Participative Research to Develop a Model for Decision Making in Precision Agriculture

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Abstract

This paper demonstrates the learning process of a University Farm (UF) manager during a systems analysis. The analysis included Human-Activity analysis, Socio-Technical analysis, Information analysis, and Decision Analysis. The Human-Activity analysis described the organizational structure of the UF. The Socio-Technical analysis covered the satisfaction level of the UF employees. The Structured Analysis and Design identified assisted in handling precision agriculture and research trials' data on the UF. The Decision Analysis identified and structured the decisions made for field operations. Having the farm manager participating in the whole process enabled her to see the whole farm in a different perspective, understood employees' skills and needs and learnt more about all levels of farm management decisions.

Keywords
Systems analysis, precision agriculture, participation, learning process

Introduction

Precision Agriculture (PA) can be defined as the management of spatial and temporal variability to improve economic returns and reduce environmental impact. This can be achieved through using appropriate technologies within a coherent management structure. PA technology now has the ability to produce data about soils and crop at sub metre level across the whole field, but the capability to use this data is very limited until suitable information systems and effective decision making procedures are developed (Blackmore, *et al*. 2002). The necessity of management information systems to support decision-making in PA has been also recognised by a number of researchers and producers. Atherton et al. (1999) claimed that the gap between acquiring site-specific information and using it effectively in making agricultural management decisions has widened. They concluded that there is no "cook book" to cover those issues, but that each manager must collect only those data that can be used effectively for management decisions. The U.S. National Research Council (1997) proposed that systems principles are required for decision-making in PA and ways to respond to questions on information needs.

This project was based on the Royal Veterinary and Agricultural University's (KVL) farm. KVL University Farm (UF) has four farms in Taastrup, East to Copenhagen, with a total area of 210 ha, 2000 m^2 glasshouse, 14 growth chambers and several other experimental facilities. The UF is organizing and carrying out research experiments as an internal charged service for researchers at KVL. It is a well-organised section with around 15 employees. The KVL UF faces many difficulties on how to deal with all the spatial and temporal data, gathered with the use of PA as well as the results of the research trials and be ready to adopt new technologies, such as data gathering from autonomous vehicles' operations. As a result, the UF would like to be at the cutting edge of the new technologies for educational, experimental and production purposes. To understand the current situation in the UF, a systems analysis

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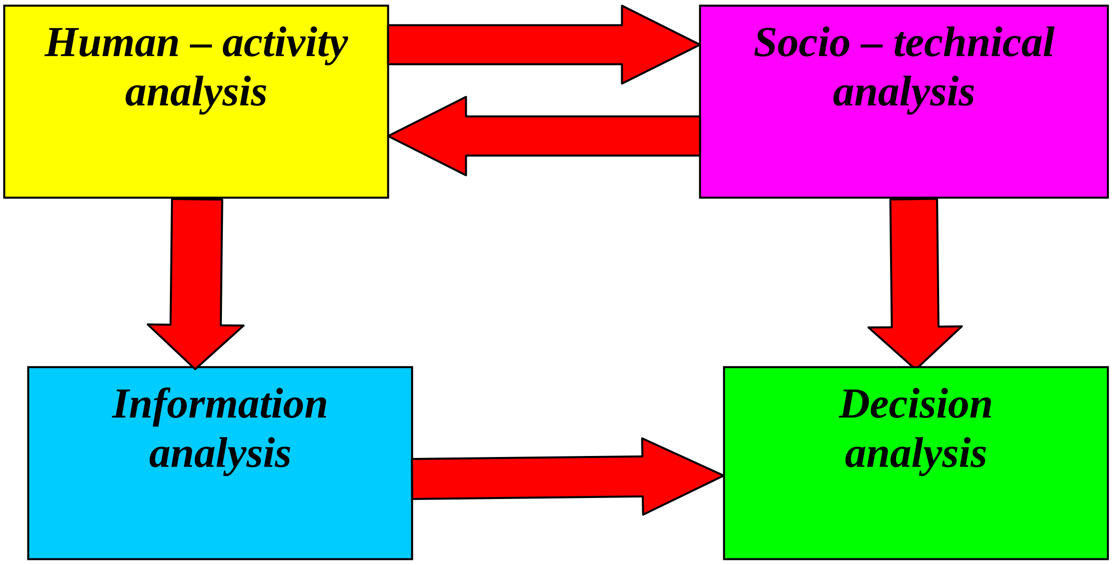
was carried out to identify users requirements, skills and perception of the staff towards the new technologies and problems in information management and decision-making process. Furthermore, an information system was proposed to store, process, visualise and incorporate the data gathered from the use of PA and research trials.

