A TAXONOMY OF SEQUENTIAL DECISION SUPPORT SYSTEMS

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Abstract

*Advances in information technology and explosion of internet technology is creating new professional users, across and within countries. These users are looking at technology to provide decision support for non-recurring tasks, to provide prototyping capabilities and to provide research support. However, organizational decision environment is also changing, creating havoc for system builders who must match changing technology to changing decision environment. This paper focuses on one such technology, namely, Decision Support System (DSS) and one such decision environment, namely, sequential decisions. It is argued that the next millennium DSS must focus on the 'D' of DSS because of the complexities of the decisions they are trying to support. These DSSs, called SDSSs, are further examined in the context of data-dialog-model-**communication**. Communication component is needed because of the complexity of sequential decision-making which spans across several hierarchical levels or involves several decision makers at the same level.*

Keywords: Sequential decision, Interdependent decisions, Independent decisions, Sequential decision support systems

Introduction

A Decision Support System (DSS) is defined as a computerized system that integrates data and model to enhance effectiveness of knowledge workers in a user friendly environment. This is usually defined as a set of data-dialog-model capabilities (Sprague & Carlson, 1996). Since its introduction in the late 70's Decision Support Systems have gone through many evolutions. This evolution parallels the 'data-dialog-model' paradigm which in turn parallels advances in information technology. As the processing capabilities improved so did the demands on DSS. First generation DSSs were 'data' intensive (Medsker, 1984; Robak, 1984; Sprague, 1987), second generation DSSs focussed on providing better user interface ('dialog') (Benbasat, 1985; Benbasat et al, 1982; Dickson et. al, 1986; Lucas, 1981) and third generation DSSs are focusing on 'models' (Aggarwal, 1990; Aggarwal et. Al, 1992; Bonczek, 1980; Sprague, 1993; Floyd et al, 1989; Weigell et al. 1993). DSSs evolved were not mutually exclusive but used the strengths of the previous DSSs. However, for the DSS to evolve to the next millennium, or even to survive, it must keep its focus on the "D" [Decision] of the DSS (Aggarwal, 1995; Keen, 1997). The next millennium DSS must use decision as the building block and supplement it with the strengths of the previous generations and evolving internet technologies (Fishkin et al, 2000; Lucas, 2000). This is critical as the next generation web-based DSS attempt to support complex decisions that span across managerial levels or decisions that involve several people. This paper focuses on the next millennium generation DSS designed for sequential decision-making.

Literature Review

Researchers have defined three types of organizational decisions. 1. Independent - where one person has full responsibility and authority to make a decision, i.e., a person can perform the task without interaction with other persons; 2. sequential interdependent -where a decision maker makes part of a decision, which is then passed on to the next person; and 3. pooled decision -where decision results from negotiations between two or more people Sprague and Carlson (1987) and Hackathorn and Keen (1987). Much work, both theoretical and practical, has been done in the areas of independent (Aggarwal, 1996; Klaas, 1977; Robbey & Farrow, 1982) and pooled (grouped) decisions (Nunnamaker et.al, 1987; DeSanctis et. Al, 1987). How-

Taxonomy Of Sequential DSS

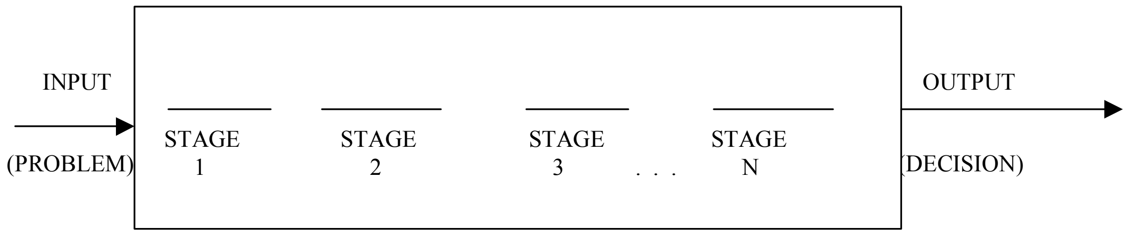


Figure 1(a): Sequential Decision Process

ever, very little has been done in the area of sequential decisions.

