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Evolution of Decision Support System Architectures: applications for land planning and management in Cuba

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ABSTRACT

The main objective of this paper centers on reviewing the evolution of Decision Support System's (DSS) architectures, particularly as they apply to natural resources. Today it is difficult to conceive the existence of a rural planning automated system that doesn't include spatial analysis functionality and that does not consider the integrated use of different analytical modules. This wider range of functions allow for solving problems from resource and environmental management. Geographical Information Systems (GIS), automated land evaluation, multi-criteria participatory analysis in decision making are but the most salient technologies in a DSS. DSS have evolved; their architecture, mode of implementation, as well as their functionality and the incorporation of new computational techniques have advanced lately. In the particular case of Cuba, the first steps in materializing this evolution have begun. At present, the National Sugar Cane Research Institute (INICA) leads a research project oriented towards the development and building of a dedicated DSS for sugar cane cropping. This is conceived as an integrated SDSS (Spatial DSS) to support decision-making and multiple problem-solving in such a fundamental productive activity such as sugar cane agriculture in Cuba.

Keywords: DSS, decision making, interoperability, Spatial Decision Support System.

1. INTRODUCTION

There is a variety of definitions on the concept of Decision Support Systems (DSS) in published work. The DSS paradigm appeared at the end of the 70s. DSS were developed for applications in different fields of specialization [16]. Some authors like [17] considered a DSS as any computer system, which should support human decision-making. Most of the existent published works coincide in their understanding of DSS as tools to aid decision-making with problems that are not well structured. This type of analysis, demanding a recursive mechanism for iterations is the justification for using software and hardware that supports the search and selection of the most appropriate alternatives for the solution of existent problems ([12], [10] and [14]).

It has been pointed out by [30] that decision support systems should provide integration and regeneration of the information, support the exploratory nature of the scientific discovery process and allow the development of alternatives to apply information system technology, in order to increase the effectiveness of those responsible for decisions, in situations where the computer can support and reinforce human judgement in the fulfillment of tasks, which have elements that cannot be specified beforehand. In these systems different modules are combined under a sole interface.

It has been pointed out [3], [5], [21], [4], [33] and [8] that the paradigm of integration in DSS has opened up a wide range of analytical possibilities and practically limitless applications are established, by the use of models, simulations, statistical analysis, image processing, 3-D and temporal dimension visualization, together with the possibility of coding expert reasoning digitally. Also, software customization is possible specifically configured to required scales and applications, to achieve a flexible inter-operational environment. All those capabilities contribute to the integration of a powerful decision making tool for agriculture, where its use in natural resource preservation and environmental management will have unquestionably profound practical benefits.

The terms intelligent DSS or expert DSS have been introduced to make reference to the use of artificial intelligence techniques to extend the capacities of the DSS in the solution of problems ([27] y [7]). The trend in the evolution of the DSS paradigm leaves clear that the focus on rational static analysis is being left in favour of a more iterative, complex and adaptative paradigm ([25]).

When the spatial component is added to DSS, then spatial information management is possible evolving into Spatial Decision Support Systems (SDSS).

Six characteristics of DSS have been identified [5] and [13]. These characteristics are: 1) explicit design to solve semi-structured problems; 2) powerful user interface and easy use; 3) ability to combine analytical models with data in a flexible way; 4) ability to explore the solution space building alternative; 5) capacity to support variety of styles in decision making; and 6) problem-solving in an interactive and recursive way. Added to the list are those capacities and functions, which distinguish an SDSS: 1) to provide mechanisms for input spatial data; 2) to allow the representation of the relationships and spatial structures; 3) to include spatial and geographical analysis techniques, and 4) to provide outputs in different spatial forms, including maps.

As [18] outlined, this type of DSS makes an important contribution, not only to advancing technology but also to incorporating the spatial dimension in the decision making process, which has great significance in areas related to conservation and management of natural resources.

2. RELATIONSHIP BETWEEN GIS AND SDSS

SDSS and Geographic Information Systems (GIS) are closely related. Specialists do not even conceive the existence of a SDSS without the inclusion of GIS elements or components.

Some authors like [26] carried out an analysis where GIS, DSS and SDSS were compared. They have concluded that a GIS is able to be an effective tool in decision making process and therefore it should be integrated with software able to carry out model management. This has been achieved with success. Storage, queries, and visualization of spatial data with GIS is possible, in spite of it having the mathematical modeling of these systems limited to simple arithmetic operations and spatial overlays. This deficiency requires of external modelling routine use and it can be corrected with the construction of SDSS.