The systems analysis consisted of Human-Activity analysis, Socio-Technical analysis, Information analysis and Decision analysis. This paper demonstrates how the UF manager benefited participating in the whole process, learning new aspects of the UF and understanding more about staff skills.

Methods

The method that found to be more appropriate was the “Multiview”. This method combines important aspects of some of the major methods into a more coherent and flexible approach, and thus offers the practitioner a broad understanding of the whole process of systems analysis (Wood-Harper et *al.*, 1985). The applied stages of the “multiview” method were Human-activity analysis, Information analysis, Socio-technical analysis. Additionally to those, a Decision analysis component was added.



At the beginning, the Human-Activity analysis was applied. Intensive interviews with the UF farm manager were carried out trying to identify the scope of the research, trying to outline the people and activities including in the system through the “rich picture” and relevant systems, following the soft systems method. Having identified the customers and the users of the system, personal interviews were carried out with both the customers and the UF staff.

The findings of the interviews from the users and customers at the early stage were used to plan and structure the socio-technical analysis. The “Ethics” method was used to construct a closed-ended questionnaire in order to describe the level of job satisfaction of the users. Additionally, two more sections were added. The one was related to the customers’ requirements towards the UF employees-users, derived from the personal interviews and the second section was related to the application of the new technologies. ETHICS (Effective Technical and Human Implementation of Computer-based Systems) was devised by Mumford (1995) based on the participative approach to information systems development. The ETHICS method consisted of five different sections (fits):The <u>knowledge fit</u> examines if the employees believe that their skills are being adequately used and that their knowledge is being developed to make them increasingly competent. The psychological fit examines if a job must fit the employee's status, advancement and work interest. The efficient fit tests the effort-reward bargain, work controls and supervisory controls. The task-structure fit measures the degree to which the employee's tasks are regarded as being demanding and fulfilling. The ethical fit examines the social value fit and measures if the values of the employee match those of the employer organisation.

The results of the Human-activity and Socio-technical analysis were used to develop the diagrams in the information analysis part. The Entity Relations diagram was tried to build parallel to the Data flow diagram for consistency.

The Decision Analysis was carried out using methods taken from Management Information Systems (MIS). A well-structured MIS has to cover a set of questions, which are called "the five W's and an H" (Mitra, 1986; Koory and Medley, 1987). These questions are: What information is needed? When is the information needed? Who needs it? Where is it needed? Why is it needed? and How much does it cost?

Results

Human-activity analysis

The human-activity analysis resulted in a rich picture, relevant systems and conceptual models for the systems that the farm manager was interested in pursuing further. The rich picture of the research farm is shown in figure 1, where in the centre is the farm office with the farm manager. The main activities of the research farm were agricultural field operations, accountancy, public relations and issues related to regulations from the Ministry of Agriculture. The key people involved were the farm manager, the staff of the farm, the researchers-customers (rend subfields for trials) and the specialists researchers (provide advice). The research farm management board, the KVL administration and the Head of Department were decided to be outside of this system. The conflicts and the problems for the farm manager can be seen to be the need for modernization and the conversation from the collected data to useful information. Moreover, the researchers who have used the farm would like to have the staff working closer to them, while the staff faced internal communication problems.

