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Critical Success Factors In Developing And Using Optimization-Based Decision Support Systems In Local/Regional Development Planning In Developing Countries

By

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Critical Success Factors in Developing and Using Optimization-Based Decision Support Systems in Local/Regional Development Planning in Developing Countries

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Introduction

Over the past 10 years, the pace of penetration and the range of applications of information technology (computers and communications) into organizations has accelerated dramatically. This has largely been fueled by the introduction of minicomputers and microcomputers, and their associated economics. For example, personal computers today have one hundred times the computing capability of a $2,000,000 computer in 1970 for 1.5% of the cost-adjusted for inflation. This change in economics has fundamentally transformed both the nature and impact of the new applications of information technology.

Information technology today affects all aspects of the activities of organizations in developed countries and is increasingly seen as a major tool for competitive advantage. The economies of IT is making it more accessible to organizations in developing countries as well.

Just as organizations compete, so do countries, regions, and cities. Traditionally, this competition has focused around actions such as improving transportation, utilities, and other public services; trade promotion; and urban redevelopment in an attempt to attract new firms and/or attract existing firms to expand their activities. In recent years, cities and regions have begun to exploit IT as a means to achieve competitive advantage through such activities as building a telecommunications infrastructure to support the needs of information-intensive industries; providing greater accessibility to public services through sophisticated networks; and improving the processes through which public institutions, encompassing various policy sectors and levels of government, attempt to regulate and guide sets of events and decide on future action. The feasibility and value of pursuing such strategies should be considered by developing countries as well.

The focus of this paper will be exploring how IT can be used to add value to the regional planning process. In particular we are interested in exploring the critical success factors in developing and implementing a
particular type of computer-based information system called an optimization-based decision support system (DSS) that has the potential to enhance the quality of decision making exhibited by professional planners in formulating and implementing regional development plans.

Decision support systems (DSS) are computer-based systems that have a primary objective of helping a decision maker devise high quality solutions to what are often only partially formulated problems. At a minimum, complex decision making involves: searching for information about the current and desired state of affairs, inventing possible courses of action, and exploring the impact of each possible course of action. All decision making involves predicting the likely consequences of a particular decision, which suggest that the decision maker should have a "model" of the problem situation being faced.

DSS can provide the technical support needed by a regional planner in a developing country. Such a planner will need to draw upon methods and models of regional analysis and planning - regional input-output analysis, cost-benefit analysis, gravity model, regional economic models. However, these models will need to be mixed with value judgements. Seldom will there be one best answer to a planning problem - in most instances, the impact of a particular plan will be favorable for some groups and unfavorable for others. Seldom will the model totally represent all critical aspects of the planning problem - some aspects will have to be examined intuitively and qualitatively. In many ways, the success of a regional planner will be dependent on his ability to use analytical techniques and the successful use of analytical techniques will require the development and use of a DSS which facilitates their use.

A key characteristic of a DSS is the incorporation of formal models. These models can be divided into two major categories: descriptive models and optimization models [Keen and Scott Morton, 1978]. A descriptive model is intended to be a close approximation of the actual problem which can be used to evaluate alternative courses of action supplied by the decision maker. An optimization model, on the other hand, is a more abstract mathematical representation of the problem that is used to prescribe the course of action that a "rational" decision maker should choose, given a known set of conditions, in order to optimize some measure of performance such as income, cost, or utility.
The easiest DSS to build and implement successfully are those built around descriptive models. Descriptive-based DSS can be used by the decision maker as a direct extension of the way he approaches a problem situation. The decision maker defines the alternatives to evaluate and directs the search process to find a "satisficing" solution. Another reason contributing to the success of descriptive-based systems is the availability of general purpose software for building and evaluating these models.

Optimization models have been used to a much lesser extent in organizations. Optimization models have been criticized as being too structured to capture the real problems being addressed by decision makers and too difficult for them to understand and to validate. This criticism to a large extent reflects on the approach used to implement optimization-based systems rather than any inherent weaknesses of optimization models themselves.

Optimization-based DSS are potentially very valuable tools for regional planners. However, they are much more difficult to design and use. In the next section, an argument is made for using optimization techniques within a DSS. This is followed by a discussion of a set of critical success factors for designing and implementing optimization-based DSS.

