Journal of Information Systems Engineering & Management
2019, 4(4), em0106
ISSN: 2468-4376

Web-based System for Decision Support on Surface Irrigation Modernization

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Citation: Levita, T., Gonçalves, D., Miao, Q. and Gonçalves, J. M. (2019). Web-based System for Decision Support on Surface Irrigation Modernization. *Journal of Information Systems Engineering & Management*, 4(4), em0106. https://doi.org/10.29333/jisem/6350

Published: December 7, 2019

ABSTRACT

The purpose of this paper is to describe a web-based system to assist on-farm design and management of surface irrigation systems. This application was designed to be an appropriate tool for generating design alternatives associated with attributes of technical, economic, and environmental nature, and handling and evaluating a large number of input and output data. It also allows the evaluation and ranking of design alternatives using multicriteria analysis where criteria are weighted according to the priorities and perception of the designer and users, and provides an appropriate dialogue between the designer and the user, with an effective help support with information about equipments and irrigation practices. The application has tools for the resolution of specific problems, such as land leveling, pipe sizing and economic calculation. Built with a simple user friendly interface, with several optional languages and online help for technical aspects, this tool will contribute to support the dissemination of knowledge, design procedures and field practices of surface irrigation. Tests and demonstrations are being done on Hetao Irrigation District, China.

Keywords: surface irrigation systems, Decision Support Systems (DSS), Web-service, multicriteria analysis, Hetao Irrigation District

INTRODUCTION

Information and communication technologies (ICT) in agriculture domain have allowed the creation of new technological paradigms, like precision agriculture or digital agriculture, and the facilitated access to knowledge in a quick and efficient manner. In the context of irrigation, ICT have allowed great advances in real-time data aquisition and processing, as well as improvement in project and management procedures. This translates in a more rational use of resources and in productivity increase. The socioeconomic and environmental impacts of ICT in irrigation and agriculture fields are very significant, being the reason why this subject is so studied and applied worldwide, both at the scientific and at the business level. There are, nonetheless, many challenges regarding the knowledge transmission efficacy, the practical application of the technologies by the farmers, and the economic sustainability. These challenges have in common requiring considerable financial investment for the implementation and for the continued support on the delivery of knowledge to the end users, the farmers or the technicians.

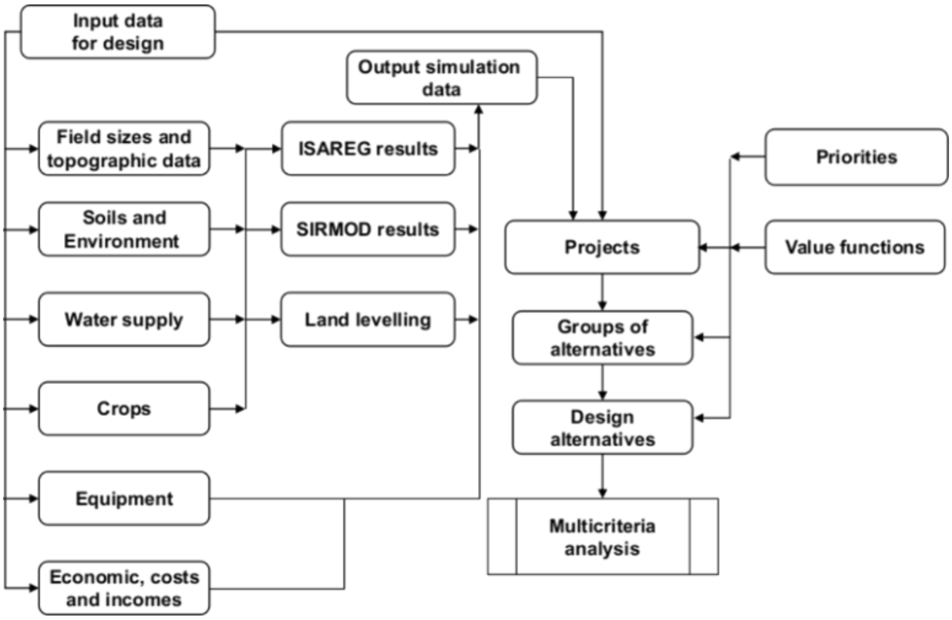

Figure 1. Irrigation Modeling components (Gonçalves and Pereira, 2009)