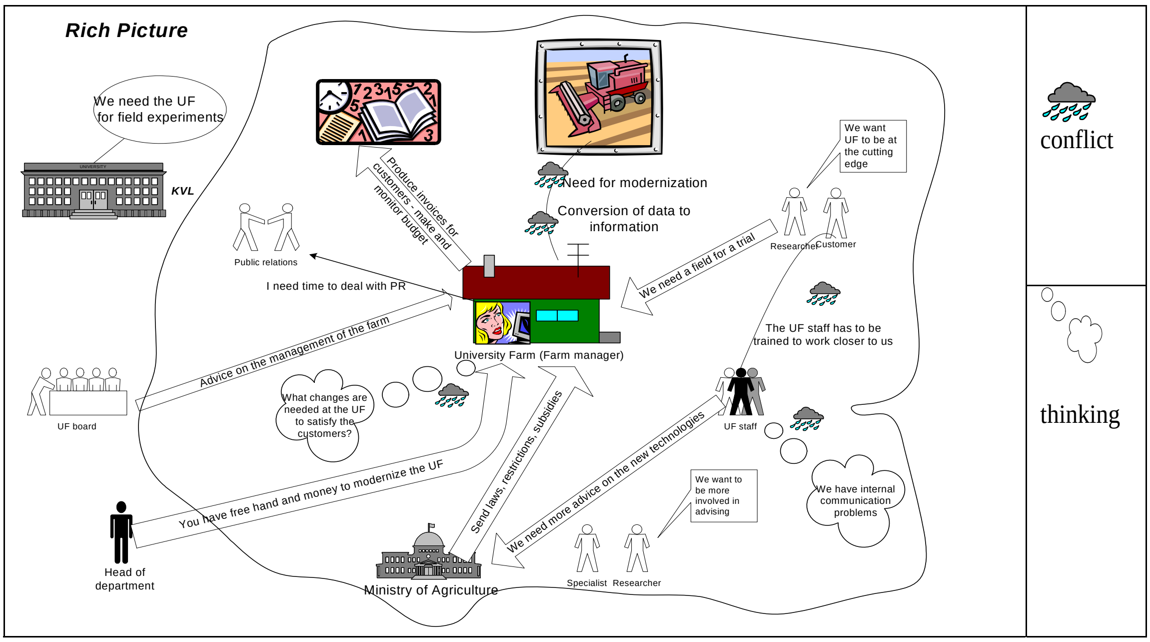


Figure 1. Rich picture

With the completion of the soft systems analysis, data flow diagrams and entity relationship diagrams were developed to describe the proposed system. The root definition of the most relevant system was: "A university owned and operated system to handle spatial data from the fields, by means of precision farming management tools, in conformance with scientific needs, in order to demonstrate the information from the crop production to researchers at KVL. The CATWOE for this root definition was the following:

Customer: Researchers; *Actor*: UF staff; *Transformation*: field trials -> spatial information; *Weltanschauung*: the belief that spatial and historical field data should be easily viewed and utilized by all interested researchers; *Owners*: UF manager; *Environmental constraints*: University expectations

Socio-technical analysis

The findings of the interviews from the users and customers at the early stage were used to implement the ETHICS questionnaire with two more sections. The one was related to the customers' requirements towards the UF employees, derived from the personal interviews and the second section was related to the application of the new technologies with focus on precision agriculture and autonomous vehicles. A questionnaire of 65 questions was distributed among 13 of the UF employees. The questionnaires were divided into two groups: the foremans and the non-foremans (technicians). The main findings on each category are summarised below:

Knowledge fit
In general terms there is a high degree of knowledge fit. The only problem is the non-foremen (technicians), who feel that their knowledge is not utilised fully (~80%)

Psychological fit
The UF staff is friendly and ambitious. These are important factors in order to agree on any kind of modernisation. They would like to carry out more responsibility and that comes along with the customers' requirements. However, they would like to receive more recognition from the management, when they accomplish good job.

Efficiency fit
The efficiency fit has to be further examined. In general terms, the staff was happy with the support and information they need, but not in a high degree. The non-foremen like to carry out the job without management intervention. That implies an improvement in the information and support they need. The time registrations database system (the way UF staff register time consumption) doesn't find all of them to have the same opinion. It is important and has to be further examined. The most important finding is the trust of the management in a very high degree.

Task-structure fit
There was a very distinct view non-foremen would like to work more independently, taking more decisions and be more team players. It seems that there was no certain problem with the foremen, as they feel happy with the existent situation. Therefore, there is a task-structure fit on the foremen, but not so much for the rest of the staff.

Ethical fit
There was not adequate ethical-fit as mainly foremen feel that they do not participate in the overall running and decision-making of the UF. The main problem was the lack of communication, although they felt that their manager cared about them in some extent.