**Optimization - Is It Appropriate for DSS?**

The early proponents of DSS have rightfully criticized the traditional "management science approach" to the application of optimization models for decision analysis. The primary focus of management science researchers and practitioners has been oriented toward the model itself and not the decision process which it is designed to support. Consequently, systems which incorporated optimization models tended to have intricate model formulations and ingenious solution algorithms along with user interfaces which required a significant level of specialized technical expertise. The system bore little or no relationship to the decision maker's conceptualization of the problem situation. The management scientist was the system user (because no one else could be) and the decision maker for whom the model was designed played a secondary role. This traditional approach, while achieving some limited measure of success, typically has
left the decision maker feeling uninvolved, unconvinced of the validity of results, and unwilling (or unable) to incorporate the analysis into an ongoing planning process.

As a result of this experience, decision makers have largely shunned the use of optimization models in DSS. These models have been criticized as being too structured to capture real problems and too difficult to understand. It is our contention that this situation is due to the traditional implementation approach and not to any inherent limitations of optimization technology itself. On the contrary, the traditional focus on modeling and solution technology has resulted in monumental advances in the past two decades. As a result, optimization technology has advanced to a point where it can be used to address very successfully a wide variety of real problem situations.

The benefit of optimization models can be realized through a DSS which incorporates appropriate user interfaces and data management capabilities. Such a system can be an extremely powerful addition to the manager's set of planning tools. Since optimization provides the "best" plan for alternative scenarios, optimization techniques allow precise determination of the marginal economic impact of possible alternative solutions. Thus planners can get reliable, quantitative answers to "what if ...?" type questions. Simulation methods which are based on average results cannot provide the same level of reliability.

The challenge is to build optimization-based DSS that can deliver these benefits. The critical success factors in meeting this challenge are discussed below.

**Critical Success Factor #1 - Select the Appropriate Problem Environment**

An understanding of managerial activities is a prerequisite for effective decision support system design and implementation. Managerial activities can be divided into three levels - strategic planning, tactical planning (management control), and operational control - where each level can be characterized by three basic functions: establishing goals, defining constraints and policies, and formulating a current set of plans which will move the organization toward attaining the goals [Anthony 1965; Vancil
The relationships between these categories can be viewed in terms of the matrix shown in Figure 1. The interactions between the cells of the matrix, represented by arrows, depict in an abstract way the management process in an organization.

As one would expect, for a given level, goals, policies, and plans are interrelated (horizontal arrows). It is interesting to note the implications of the diagonal arrows. Constraints and policies at one level tend to become goals at the next lower level, and plans at one level become constraints and policies at the next lower level. This reinforces the conclusion that the nature and scope of the activities at each management level are different enough to warrant different types of DSS. In this section, we will examine the characteristics of strategic planning, tactical planning, and operational control and discuss the use of optimization models as the technological base for supporting decision at each level.

Strategic planning is concerned with setting the long-term goals or purposes of the organization. These goals are generally stated in broad, general terms dealing with issues of image, style, and general intent. The constraints and policies determine the best set of activities to engage in - given the organization's strengths and the goals to be achieved. The plans govern the acquisition, use, and disposition of resources needed to support these activities. Strategic planning is strongly influenced by both the manager's own perceptions and assessments of opportunities as well as by his personal aspirations and professional obligations. It is very difficult if not impossible to capture these factors in an abstract mathematical formulation. Thus, the use of optimization models, which need a predefined structure and quantifiable goals, is limited in the domain of strategic planning.

Tactical planning is defined as the process by which managers ensure that the resources obtained are used efficiently in carrying out the activities defined at the strategic level. Tactical planning is generally concerned with a 1-2 year time horizon. The goals at this level are more appropriately viewed as objectives - i.e., specific achievements that are to be accomplished in the near-term. These objectives, as pointed out,
Three Levels of Managerial Activity
Figure 1
earlier, are formed from the constraints and policies developed at the strategic planning level. The objectives require a resource commitment and are quantifiably measured in terms of the management of these resources. The constraints and policies at this level define the available patterns for allocating the resources and the plans identify those patterns that contribute the most to achieving the objectives. The identification of these plans given the structure provided by the strategic planning level is amenable to an optimization approach as long as the objectives, constraints, and policies can be captured mathematically. It should be noted that the strategic planning level provides a structure rather than imposing a structure for tactical planning. Thus the use of optimization models at this level can be viewed as a vehicle through which managers can evaluate different constraints and policies in terms of multiple objectives that are consistent with the overall structure provided by the strategic planning level.