On the other hand, [5] exposed GIS limitations and why sometimes it is necessary to use SDSS for a group of problems:

1. The capacities of analytical modeling frequently are not part of the GIS.
2. The group of variables or layers in the database can be insufficient for complex models.
3. Data have insufficient scale and resolution.

At the present time, SDSS implementation is not conceived without considering GIS integration in order to link it with the geospatial data and with a group of analytical modules, based on models of diverse types and orientations.

Today, there is an increasing interest in the development of SDSS. These systems are characterized by the spatial and geometric relationships of data representing objects and their position in the geographical space. Tools of spatial decision, such as GIS and Computer Aid Design (CAD) do not include the analytical capacities represented by the modules mentioned above, therefore they are not able to provide complete answers to satisfy the needs of modern decision making. The integration of all these automated tools inside a single working environment and a single user graphical interface is desirable if not essential. However, many technical problems should be solved, and they are related to data management and data inter-operability between modules. Data exchange and transfer, sharing of results and of parameters between models, for a smooth data flow and efficient information processing.

Well designed and functional interoperability tasks are needed in order to support an efficient decision making process. Interoperability is the capacity to organize and transfer information among models and analytical modules and functional components, which appear integrated in a system. In the components of a DSS, interoperability is measured by the ability of the system to orchestrate the acquisition, transformation and presentation of the information during the whole decision making process ([32]).

3. ARCHITECTURES OF A SDSS

A SDSS, from the stand point of its operation, requires essentially of 4 modules or major operations s to support decision-making. These are: Data input (e.g. images and data), Database Management, Analysis and Presentation. Five key modules for SDSS architecture have been suggested by [1]. These are:

1. A Database Management System.
2. Analytical procedures in a Model Base Management System.
3. A screen generator.
4. A report generator.
5. User interface.

The components of a SDSS as defined by [20] are:

1. Database Management System (DBMS), which contains the functions of manipulation of the geographical database.
2. Model Base Management System (MBMS), which contains the functions for model use and management.
3. Dialogue generation and management system, which manages the interface between the user and the rest of the components of the system.

For the programmer, this modular structure facilitates the development of the software and from the user's perspective the SDSS appears as seamlessly integrated.

Different authors have examined the history and evolution of the DSS. For instance,[28] divided it in 5 stages according to the evolution of their architectures. For this analysis the pattern SMP (Structures, Mechanisms and Policies) paradigm was used, ([23]), beginning from algorithms and simple programs and the first computers until the employment of object-orientation , sophisticated computers and the architecture DSP (Decision Support Process – Decision Support System) with Executable Modeling Languages (EML) (Figure 1). This type of DSS model has presents 3 major advantages:

1. It is independent of the types of necessary models in the decision support system; making the DSP to be portable through several domains of problems and tools.

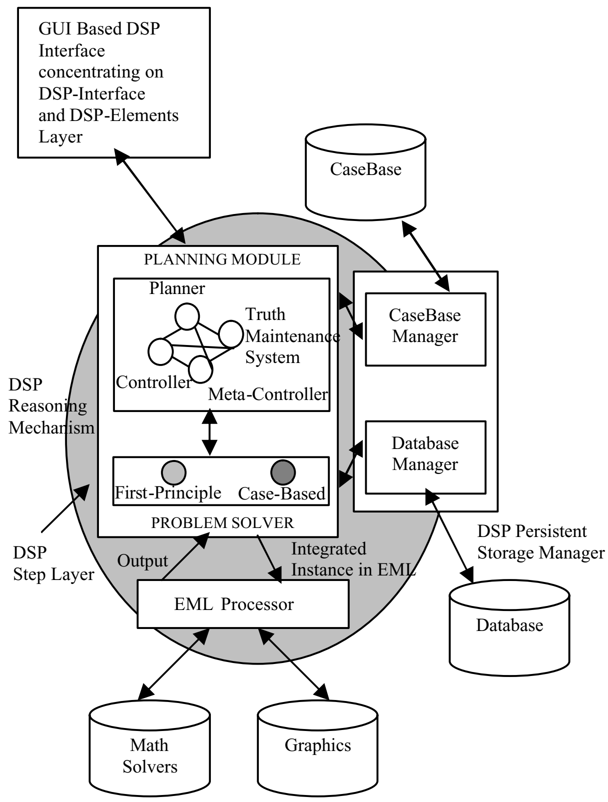

Figure 1. DSP architecture proposed by [28].