The web-based services are particularly effective to contribute to upgrading irrigation management, allowing an easy access of simulation models and data, namely: a) to broaden the range of users of simulation models, including extension agricultural technicians, as an effective means of assisting farmers, both for design and for management purposes; b) to facilitate automatic access to up-to-date data and new versions of the programs; c) to develop applications for practical use in the field, namely for automation and control of irrigation systems; d) to support the operation of the systems, in irrigation scheduling, in applied depths control and optimization, and in the integration of the water management process with other processes from the on-farm crop cultivation. The development of DSS for web (Antonopoulou et al., 2010) allows reaching a large number of users, and improving the user support through remote access to databases. This is particularly significant in world areas where water scarcity demands a better use of irrigation water and in areas in development, with gaps in the technical support to the farmers, where web-based services can potentiate a faster and more sustainable grow. Several examples of web applications in the irrigation domain show its usefulness (Car et al., 2008; Gonçalves et al., 2011; Rinaldi et al., 2014; Thysen et al., 2006; Zazueta et al., 2006).

This paper presents a web-based application to support on-farm design and management of surface irrigation systems, an application that allows an easy access to simulation models, data and knowledge, within a DSS framework, to improve the procedures of evaluation, operation and design of field irrigation systems. Models and data are located on a server allowing data sharing and comparison of results by different users.

This software uses a client-server and multi-user approach. This means that the simulation and the models are centralized and easy to fix and adjust to all users. The user interface is web-based so a user can access it on most devices and access his data anywhere. It has a user-friendly interface, available in both English and Chinese, with an effective user help. It also has access to an online portfolio with technical documents to self-user aid.

IRRIGATION MODELING

This web-based application applies a DSS developed to assist the process of designing and planning improvements in farm surface irrigation systems (Gonçalves and Pereira, 2009). This process considers that the user chooses the irrigation method, land leveling, crop data, field water supply, and economic data; and then applies associated model tools to create alternatives of possible solutions, and calculate its performance indicators and its comparison using multicriteria analysis (**Figure 1**).

The irrigation simulation is based on the hydraulic modeling that is based on the fundamental principles of the conservation of the mass and the momentum, through the equations of Saint-Venant. In the calculation of the infiltration several equations are used, being the most used the one of Kostiakov. The simulation models have a great value in irrigation design and management, allowing experimentation on the functioning of the systems in the sense of analysis and optimization of results. They are also used in the evaluation of an irrigation system, in addition to the data observed in the field, and in real-time irrigation control systems. The description of the operating conditions of the irrigation system for the application of simulation models is carried out by a set of parameters, obtained from field observations, such as in infiltration tests.

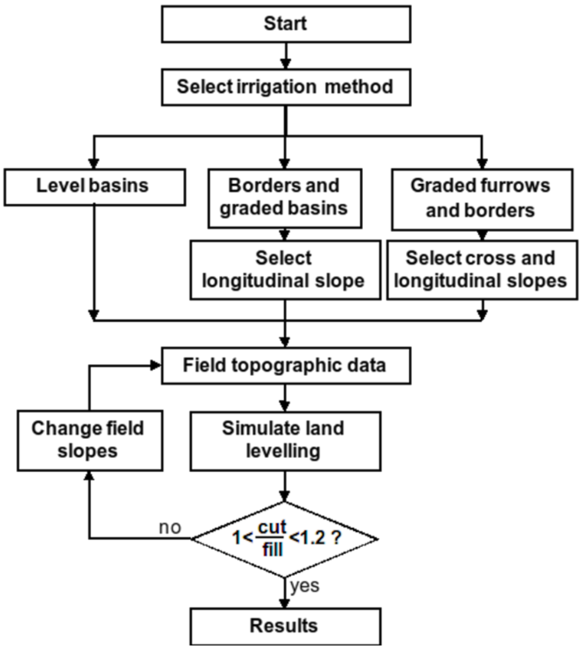

Figure 2. Flowchart of the application of the land leveling simulation tool

The basic object of the simulation application is a farm land parcel or fields of rectangular shape, with a well known geographical location, supplied by a hydrant, a gate or other facility at its upstream end. A field is characterized by its length and width, slope and land surface unevenness, soil infiltration and soil water retention characteristics, both assumed as spatially uniform for design purposes.

Data referring to each field includes the projects, which data structure is aimed at developing a set of design alternatives relative to the crop type (e.g. cereals vs. row crops), the irrigation method, the land leveling solution, to be defined in agreement with the irrigation method, field longitudinal and cross slopes, and the selected upstream distribution side, the water supply conditions that influence together with the irrigation method, the options relative to the number and size of units and the outlets discharge, and costs and other financial parameters.