Operational control is defined as the process by which specific tasks are carried out efficiently. The goals at this level are stated in terms that are appropriate to the operational manager's assigned task. The constraints and policies at the tactical planning level define these tasks and thus impose a structure on the set of actions available to a manager. Less judgement is necessary since the goals, tasks, and required resources have been carefully delineated. In order to accomplish his assigned task, the operational manager must establish priorities and examine the performance implications of alternative actions to accomplish a task. At this level, the structure of the task is defined mainly in terms of concrete, physical components rather than abstract managerial considerations. Defining an optimization model is fairly straightforward. Optimization models, thus, have been used extensively at this level, although mainly for situations where the decision process can be automated (i.e., the models provide the "answer" while managers monitor the recommendations.) By adopting the decision support system approach outlined in the previous section, optimization models can also be used for operational control decisions which require the direct involvement of the decision maker.

Decision support implies a shared responsibility between the decision maker and the system designed to support decision making. For regional planning problems falling into the tactical planning and operational
control levels that require this shared decision-making responsibility, optimization is a viable technology for implementing decision support systems to address these problems. The advancements in modeling and solution technology have made it possible to capture the broader constraints and policies necessary at the tactical planning level and the decision support approach to design and implementation [Keen and Scott Morton 1978] has provided a framework for using optimization as a tool for decision support rather than for decision making.

To illustrate the use of optimization models in DSS at the tactical planning and operational level, three applications will be described briefly below.

Application #1: A major chemical company currently uses an optimization-based DSS to evaluate tactical planning and operational control decision related to the production, distribution, and inventorying of chemical products [Elam, 1985]. At the tactical level, the system is used to evaluate policies involving marketing promotions, distribution patterns, and production options (produce internally or contract outside). At the operational level, the system is used to determine a minimum cost allocation of product through the distribution system. The underlying optimization model represents both the physical characteristics of the distribution network (i.e., plants, warehouses, customers) as well as a range of managerial policies involving backordering, inventorying, and lost sales.

Application #2: Assessing the productivity of school districts represents another application of an optimization-based DSS [Bessent, Bessent, Elam and Long 1984]. A school may be viewed as an enterprise in which the professional staff provide the operating conditions for converting quantifiable resources (budgets, teacher assignments, etc.) into pupil learning (as measured by various standardized test
scores). An important activity at the tactical planning level in a school district is to compare the performance of district schools in meeting the established learning objectives given the available resources. Given a comparison set of schools, an optimization model is used to assign an efficiency rating to each school which is relative to the other schools in the analysis. A DSS built around this model allows an educational administrator to locate inefficient schools, determine efficient patterns of resource usage, and make recommendations for either reallocating resources or implementing new operating procedures to eliminate these inefficiencies [Bessent, Bessent, Elam, and Schneider 1988].

Application #3: A community mental health board is currently using a DSS built around a multi-criteria optimization model to aid in the development of an annual budget [Henderson and Schilling 1985]. In 1981, the mental health board had an annual budget of nearly twenty million dollars to support forty agencies providing approximately 200 different types of services. The budgeting process is highly political and requires consensus from individual board members who many times have conflicting priorities. This system was effective in facilitating discussion concerning allocation decisions and in clarifying areas of agreement and areas of conflict. The use of the optimization model helped make the decision process more objective and allowed board members to measure quantitatively the impact of increasing the priority (and hence the funding) of certain services over other services to be provided.