2. It provides a stable DSS architecture due to the fact that new tools and agents can be added without having to modify the superior layers of the architecture.
3. It creates a tool integration environment.

A DSP architecture provides independence, stability and integration, three desirable elements that must be included in a general design of an Automated Geospatial Decision Support System for sugar cane Planning in Cuba (AGDSSP).
The basic architecture of a SDSS leaning on the elements that [13] exposed on the definition of these systems, was shown by [15] in Figure 2.
Some of the design problems were exposed by [2]. The first DSS presented such problems and showed how the advances in information technologies have influenced the creation of more flexible designs faster and more responsive systems. The examinations provided by [22], [6], and [19], indicates the importance of the object-orientation paradigm, achieving benefits in the design of SDSS, and making them more interactive systems (Figure 3).

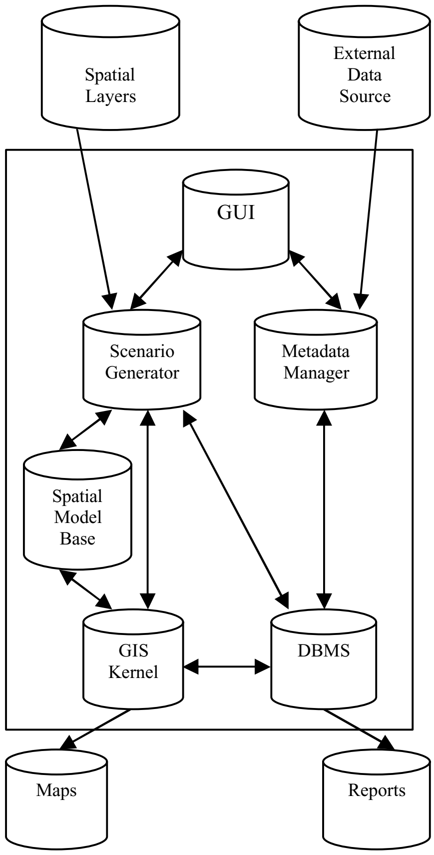

Figure 2. SDSS Architecture suggested by [15].

An integrated focus for DSS in related areas with conservation and natural resource management was suggested by [10] (Figure 4).
As [25] recognized, this approach can only be feasible for sophisticated software keeping in mind the inclusion of aspects and functionality for participatory decision-making. Specialists like [14] added new elements, which allow to correct the deficiencies of the previous one as to meet the needs of the different users, which impact on the decision making (Figure 5). Nevertheless, this approach does not include feedback mechanisms, which affects negatively in the participatory process.
In general, DSS frameworks are based on sophisticated computer software but we have considered that it is very important for the development of AGDSSP to incorporate as components participatory decision making tools and models and GIS. Thus, multi-objective optimization tools and multi-criteria group decision making have been considered as important components in AGDSSP to guarantee the searching for the best solutions and feedback mechanisms.

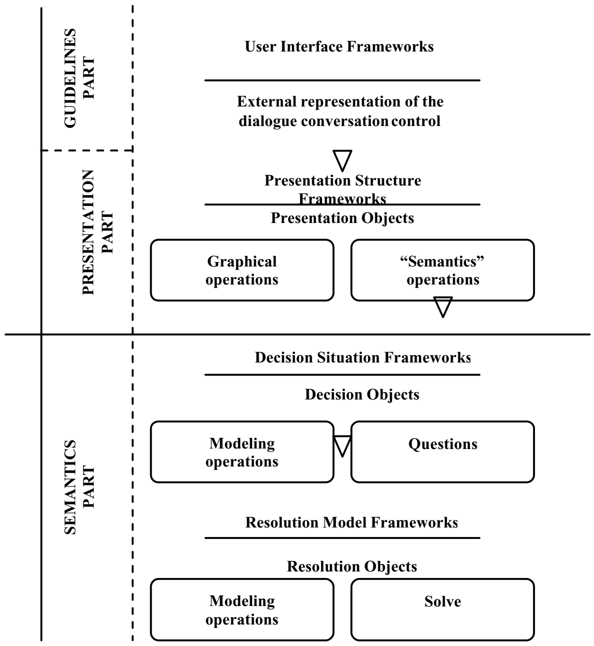

Figure 3. Object-oriented DSS architecture suggested by [2].