One modeling component is the land leveling simulation tool, which calculates the amount of land involved in the field operation based on the surface elevation differences, and identifies the areas of excavation and landfill (**Figure 2**). The ratio of excavation and fill volumes required to balance of earth moved is calculated by an iterative process to find the position of the plane for the specified ratio. The program also determines the slope which optimizes the leveling operation based on the least-squares best fit and on the criteria of minimization of the volume of earth work required while obtaining a desirable smooth surface, which optimizes the operation cost and the negative soil impacts. When starting a project, the user must select the irrigation method, the upstream distribution side, and carry out a land leveling simulation adopting cross and longitudinal field slopes appropriate to the considered irrigation method and the actual field slopes. The simulation tool computes the cut and fill volumes required to change from the actual elevations into the target elevations. The plan position is iteratively changed until the cut to fill ratio becomes convenient (**Figure 2**). Results include the cut and fill depths and volumes, and related costs.

MULTICRITERIA DECISION SUPPORT

The design alternatives are clustered into groups included in a project, relative to the upstream distribution system, which depends upon the selected irrigation method and available equipment, and the tail end management system. The alternatives constitute complete design solutions, which are differentiated within a group by the operative parameters, particularly the inflow rate per unit of width of land being irrigated.

The selection of the best irrigation design alternative is a multiple objective problem whose rational solution requires multicriteria analysis. This methodology integrates different types of attributes on a trade-off analysis, allowing the comparison between environmental and economic criteria (Pomerol and Romero, 2000). It supports a better understanding of the irrigation impacts while enabling us to achieve a satisfactory compromise between adversative decision-maker objectives, being an efective decison-aid tool. The process starts with the definition of the design objectives and related attributes, then transformed into criteria through user-defined value functions. The alternatives and respective criteria are tabled in a payoff matrix, which synthesizes the more relevant data for the selection analysis. The decision criteria refer to: a) economic criteria relative to the yield value, the initial

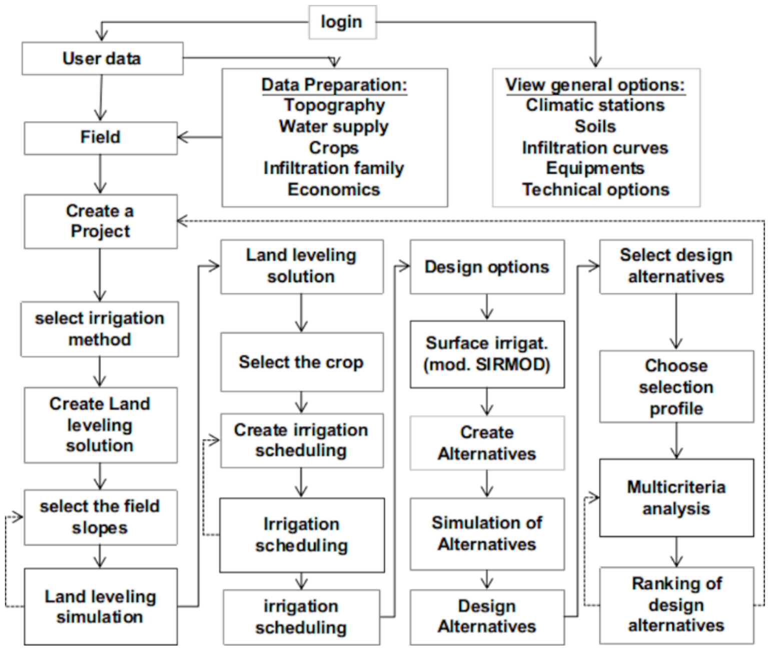

Figure 3. Data and simulation flowchart

investment cost, and the operation and maintenance costs; b) environmental criteria relative to the potential degradation of groundwater and surface waters and the reduction of non beneficial water uses relative to tail-end runoff and deep percolation, potential erosion due to irrigation water flowing over the soil surface, and soil degradation due to land leveling cuts; c) hydraulic criteria is represented in the environmental criteria through the control of runoff and percolation.

The multicriteria analysis allows the alternative selection for each project. This analysis plays an important role on automatic management of large amount of data, screening the alternatives, removing those not satisfactory, and ranking and selecting the most adequate according to the user priorities.

WEB SOFTWARE METHODOLOGY

This software uses a client-server and multi-user approach (Levita et al., 2019). This means that the simulation and the models, built in Java language (Oracle, n.d.), are centralized and easy to fix and adjust to all users. The user interface is web-based, and built in PHP (PHP, n.d.), so a user can access it on most devices and access his data anywhere. This web application has a user-friendly interface both in English and Chinese, with an effective user help. It also has access to an online portfolio with technical documents to self-user aid.