Selecting the right planning problem is the first step in successfully using an optimization-based DSS in the regional planning area. The next step is to put in place the organization to develop and implement the DSS.
Critical Success #2: Organize for Development and Implementation

There are many organizational considerations which arise when employing optimization models as the core technology for DSS. First, the mathematical models used in tactical and operational planning environments are typically very large, possibly representing thousands of activities over a long time frame to be analyzed. As a result, these models are very data intensive. It is therefore extremely important that there is an established data management function to collect and validate the data required for this model. The data management activities represent a significant proportion of the effort required to implement an optimization-based DSS.

By necessity there are several players in the development and implementation of an optimization-based DSS [Sprague and Carlson 1981]. The decision maker who is seeking support should be in the role of the primary motivator and ultimate evaluator of the system. This point may seem obvious, but it was precisely the lack of involvement and control by the decision maker which caused the traditional management science approach to be ineffective. The decision maker is best equipped to define and evaluate the DSS requirements and capabilities.

Another key player is the DSS builder. His role is that of a system architect. Given the requirements of the decision maker, the builder will have primary responsibility for the design and construction of the system. Obtaining the full potential from using optimization as the core technology for a DSS may also require access to a management scientist for consultation and training. The DSS builder should be knowledgeable of the underlying methodology and modeling approach to be used in the optimization-based DSS. Access to a management scientist can provide this knowledge. The management scientist should not be allowed to assume the role of system builder regardless of his familiarity with DSS technology since the two roles often have conflicting goals.

In addition to these players, any organizational unit which will be affected by the DSS should be involved from the outset. Approval of the organizational unit who will review plans, recommendations, and results generated from the DSS is absolutely necessary. Also, the cooperation of
any support staff such as data processing must be enlisted.

The design and implementation process consists of a complex interaction of all of these players at varying levels of involvement through its many stages. The DSS builder will orchestrate this interaction into a focused effort. The early stages consist of a description of the problem situation, and as much as possible a definition of the decision maker's support requirements. These stages involve the decision maker, DSS builder, and possibly, the management scientist. Then the model formulation and refinement is performed by the DSS builder with input from the decision maker.

Once a model has been tentatively formalized and its data requirements specified, the DSS builder begins a prototyping effort working with all concerned parties. With the data processing staff, the DSS builder assesses the availability and validity of the data required. The DSS builder begins the design of the DSS. As the system design begins to emerge, the data processing staff should assess the impact of the DSS on any shared computing facility and if necessary obtain more resources.

An evolutionary approach to implementation is strongly recommended. This approach is embodied in the concept of prototyping. A prototype system is a "first cut" toward the final system. It should be used, misused, expanded, contracted, molded, redesigned, and possibly discarded. DSS technology, in general, and optimization technology, in particular, are so new to decision makers that they can't possibly pre-define all of their decision support requirements. The DSS builder can help, but the decision maker is the authority on his problem situation and ultimately the system must conform to his needs. The advantages of building a prototype system include: it can be created relatively quickly (in contrast to building the total system); it allows a vehicle for data validation; and it allows evaluation of computer resource requirements. The experiences gained from using a prototype system are invaluable and will result in a more effective, usable final product.

**Critical Success Factor #3: Build the Right Type of System**

An optimization-based DSS is composed of three basic components: the data subsystem, the model subsystem, and the user interface system.
[Sprague and Carlson 1981]. The data subsystem houses all data management capabilities: creation, retrieval, update, etc. The model subsystem encompasses the model generation and model solution capabilities. The interface subsystem provides all user interface capabilities as well as invoking and overseeing the operations of the other two subsystems. Due to its crucial role, the proper design of the interface subsystem is of paramount importance.

In the traditional implementation approach to optimization models, operation of the model subsystem received the highest priority. Unfortunately, more times than not, absolute solution, efficiency and user friendliness are opposing goals. In the DSS approach, the needs of the decision maker have highest priority, and the system components and their internal interfaces should be designed around the objectives of meeting these needs. Consequently, it is not necessarily true, as was the case in the traditional approach, that the most compact model is the best. In most cases a somewhat inefficient model is most likely to better match the decision maker's conceptualization of his problem situation and decision process and may therefore be preferable.

One of the biggest obstacles to overcome in using an optimization-based DSS is that the solution approach does not match how the decision maker would solve the problem. The lack of understanding that results causes a large number of optimization-based DSS not to be used. A well-designed user interface can address this problem.