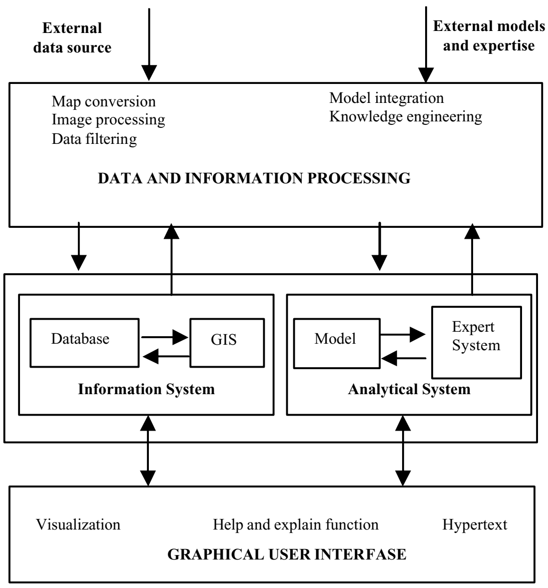

Figure 4. Integrated schema proposed by [10].

As it was mentioned before, SDSS need GIS elements for their implementation. Current developments in GIS tools have ported the technology to the internet, in what has come to be known as WebGIS, which allow for distributed GIS functionality in both, Internet and intranets in real time. The functional characteristics of systems that use such tools have been exposed by [11] and [29]. In the near future, the National Sugar Cane Research Institute (NSCRI) could develop architecture such as that proposed for AGDSSP due to the fact that this agency is a research institution with a network of 14 research stations n in different zones of the country.

Multimedia techniques have also been incorporated to SDSS. Two new technological developments where they could make use of GIS-hypermedia are PDA (Personal Digital Assistants) and GPS (Global Positioning Systems); they contribute to improve the understanding of the different phases and tasks of the system, because their technologies allow presenting the information in a way closer to the form required for decision-making.

GPS and GIS technologies can be incorporated to AGDSSP by the time when some of the studies conducted in precision agriculture for sugar cane crop to determine fertilizer recommendations at specific sites, are finished.

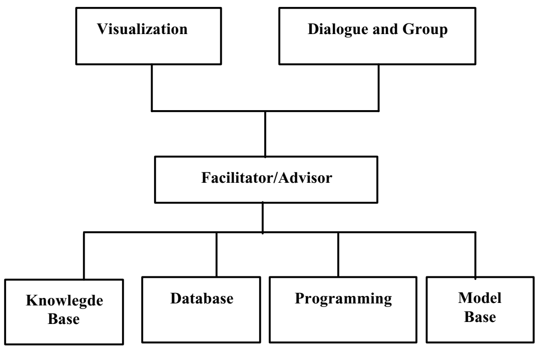

Figure 5. A schema proposed by [14].

4. TECHNOLOGIES FOR THE DEVELOPMENT OF A SDSS

There are three indispensable technologies for the construction and implementation of a SDSS. They are: SDSS Tools, SDSS Generator and SDSS specific functions ([20]):

1. Examples of SDSS Tools are:
Programming languages and libraries (ARC MACRO Language of ARC/INFO, ISL of ILWIS, Mapbasic Language of MapInfo). Visual Programming Languages (Microsoft Visual Basic, Microsoft C++, Borland Delphi).
Software of communication inter-applications (Dynamic Data Exchange (DDE), Object Linking (OLE), Open Database Connectivity (ODBC)).
Languages and simulation software (MATEMATHICA, SIMULINK, MAPLE, MATLAB).
Programming interfaces for applications (API) (IBM's geoManager API, Java Advanced Imaging API).
Visual interfaces, graphical subroutines and treatment of colors (Graphical User Interfaces - GUI).

2. SDSS Generator examples are:
GIS (ARC/INFO, ARCVIEW, MAPOBJECTS, ILWIS, IDRISI, MAPINFO, CARIS).
Database packages (family dBase, Microsoft Access, Paradox, Informix, ORACLE).
Analysis Programs, Operations and Optimization.
Statistical analysis (SAS, S-PLUS, or SPSS).

3. Specific SDSS examples are:
GeoMed
winR +GIS Spatial Decision Support

Figure 6, [31] represents a DSS Generator, which are tools making possible the building of a specific DSS in a quick way. On the other hand, [20] aimed they consist of packages which relate hardware and software that offer a group of capabilities to build a specific SDSS in an easy and flexible way.

