window.

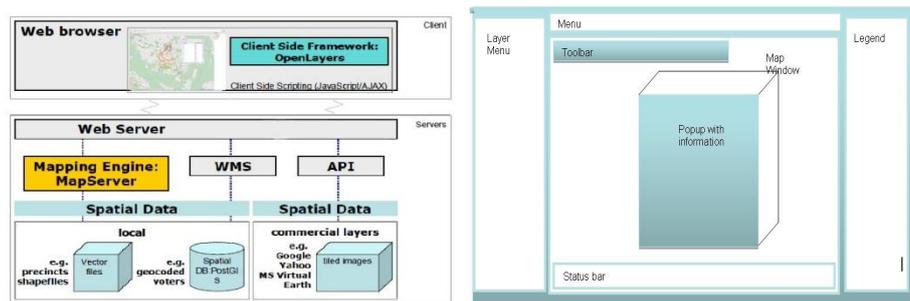


Figure 4 Structure of VisREACHER(left); User Interface Design (right)

4 IMPLEMENTATION

The overview of the VisREACHER is shown below. (Fig 6) The main page is separated into four parts: map window, tool bar, legend bar and status information. The layer control can be selected from the tool bar and the box of it can be dragged onto anywhere of the screen which solves the problem of matching different screen resolutions and meanwhile save the space for the viewport. Layers in the layer control are abstracted into two classes: Base Layers and Active Layers. The first one mainly represents the static layers which are the basic information of the study area, e.g. topological information and position of the spatial features. The second one represents the layers that can be changed dynamically by editing the parameters. Within each class, the subfolders can declare the different study areas, e.g. Odense is one of the study area and more areas can be added in. In this version, we have two options for popup representation: normal popup and 3D popup.

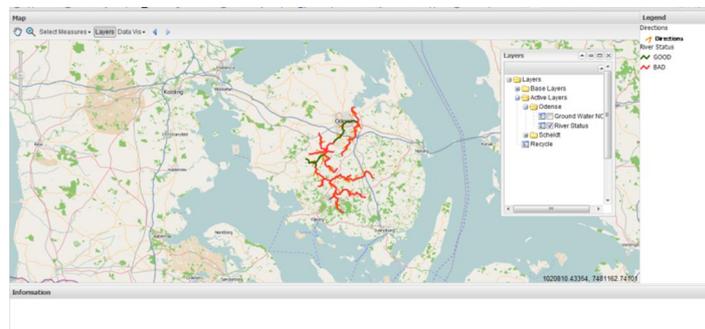


Figure 5 Overview of the VisREACHER

Remedial measures are the most important component in the REACHER tool which helps the stakeholder understanding what the consequences of the

measures are. Because agriculture is the dominant land use in the study area so that the reduction over the fertilizer has been chosen as the first remedial measure. The assumption is that the reduction measures are working in the reaches so that the user can click on the reach for the selection of the measures. As mentioned in section 3.1, 'Good' and 'Bad' are the two statuses for describing the general situation of the specific area. Green and Red are chosen to represent these two statuses for a clear view of the influence. Two measures are prepared to achieve the 'Good' scenarios, i.e. 30% reduction over the fertilizer, 60% reduction over the fertilizer. After clicking on the layer of 'River Status' in the 'Active Layers' and select the selection mode from the 'select measures' option, users can click on the reach they want to implement the measures. They can single select on the reaches or by press 'Ctrl' and then group select the different reaches. After clicking on the specific reach, a popup will show out with the options about the measures and the information about the selected items. Then, the user can select the measures over this or that reach. The selection will trigger the simulation core to calculate the update scenarios of the river basin and propagate these to the downstream area. The status bar will record what has been done till this moment. In the pilot study, we make an assumption to link the measures over the reach to the groundwater polygons to test the ability of this modification functionality. In this test, users operate the remedial measure on the river basin or riparian zone and can then to see the impact to the receiving groundwater or river reach. In real case, the functions that link selected measures to pollution reduction need to be identified. Although the functions are assumed now, the method to visualize this cross-layer impact is the same and flexible to add the new functions.