Sequential decision means different things to different researchers. Several researchers have studied decision making as a pre- post situation, i.e., initial and the subsequent decision (Bateman, 1986; Staw, 1981; Staw et al, 1977). These authors study factors that influence an individual's escalation of commitment to a previously chosen course of action. Stawet al., in their pre-, post study of financial managers found that 'maximization of future utility, assumed by traditional subjective expected-utility models, often is overridden by the psychological influence of previous expenditure'. Another definition of sequential decision is provided in the context of multi-stage manufacturing systems (Chen et al, 1986; Norbis, 1988; Vemuganti et al, 1989). Researchers in this area have concentrated on providing an optimal schedule of single or multiple products or people within production and/or financial constraints. For example, Vemuganti et al (1989), provide optimal replacement policies for a fleet of vehicle at each planning stage. Some researchers have used the concept of a 'state' instead of a 'stage' and define sequential decision making as a Markovian decision process. Their focus is on decision making as the system moves from one 'state' to another 'state' in a stochastic environment (Rosenhead et al, 1979; White et al, 1989; Burnetas, 1997). A different interpretation is used by several other authors (Moore et al,

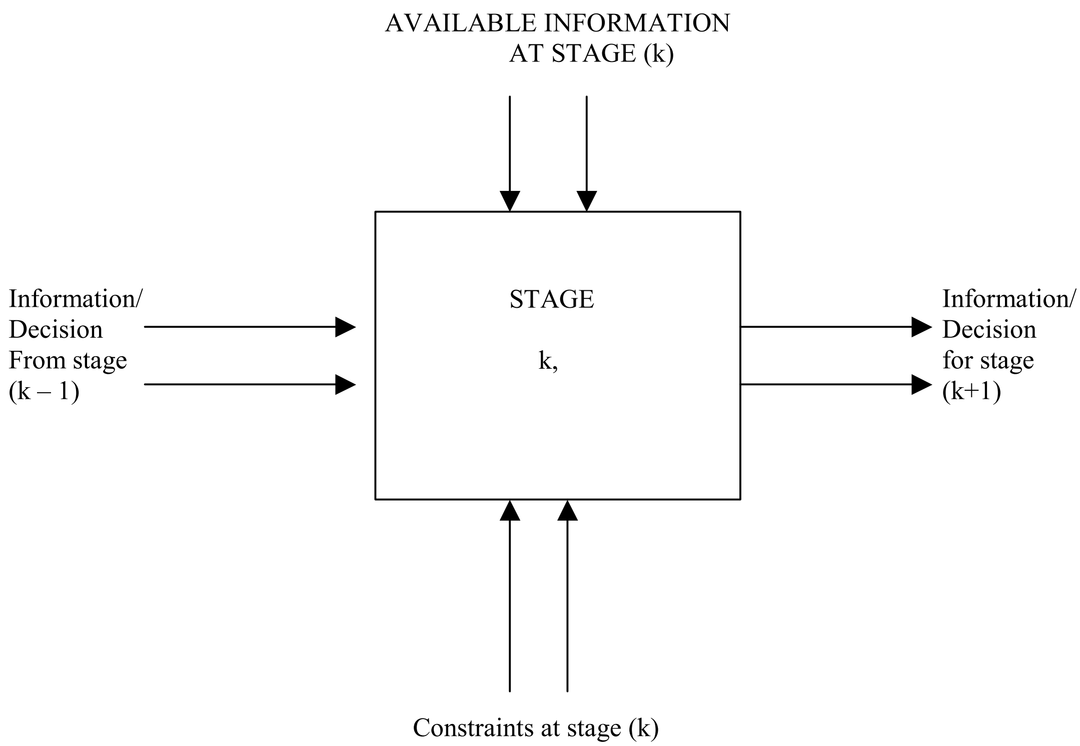


Figure 1(b): A Typical Sequential Stage

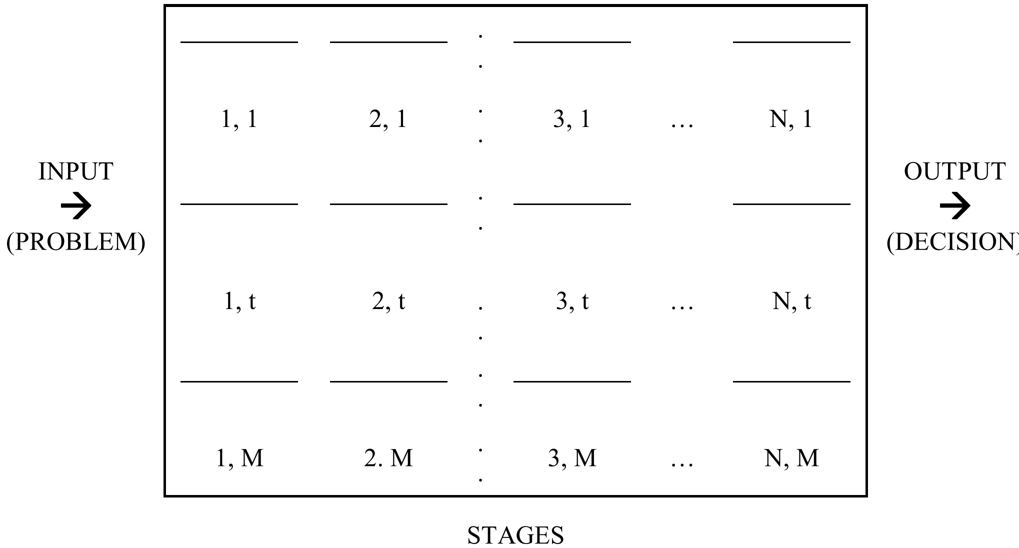


Figure 2(a): Parallel Decision Process with Multiple Stages

1986; Quinn, 1978; Staw et al, 1981). They have used 'incremental' in place of 'sequential' decision making. They argue that managers gather information in stages before a final decision is made.

Sequential Decisions