The DSS Tool intervenes and helps in the development of DSS Generator or on the development of a dedicated DSS. The last one of the dedicated systems are oriented to the solution of group particular problems.

The three technologies described above were used for the construction of AGDSSP.

SDSS Tools in AGDSSP:
Programming languages and libraries for development have been selected. In our case ILWIS Script Language and CARIS GIS Macro languages have been selected and used. They have been useful to build some queries and routines from GIS software. Some examples of scripts which have been developed can be found within the Integrated Land and Water Information System (ILWIS) script generation. Among the scripts developed are maps of available soil phosphorus and potassium content and pH. Required fertilizer application (NPK), tillage requirements and area balance calculations in sugar cane crop.

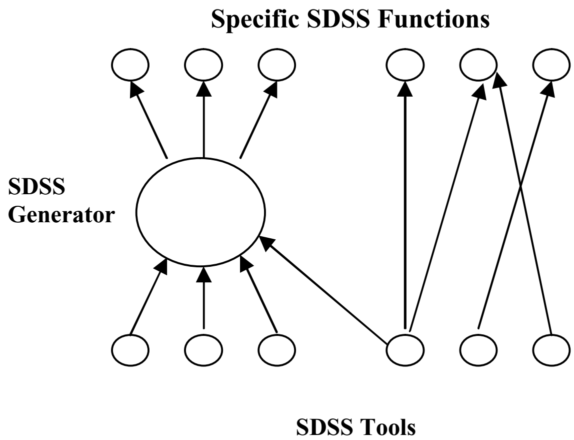

Figure 6. DSS Technologies by [31].

Modelling and data processing applications made through Visual interfaces are implemented and at the same time can link with some customizing scripts and the output of these applications can be presented spatially as maps with GIS.

A Graphical User Guide (GUI) is in construction. It must be able to allow for a seamless integration and to hide the "jumps" between AGDSSP modules.

SDSS Generator in AGDSSP:
As it was mentioned earlier, GIS is an important component in a SDSS. ILWIS and CARIS GIS were selected to add GIS component functionality to our AGDSSP.

ILWIS is known as a user-friendly and widely distributed GIS and Image Processing package. ILWIS provides a powerful tool for collection, storage, analysis, transformation and presentation of data. From data input, information can be generated to model the spatial and temporal patterns and processes on the ground. In principle, it is possible to build an interface between ILWIS and the Automated Evaluation System (ALES), which is the software used for the application of land evaluation models.

CARIS GIS is a fully functional state-of-the-art suite of tools for data capture, editing and updating, manipulation and presentation of spatial data. The design is modular, allowing customized packaging of the software to meet varying user requirements.
AGDSSP is prepared to support database of dBase family and Microsoft Access because sugar cane data in Cuba is stored in these format.
A solver can be used in the optimization process and the analytical hierarchical process (AHP) for eliciting input from stake-holders. The latter are fundamental modules in a Decision Support System for natural resource planning.
AGDSSP will be a dedicated SDSS for sugar cane, when its development is completed and then it can be available for specialists, researchers, experts, producers and other users with interest in the various aspects of the production of sugar cane.

5. DESIGN OF A SDSS FOR SUGAR CANE IN CUBA

In Cuba, sugar cane crop represents the main agricultural and industrial product and it is source of income and wealth. It is for this reason that around 1,5 million hectares representing little more than 21% of the total area cultivated, are dedicated to sugar cane plantations in the whole country.
The implementation of a AGDSSP in sugar cane has as main purpose to contribute to the rational decision making and the strategic planning of land resource use and production, based on information, and then to improve the crop yields of sugar cane and alternative crops, by introducing modern techniques of digital information management, to achieve the sustainable use of the production resources, through the use of an expert system integrated to AGDSSP.
A brief description of the system's architecture and the interaction among the basic integrated components is shown in figure 7. The spatial component has great importance in the information of natural resources. The GIS is conceived as the central nucleus of the GDSASP, which will allow to interrelate the results of the different modules and it will be able to support a user interface that achieves the navigation through each one of the integral parts of the system in a harmonic and intuitive way. In addition to map output, GIS is also able to make graphical output and the generation of reports.
At the core of AGDSSP is a GIS and a group of computer tools, responsible for the implementation of the modules of land evaluation, optimization of scenarios generated in a participatory way, as well as recommendations of agronomic practices.
Land evaluation is implemented by the use of two tools. The first one allows making a physical land evaluation for sugar cane crop through the method of the maximum limitation method that affects the potential yield (Agro24 system). A socioeconomic evaluation is implemented, based on the FAO (Food and Agriculture Organization of the United Nations) methodology by the ALES software (Automated Land Evaluation System). As a result of this process a matrix of suitability ratings (classes) is obtained, where each land unit evaluated corresponds to a suitability level in connection with the land utilization types (LUT) defined by experts. The results will be represented in a GIS with ease by the use of the built-in interface between GIS and ALES for information transfer. The generation of optimization of land use scenarios is still under study. As [9] pointed out the results of the assessment is to obtain a LUT for each land unit, generating with it a group of fine LUT, according to an objective function and its corresponding constraints. The results generated at the level of land units can be shared readily with the GIS. Solver tools will be acquired and evaluated to decide which is the most compatible to reach the objective layouts.