This software can be divided in two main parts: the simulation and the problem properties. The simulator is as agnostic as possible and very customizable regarding the problem definition. The properties of the problem are all the input the simulator needs. It was aimed to keep the user-interface friendly and to serve specific users with a subset of needs. To keep the UI simple and specific, most of the problem inputs that are constant through their simulations are hidden. This also means that the help and the documentation can be easily targeted to the userbase. A model-view-controller approach (Reenskaug, n.d.) was used to develop this interaction between the the simulation and the user. The data flow and logic of the execution are represented in the diagram of **Figure 3**. To access the application, the user needs to register beforehand with permission from the system administrator, and with conditional access by keyword.

The UI gathers the information the user inputs and the constants built-in and calls the respective simulator. Then, the UI receives the results and shows them to the users. Being web-based, it can be easily accessed through any web browser, making it compatible with mobile devices, mainly with the functionality of irrigation system operation or real-time systems management.

DEMONSTRATION ON HETAO IRRIGATION DISTRICT

The Hetao irrigation district (Hetao), Inner Mongolia province, located in the upper reaches of the Yellow River, is one of the three largest irrigation districts of China, with 570 000 ha of irrigated land, with 250 km long and more than 50 km wide. Hetao has a continental monsoon climate, a semi-arid area with an average annual rainfall of about 200 mm, where only irrigated agriculture is feasible. The irrigation canal network is supplied

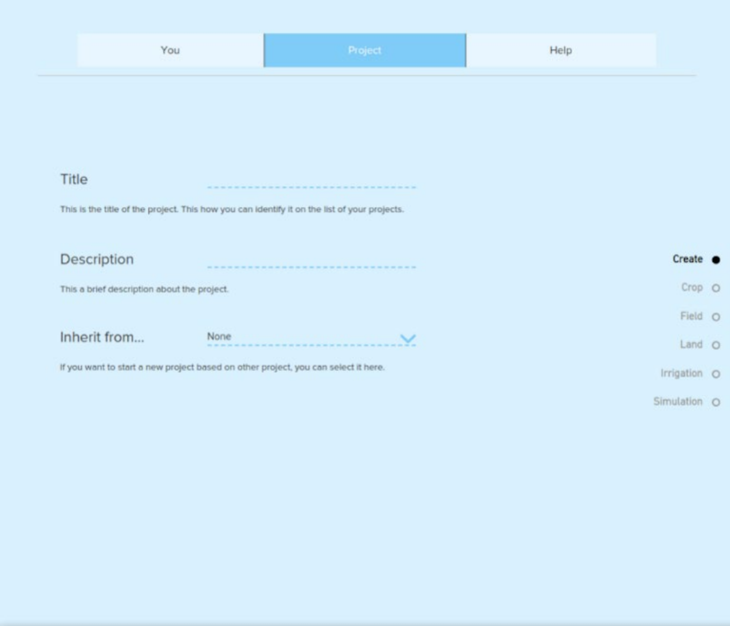

Figure 4. Program creation window

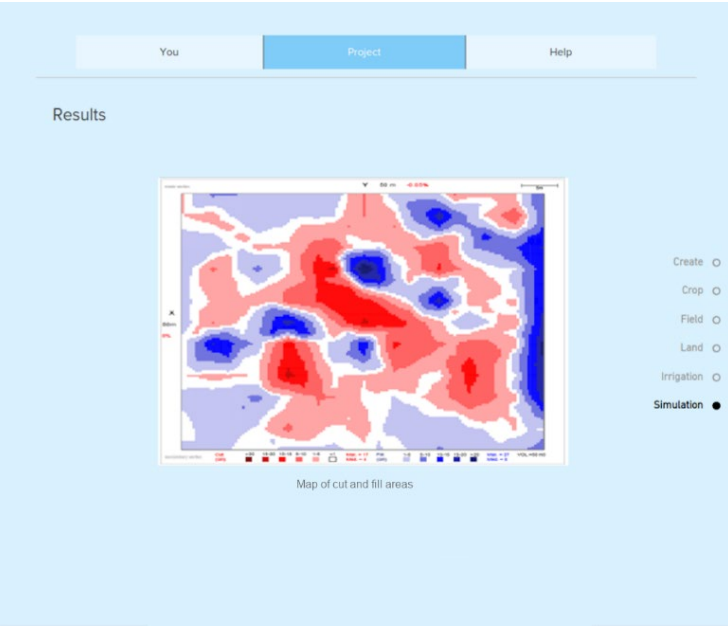

Figure 5. Example layout of land leveling simulation tool for a field parcel, showing the map of cut and fill area