Customers' requests
UF staff would like to have flexible working time. They would like researchers to work closer to them. They believed that they take the initiatives for new technologies in their areas. They also found the explanations of the project from the researchers good enough, but they would like more detailed explanations. They also supported that the UF management had to get new tools for farm management. Finally, they pointed out that UF management decisions are short-term oriented.

Precision agriculture (PA)
UF staff was not so convinced on the benefits of PA. They didn't also know where to seek and access information regarding PA. Half of the staff gets information regarding PA from magazines and exhibitions. They were also very sceptical about the use of driverless machines.

Information Analysis

In this stage, the main activities identified by the conceptual model from the Human-activity analysis stage were decomposed into Data Flow Diagrams (DFD) following the semantics of Structured Analysis and Design. An Entity Relationship diagram was also developed capturing all the data collecting in the UF and their relationships. In this case, the data from the use of PA was combined with the data of the research trials with the an entity called sub-field. Finally, a Data Dictionary was made to show the data attributes for each entity and process.

Decision analysis

Another part of the systems analysis process at the KVL UF was to gain a comprehension of how practitioners of PA organise their data to make decisions in a structured way. The information gathered through interviews with farm manager was used to develop a general model of the decision making information flow in PA. Initially, the farm manager listed the farm operations within a growing season, from field preparation to post harvest. Secondly, the decisions taken for each farm operation were identified and listed in chronological order, as well as the decision category for each decision: strategic, tactical or operational. The third stage, consisted of personal interviews with the farm manager at which all the decisions listed at stage two were analysed, by using the identified set of questions. To present how the decision analysis works, an example analyzing one decision (what is the seeding rate in variable rate seeding applications) is illustrated in Table 1.

Table 1. Analysis of decision "what seeding rate?"

Decision-analysis factors	Answers
Decision context	Variable rate seeding applications
Decision name: (Decision level) Decision outcomes:	What is the seeding rate? (Tactical) Application map; planting date; yield potential
Decision-maker: Participants: Influential people:	Myself My partners Seed dealers
Decision frequency: Decision timing:	Annually January
Decision triggers	Seeding date; It has to be done by April
Decision precedence	- Chemical programs, which we decided at the same time - Selection of seed variety
Management strategy:	Maximize yield
Information needed to help make decision:	Soil type data (1); Yield data (2); Soil moisture data (3); Field records or previous seeding (4); Public and private research information (5); Observation and experience from seed dealers (6); Seed rate recommended (7); Drainage information (8)
Desired-extra information	More information about weather; location to be available electronically and make the analysis from that; real-time sensing of the soil and estimation of weed population; soil moisture sensor data; good remote sensing data
Source of data or information: [Physical location]: {Access cost}:	Paper & spreadsheets [PC], Personal experience (1,2,4); Field samples (3); Remote sensing data [Consultant] {High cost}, Personal experience (3, 8); Published materials, magazines, newsletters [Internet, office] (5); Personal communication with seed dealers (6,7)
Description of information processing:	Make adjustments to the algorithm of the computer and generate the variable rate application map
Tools needed for processing:	- PC - Good GIS package and creation of an output file for the controller - If there is remote sensing data, GIS tools
Resource availability affecting decision:	-
Critical Assumptions:	The whole thing; We assume that maps are correct; Weather is going to be the most critical factor; Is the variety going to respond?

The decision analysis factors were assembled to form a DFD. Figure 2 demonstrates the tactical decision, which was described in table 1, about "what seeding rates" As indicated, soil type data (1), yield data (2), field records (4), drainage (8) are taken from the historical data database. These data are either stored as raw data or they produce papers of spreadsheets. The public and private research information (5) are taken from the "external information" database. The information about seeds were provided by advisors (6,7,8). The decision outcome of this decision fed the decision records database. These data can then be used for the next year's decision.

The Decision analysis method was developed at the KVL UF was further tested on two of Purdue University Farms, five commercial Indiana farms, one US crop consultant and two US extension educators. At the three University Farms (one in Denmark and two in the USA), the farm managers analysed all the decisions for field operations within a growing season. The commercial farmers analysed the decisions they make for one field operation. The analysis of the decisions was based on the decision analysis factors described in table 1.