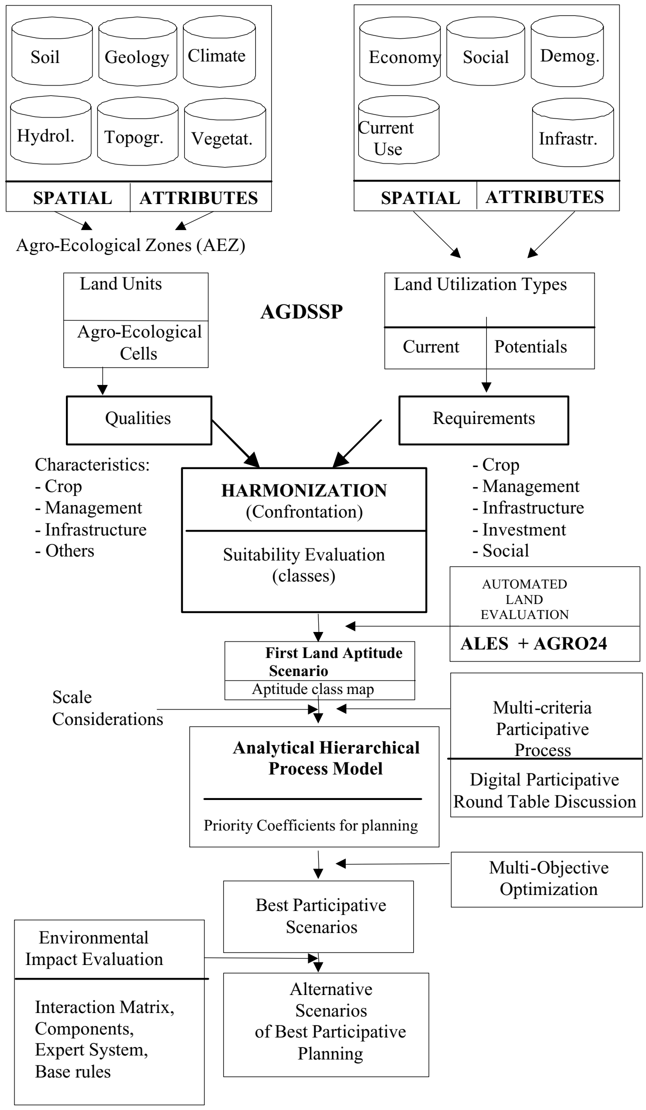

Figure 7. Geospatial Decision Support Automated System of Planning in sugar cane Methodology.

The Analytical Hierarchy Process will be chosen for allowing stake-holders input into the generation of scenarios of land use in a participatory way.
The multi-objective optimization model is structurally a function of objective functions. That is a global or objective function for the zoning area, which is made up of the individual objective functions representing the interests of resource users or stake-holders. The use of goal programming (GP) represents a viable approach to the solution of the problem and for the building of the objective functions. Although GP is not a technique for multi-objective optimization *strictus sensus*, it allows to structure the problem but in a marked relative simplicity ([24]).

In terms of progress made in the development of AGDSSP, the stages developed so far are:

? Spatial and attribute databases about biophysical characteristics (soil, climate and other databases)
? Agro-Ecological Zoning (this is the process of being extended to the national level).
? Land evaluation through the maximum limitation method produced at national level through the use of the Agro24 system. Also the results of land evaluation exercises in cropping areas part of the domain of a sugar mill. Such areas service the mill with raw materials (sugar crop) and are evaluated according to the FAO methodology through the use of ALES.
? Definition of the first scenarios of land suitability.
? Spatial representation of the results of the land suitability assessments obtained through ILWIS.