The basic component of the user interface is the user's conceptual model which provides the vehicle through which a user can define a problem, can analyze different policies and constraints, and can interpret the results. Without such a model, the user can do little more than follow instructions and never develops an understanding of how to use the system as a tool for solving problems. The user's conceptual model should be based on objects and relationships between these objects that are familiar to him.

A responsibility of the DSS builder is to develop strategies for teaching the conceptual model to the user. How does one influence the development of a user conceptual model? Possible strategies include (1) training and documentation, (2) designing the DSS to "show" the conceptual model, (3) encouraging user experimentation to discover the conceptual model, and
(4) choosing a conceptual model that matches the real problem environment.

It is important to note that the decision maker’s conceptual model and the management scientist’s conceptual model of the same problem domain will be different, the former being problem oriented and the latter being structure oriented. The conceptual model supported in an optimization-based DSS must be problem oriented; appropriate software must be provided to convert the problem defined in terms of the user’s conceptual model into an appropriate mathematical model and to convert the results defined in terms of the mathematical model back into the framework of the user’s conceptual model.

Once the user has a conceptual model, he needs commands or operators to manipulate it. These commands should correspond closely to the activities that the user currently engages in during problem solving. These activities can only be identified after a descriptive analysis of the current decision making environment has been completed. A sample classification of the activities prevalent in many problem solving situations along with some possible commands to support these activities are shown in Figure 2. Through these commands the user controls the decision-making process and uses the system and its underlying model strictly as a tool to support this process.
<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>COMMANDS</th>
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<tr>
<td>Searching for and receiving information</td>
<td>DETECT, INSPECT, SCAN, SURVEY</td>
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<tr>
<td>Identifying objects, actions, events</td>
<td>DEFINE, IDENTIFY, DISCRIMINATE, LOCATE</td>
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<tr>
<td>Information Processing</td>
<td>CATEGORIZE, CALCULATE, ITEMIZE, TRANSLATE</td>
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<tr>
<td>Decision Making</td>
<td>ANALYZE, CHOOSE, COMPARE, ESTIMATE, PLAN</td>
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<tr>
<td>Communication</td>
<td>ADVISE, COMMUNICATE, INFORM, INSTRUCT</td>
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Sample Classification of Problem Solving Activities

Figure 2
Another component of the user interface is feedback. On one level, feedback helps a user be sure that his commands are accurately received and understood by the system. On a higher level, feedback helps a user be sure that the underlying model driving the DSS accurately represents the problem environment. The feedback provided in an optimization-based DSS should therefore be able to tell a user why a particular solution was reached. This capability has long been recognized as a key component of expert consulting systems developed by the artificial intelligence community. For example, expert medical consulting systems determine a diagnosis and treatment plan from patient information and then allow the physician to check the system's "line-of-reasoning" to validate questionable diagnoses. Including this type of feedback in optimization-based DSS will contribute greatly to their acceptance and use in organizations.

The software building blocks which comprise an optimization-based DSS can be obtained from a wide variety of sources. These systems do not have to be entirely custom-built. Solution software ranging from the most general purpose to the most specific is commercially available for a wide variety of optimization models. In addition general purpose model generation and data management software with more than adequate capability for most application is also readily available. In fact, entire packaged optimization-based systems for specialized applications are beginning to appear. The degree to which custom built software components or existing components are utilized should be the decision of the DSS builder. Typically the use of existing components will reduce system implementation time and cost. However, the right components are not always available. The unique and delicate nature of the buffer provided between the decision maker and the mathematical model by the user interface requires that this component to be custom built many times. As our experience with optimization-based DSS broadens, perhaps general purpose "off-the-shelf" user interface software components with adequate capability will also become readily available.

Conclusions

This paper has discussed the use of optimization models in DSS. By adopting a DSS approach to design and implementation and utilizing the latest advance in modeling techniques and software, regional planners in
developing countries can begin to utilize a powerful tool to enhance the quality of their plans.

The use of optimization as the core technology for DSS will impose unique demands upon the regional planning organization that elect to adopt this new management tool. However, by attending to the three critical success factors outlined in this paper, the development and use of these systems can lead to substantial benefits for the organization.
References