Table 2. Field operations and decisions identified by the three university farms

University Farms	No of field operations	No. of decisions	Years practising PA	Cultivated crops
KVL Research Farm	29	42	4	Spring cereals
Purdue Ag Center (DAVIS)	23	30	8	Corn/Soybeans
Purdue Ag Center (NEPAC)	12	104	2	Corn/Soybeans

Table 2 shows the number of field operations, decisions, years practising PA, cultivated area and cultivated crops, throughout the analysis of the research farms. It is interesting to see the difference in the number of operations and the number of decisions each farm manager in the universities identified. This is due to the way each farm manager thinks and organizes his or her work and thoughts. It illustrates the learning process farm managers go through analyzing the farm management decisions they make.

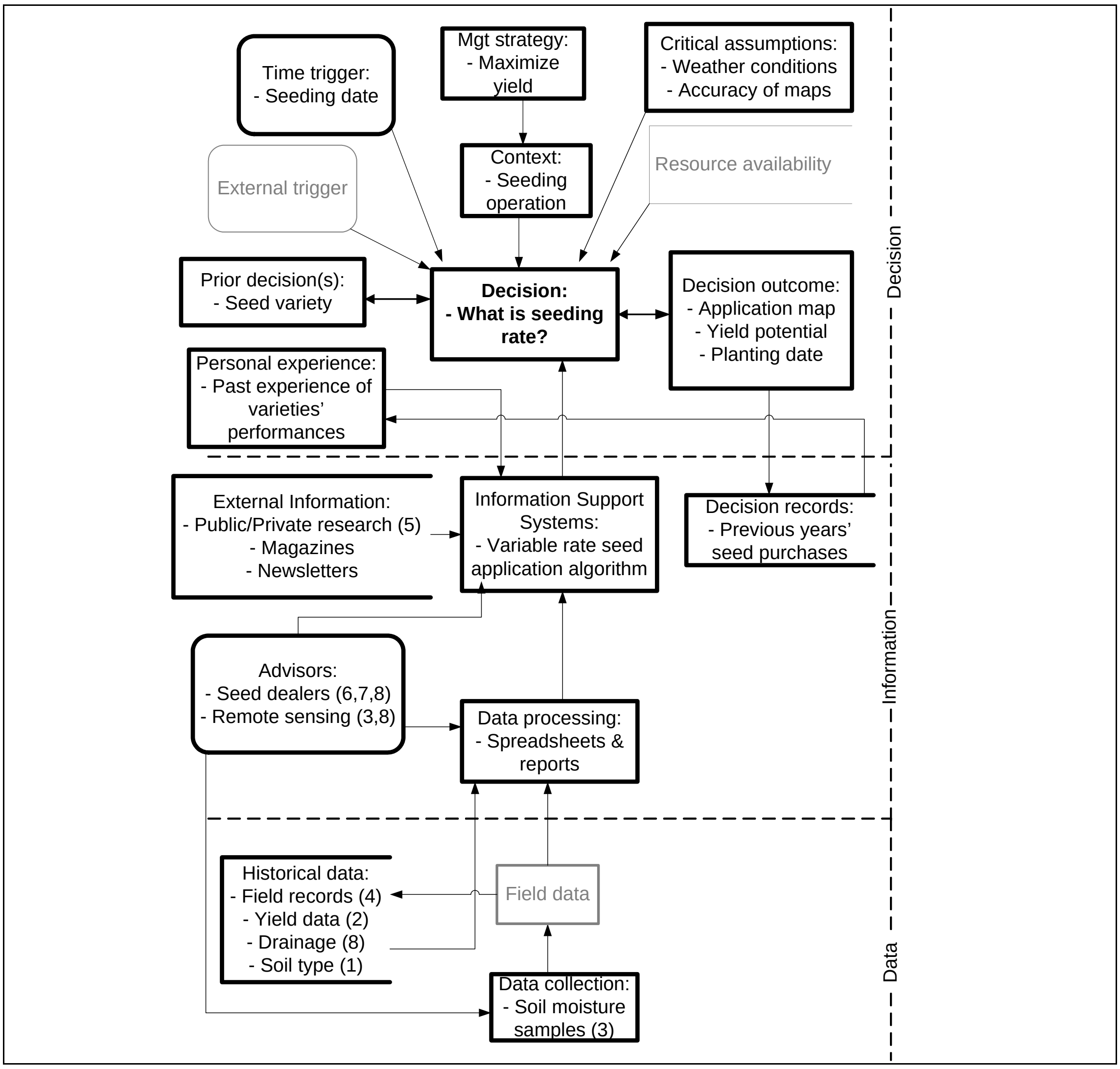
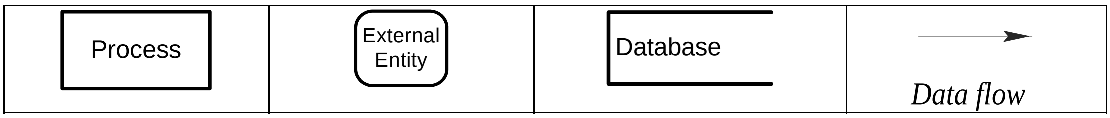