The immediate steps to be taken by the development team are as follows:

? Gathering of social and economic data.
? Definition of different Land Utilization Types not included yet in the analysis.
? Development of new land evaluation models, where biophysical factors as well as socio-economic ones are involved.
? Development of scenarios keeping in mind the aspects of the previous step.
? Development of the participative process of decision making to strengthen and to enlarge the technical results obtained, through the revelation of the actor preferences involved in the decision making with land use in each area.

The integral recommendations of agronomic management system will have as objective the election of the best land for sugar cane and its corresponding management technology, for land preparation, planting, cropping and harvest practices that influence directly agricultural yields. Also, the inclusion of economic and other factors that influence directly in the agricultural yields.

6. CONCLUSIONS

The SDSS constitutes a special case of DSS, which have incorporated the manipulation and data analysis and spatial models in the search of optimal solutions for no-structured problems through different alternative techniques. These require GIS capabilities and functionality.

The evolution of DSS and their variety as for conception for problem solution have allowed to the implementation of different structures and architectures which have been improved with the time, thanks to the development of different specialties of the computer science with software and more sophisticated hardware.

The key point of user interface in a SDSS, in spite of the demands of intuition and clarity for the development of the different tasks, rests in achieving the smooth manipulation of the different modules in a way seamless to the users.

Multimedia and internet tools are emerging as services which are opening a new era in the functionality and development of DSS. These allow for a bigger access to resources to users and managers responsible for decision-making.

The AGDSSP will represent an important contribution to efforts for sustainable agricultural development in sugar cane cropping in Cuba.

7. REFERENCES

[1] M.P. Armstrong, P.J. Densham, Database organization alternatives for spatial decision support systems, International Journal of Geographical Information Systems, Vol 3(1): Describes the advantages of the extended network model for network-based problems, 1990.

[2] K. Becker, F. Bodart, An Object-Oriented Framework-based Architecture for Decision Support Systems, 18 pp, http://citeseer.nj.nec.com/becker96objectoriented.html, 1998.

[3] W.J. Craig, D.D. Moyer,: Progress on the Research Agenda: URISA'90. URISA Journal, Volume 3, Number 1, Spring 1991, pp. 90-96.

[4] J.V. Davidson, Tool Integration: Beyond Shared Files and Macros. GIS/LIS '92, Vol. 1: 165-176, 1992.

[5] P.J. Densham, Spatial Decision Support Systems, In: Maguire, D.J., M.F. Goodchild, and D.W. Rhind, eds. Geographical Information Systems: Principles and Applications, vol 1, London: Langman, 403-412. http://www.geog.ubc.ca/courses/klink/gis.notes/ncgia/u59.html, 1991.

[6] D.R. Dolk, M. Ackroyd, Enterprise modeling and object technology. In: Third International Conference on Decision Support Systems – Hong Kong, June 22-24, 1995. Proceedings, p. 235-245.

[7] M.K. El-Nadjdavi, A.C. Stylianou, Expert Support Systems: Integrating Technologies. Commun. ACM 36, 12 (1993).

[8] M. Enache, Maximizing the Value of Information in Urban Policy-Making. URISA Proceedings, Vol.IV, pp. 65-76, 1991.

[9]FAO, Proyecto Regional Información sobre Tierras y Aguas para un Desarrollo Agrícola Sostenible, Proyecto GCP/RLA/126/JPN. Informe Técnico No. 1 Volumen 1. Sistema de Información de Recursos de Tierras para la Planificación: Una Herramienta de Apoyo para la Planificación y Ordenamiento del Uso del Territorio, 76pp, 2000.

[10] K. Fedra, Decision support for natural resources management: models, GIS, and expert systems. AI Applications, 9/3 (1995) pp. 3-19. http://www.ess.co.at/docs/papers/dssc.html.

[11] K.E. Foote, A.P. Kirvan, WebGIS, NCGIA Core Curriculum in GIScience, http://www.ncgia.ucsb.edu/giscc/units/u133/u133.html, posted July 13, 1998.

[12] S. French, Y. Liang, Decision Supports Systems: A Decision Analytic Perspective. Published in: J. Norman (ed) OR Society Tutorial Papers, 1993.