directly from the Yellow River, with a complex conveyance system, being the irrigated area organized by 361 divisions. Each division comprises several sectors, each one supplied by a unique branch canal, with a relative independent operation. Each division has a Water Users Association, uncharged of water distribution operation and collective hydraulic structures maintenance. Hetao traditionally uses 5,0x10^{9} m^{3} year^{-1} of irrigation water. Nowadays, due to increased demand for non-agricultural sectors, the Yellow River Commission aims to reduce the Hetao demand to 4,0x10^{9} m^{3} year^{-1} over the 2020s, that require to adapt, including the adoption of various water-saving technologies (Wang et al., 2016). The problem is aggravated during periods of drought and severe water scarcity if the water use priority is given to non-agricultural uses. However, a heavy reduction in water for agriculture may have very important social consequences, thus a more flexible water allocation policy is advocated, limiting restrictions to irrigation to no more than 10% of the average quota in dry years. Nevertheless, the need for sustainable use of water and land resources in the basin implies that water conservation and water-saving practices should be implemented for alleviation of water scarcity (Shao et al., 2009). This demonstration uses a database and examples of a previous study developed on Hetao (Miao et al., 2018).

The web application user interface applies a general structure, which template is presented in **Figure 5**. It is a simple graphical window that helps the user to understand the logic of the data flux (**Figure 3**), using tabs, lists and input boxes. It allows to view the technical database, like the characteristics of equipment or other options to

Figure 6. Example of a graphical output of irrigation alternatives comparison

create alternatives, as to insert a new land field parcel, referred by its location, soil type, and size and topography data. Also, to build a project to create alternatives, according to the user design options.

The user will also have access to the simulation results, which include the volumes handled, the spatial distribution of the depths of excavation and fill and the estimated time of execution of work and its cost. **Figure 5** presents an example of the layout of simulation tool for a typical field parcel where traditional land smooting has been applied in the past. It presents a map of the cut and fill area before precise land leveling, corresponding to the actual elevation data, obtained from the topographic survey. Interactively, the user can do several simulations to find a solution that considers appropriate for the project.

After the simulations, the user can view and analyse the alternatives developed through the multicriteria analysis module, as exemplified in **Figure 6**, that presents a graphical comparison among several alternatives. This process is interactive with the user, which could generate new rankings when changing his selection priorities.

CONCLUSIONS

The web-based application being developed aims to overcome some of the difficulties of accurate knowledge transfer to field technicians and farmers, which can have major environmental and economical consequences, resulting in excess water use in regions where water scarcity is a reality and where there is need for surface irrigation improvements and where expert technical support is more incipient. This application uses a DSS extensive tool and a model-view-controller approach with a simple and intuitive web interface with contextual help with the goal to provide quick and useful information, available from any web browser, to improve on-farm surface irrigation at the farmer level. This application can potentially also be used for educational purposes, as a learning platform for university or technology students.

The Web application is under progress and will be tested in the near future in Hetao, by a set of selected users, namely by technicians and students. Evaluating the effectiveness of this application through user satisfaction surveys will be a next step for the work team in the implementation of this project. The application maintenance and user support will be the responsibility of a multidisciplinary team of computer engineers and agronomists. Their objective is to dynamically adjust the system to the most frequent difficulties felt by the users.

Improvements can be done with the goal of making the service more flexible to other potential users by considering other irrigation techniques, specific to other local agriculture scenarios and realities. One interesting aspect to consider in further developments is the integration of data measured from sensing systems already used in irrigation and agriculture, which will streamline the data introduction and will ultimately provide more accurate results. Another aspect to consider is the possibility to build a smartphone application.

ACKNOWLEDGEMENT

This study was funded by University for Young Scientific and Technological Backbone, No.2017XQG-4, and the project of Inner Mongolia Agricultural University, No. NDYB2016-23. National Thirteenth Project Five-Year Scientific and Technical Support Plan, No. 2016YFC0400205, contracted with the Ministry of Science and Technology, China. The support of FCT, Portugal, through the research unit Linking Landscape, Environment, Agriculture and Food - LEAF (UID/AGR/04129/2013) is acknowledged. The support of Instituto Politécnico de Coimbra, Escola Superior Agrária de Coimbra - ESAC, Portugal, is acknowledged.

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