Figure 2. DFD model for the decision "What is the seeding rate?"



Key to figure 2

Discussion

This paper presented the results of the application of a soft systems method in the KVL UF and the development of a decision-making model within PA. This research was a part of a systems analysis research within PA, which also included socio-economic and hard systems analysis. The farm manager at KVL participated throughout the whole process in developing the different components of the soft and hard systems method, socio-technical analysis and decision-making. The farm manager was going through the terminology of the theory of all the different methods, learning by herself the systems analysis techniques and working together with the analysts during the whole period. As a result, she saw the organization (research farm) she manages in a different perspective. Moreover, the whole process helped the farm manager to better understand the role of her staff in different operations within the farm, how to further utilize their skills and their own perception of the farm's future development.

For this experience the farm manager at KVL research farm mentioned: "The whole process was very time consuming and the items and the way of thinking was unusual for a scientifically educated person. In that context the analyst's role was essential as a facilitator of the process. Therefore, as the process proceeded the point became more and more clear and I realized how much I would finally benefit from it. The two main outcomes were: 1. Clarification of the decision-making processes including the several elements of each process and the role of the participants in the different parts of each process, and 2. The data flow analysis and the DFD that now constitutes the basis for the construction of a geodatabase that can handle and present all kinds of data produced and gathered at the research farm. During the evaluation that was done in the following growing season I learned that we had done the analysis very thoroughly since I discovered no needs for iterations."

The learning process between analysts and users is also supported in the bibliography. McCown (2002) mentioned that there should be put emphasis from design to learning, trying to learn what the farmers are learning and learn what this means for conduct of their own future activity ("action research"), which is also the approach taking on this analysis in the decision making process, to understand how actually farmers make decisions.

Furthermore, the farm manager at North East Purdue Ag Centre (NEPAC), who applied the decision making method at his farm mentioned: "the decision-making process has been difficult and incomprehensible to me, especially when trying to organize and classify all the data that I have collected at NEPAC in the past eleven years. My goal has been to have concise and understandable databases (whether on PC or on paper) for NEPAC from which I can easily and quickly extract the data I need for decision making. I think that through this exercise you are helping me to learn how my mind works and I will come much closer to achieving my goal."

The decision analysis model is a systems approach incorporating the information gathered through field operations and analyses into the process of making a decision outcome. It was developed in a research farm in Denmark, but it was proved to be applicable in both research and commercial farms in the USA with different crops. The changes needed from the decision analysis factors or the model that was developed in Europe, were very limited after testing it in the USA. This shows that the general perception and use of the information for making a decision in different agricultural systems is not significantly different. However, the application of the process in the whole range of field operations proved to be very time consuming. The number of operations and decisions identified for the same agricultural systems, such as the two Purdue Ag Centres, shows the different grouping of perception and detail that a farm manager can apply. Moreover, aspects like timing and frequency involves uncertainty and it was not easy from the interviewees to answer. Risk and uncertainties are not referred to this method, as the model only tries to describe the decision environment and the information flow.

Conclusions

The process of systems analysis in a farm can enable farm managers get a more in depth understanding of their business. It can reveal conflicts and opportunities for changes and improvements. The decision-making method that was developed through the process can structure and formalize the farm management decisions.

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