[13] A.M. Geoffrion, Can OR/MS evolve fast enough? Interfases 13:10. Source for six essential characteristics of DSS, 1983.

[14] P.A.V. Hall, ed., Decision Support Systems for Sustainable Development: Experience and Potential: A position paper on the findings and recommendations of the International Conference on Decision Support Systems for Sustainable Development: Software Technology for Agenda 21, organized by United Nations University, International Institute for Software Technology and IDRC, 24 Feb – 8 March 1996, Macau). Ottawa: IDRC, 1997.

[15] G.B. Hall, R.L. Bowerman, R.D. Feick, GIS-based Decision Support Architecture and Applications for Developing Countries South Information Systems: Principles and Applications, 403-412, New York: John Wiley, 1997. http://www.fes.uwaterloo.ca/Tools/docs/saj.pdf

[16] W.D. Haseman, GPLAN: An Operational DSS. DATA BASE 8(3): 73-78 (1977)
[17] P. Keen, Decision Support Systems: The Next Decade. Decision Support Systems: a decade in perspective, edited by McLean, E and Sol, H.G., North-Holland, 1986.
[18] P. Keenan, Using a GIS as a DSS Generator Department of Management Information Systems. Michael Smurfit Graduate School of Business, University College Dublin. Working Paper MIS 95-9, 1997.
[19] J. Ma, An object-oriented framework for model management. Decision Support Systems, 13(2) : 133-149, February, 1995.
[20] J. Malczewski, Spatial Decision Support Systems, *NCGIA Core Curriculum in GIScience*, http://www.ncgia.ucsb.edu/giscc/units/u127/u127.html, posted October 6, 1998.
[21] NCGIA, Research Agenda for Geographic Information and Analysis. Technical Report 92-97. The National Center for Geographic Information and Analysis, 1992.
[22] O. Nierstrasz, S. Gibbs, D. Tsichritzis, Component-oriented software development. Communications of ACM, 35(9): 160-165, September 1992.
[23] D.E. Perry, G.E. Kaiser, Models of Software Development Environments, 1991.
http://www.ece.utexas.edu/~perry/work/papers/tse17-3.pdf
[24] R. Ponce Hernández, Zonificación Ecológica-Económica: Una Propuesta Metodológica para la Amazonia. Organización de Naciones Unidas para la Agricultura y la Alimentación (FAO). Proyecto GCP/RLA/128/NET Apoyo a la Secretaría Pro Tempore del Tratado de Cooperación Amazónica, Caracas, Venezuela, 1998.
[25] M.A. Rahman, A Participatory DSS to Incorporate Local Knowledge for Resource and Environmental Management in Developing Countries. *Ph.D. Comprehensive Examination (Paper)*. Department of Geography, Faculty of Environmental Studies, University of Waterloo, Canada, 1998.
http://www.fes.uwaterloo.ca/u/marahman/PhD_Comprehensive.html
[26] T.C. Ryan, Spatial Decision Support Systems, Urban and Regional Information Systems Association 1992 Proceedings, Vol. 3, p. 49-59.
[27] A. Sen, G. Biswas, Decision Support Systems: an expert systems approach. Dec. Support Syst, 1985.
[28]A. Sen, From DSS to DSP: A Taxonomic Retrospection. Lowry Mayes Colleges of Business Administration at Texas A&M University, 1996, 10 pp. http://www.acm.org/cacm/extension/sen.pdf
[29] M.J. Shiffer, Interactive Multimedia Planning Support: Moving from Stand-Alone Systems to the World Wide Web. Environment and Planning B: Planning and Design, volume 22, pp. 649-664, 1995. http://gis.mit.edu/people/mshiffer/inter.html
[30] H.G. Sol, Processes and tools for decision support: Inferences for future developments. In *Processes and Tools for Decision Support*, (ed. Sol, H.G.), North Holland, Amsterdam, the Netherlands, pp 1-6, 1983.
[31] R. Sprague, A framework for the development of Decision Support Systems. MIS Quarterly, 4, 4, December 1980.
[32] P. van Voris, W.D. Millard, J. Thomas, D. Urban, TERRA-Vision - the integration of scientific analysis into the decision making process. International Journal of Geographic Information Systems, 7, 143-164, 1983.
[33] M. Walsh, Toward spatial decision support systems in water resources .Journal of Water Resources Planning and Management v 119 n 2 Mar-Apr 1993. p 158-169.