The tail version of this 3D popup is tested on the Safari (mobile version) and Chrome(version 15.0) browser. From the test, the 3D object can show out properly with the function of rotation. Each of the side can link to a different HTML page for the more information about the selected reach. In this way, the information dimension can be extended for the user. The rotation function can only be activated when the left button of the mouse be pressed so that the select function inside the HTML page can work properly after the left button be released. Therefore, the control of the rotation and the select can be done by the activities of the mouse or finger press movement. The 3D popup works well under the mouse device environment whereas the problem about precisely selecting items exists in the touch screen device environment.

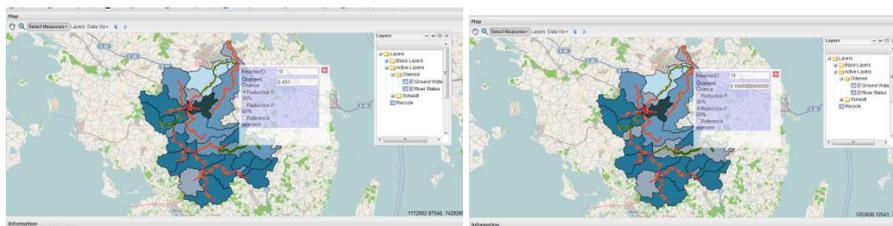


Figure 6 30% Reduction of fertilizer on NO.18 reach(left); 60% Reduction of fertilizer on NO.18 reach(right)

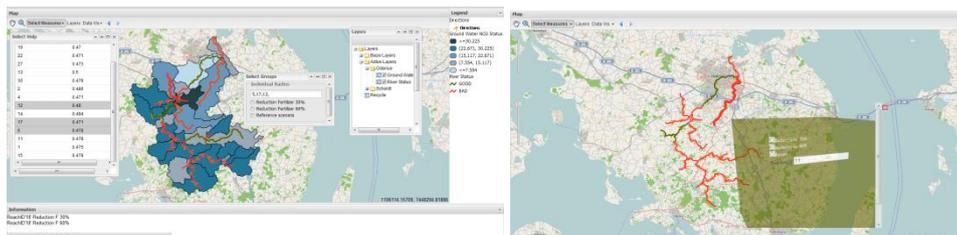


Figure 7 Group selection with the measures(left); 3D popup with the measures(right)

5 CONCLUSIONS

In decision support process, the group of users include different stakeholders from different areas. The requirements from the users not only focus on a specific modeling environment to predict the future scenarios but also an easy-to-use tool for them to understand the impact of the measures. Model and visualization are two important components in the REACHER tool design. In the tool design, a process-based model has been transfer to a surrogate model, i.e. Bayesian Belief Network (BBN) in order to represent and be able to reproduce characteristics of the complicated model. The main motivations of building the surrogate model are running time saving and flexible extend to different measures in the same time. The challenge of the easy-to-use tool is to find an appropriate visualization method to interact with the end users between the UI and the surrogate model. Map-based user interface (UI) can give the clear information of the spatial knowledge by combining the abstraction items with the realistic map together. Clickable items and Layers control are the most important factors in the map-based UI design. By clicking on the spatial features on the map, different measures can be implemented on the specific features. Upstream and downstream relationships are represented explicitly so that can help the user to understand more about the impact of the measures to the whole river basin. 3D popup can extend the dimension of the option selection in order to maintain the clear layout and save the screen space for the UI. Ajax techniques, as one of the important components in the Web 2.0, help to generate a smooth utility experience for the web applications which is also a main characteristic of the easy-to-use web based tool. Several free and open source software (FOSS) and internet standards have been implemented for the web based visualization module. The evaluations show out the compatibility of those techniques and light weight for on-line applications. The framework of VisREACHER tool can be useful for decision makers from water resource management and also for potential users who require an easy-to-use tool for understanding the impact of different measures

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