Irrespective of the interpretation, the common denominator is: certain tasks must precede some other tasks. We have taken a similar approach here, i.e., a sequential decision consists of n sequential stages, independent or interdependent, where decisions made at a stage are passed on to the next stage and the overall decision depends on the decision made at each stage. Thiscompares well with 4x4 relay race, where one runner finishes his/her leg before passing the baton to the next. In this case, each leg is independent of the other leg, but leg 1 must be finished before leg 2 and 2 before 3 and so on. However, the overall result is a function of performance at each leg.

Figure 1 (a) shows a typical sequential decision process. The input is the problem and the output is the decision. The decision is made in n consecutive stages. Then,

$$\text{Overall Decision} = \underset{i=1}{\overset{N}{O}} (D_i) \quad i = 1, ..., N$$

where
D_i = decision made at stage i
O = some operator (summation, multiplication etc.)

Figure l(b) shows a typical stage, where input to the stage is a decision or information from previous stage and output is the information/ decision for the next stage. The decision/information generated at each stage is a function of the information available at that stage, decision/information at the previous stage and the constraints at that stage.

Then, for a typical stage k,

$$D_k = f(D_{k-1}, I_k, C_k)$$

where:
I_k = Available information at stage k
C_k = Constraints at stage k

For example, a lumber drying process consists of several sequential stages like pre-dryer drying, kiln drying and dry storage. Decision related to kiln drying can not be made unless decisions related to pre dryer stages are made and dry storage decisions can not be made unless kiln drying decisions are made. In general, decisions at a stage can only be made after decisions at the previous stages have been made.

In parallel process, decisions are made simultaneously. Each stage may consist of a single or multiple stages. Figure 2(a) shows a typical parallel stage with multiple sequential stages. Stages (1,1) through (1,M) will be an example of a parallel process with single sequential stage. Input is the problem and output is the decision. Then,

$$\text{Overall Decision} = \underset{j=1}{\overset{M}{0}} \left(\underset{i=1}{\overset{N}{0}} D_{ij} \right)$$

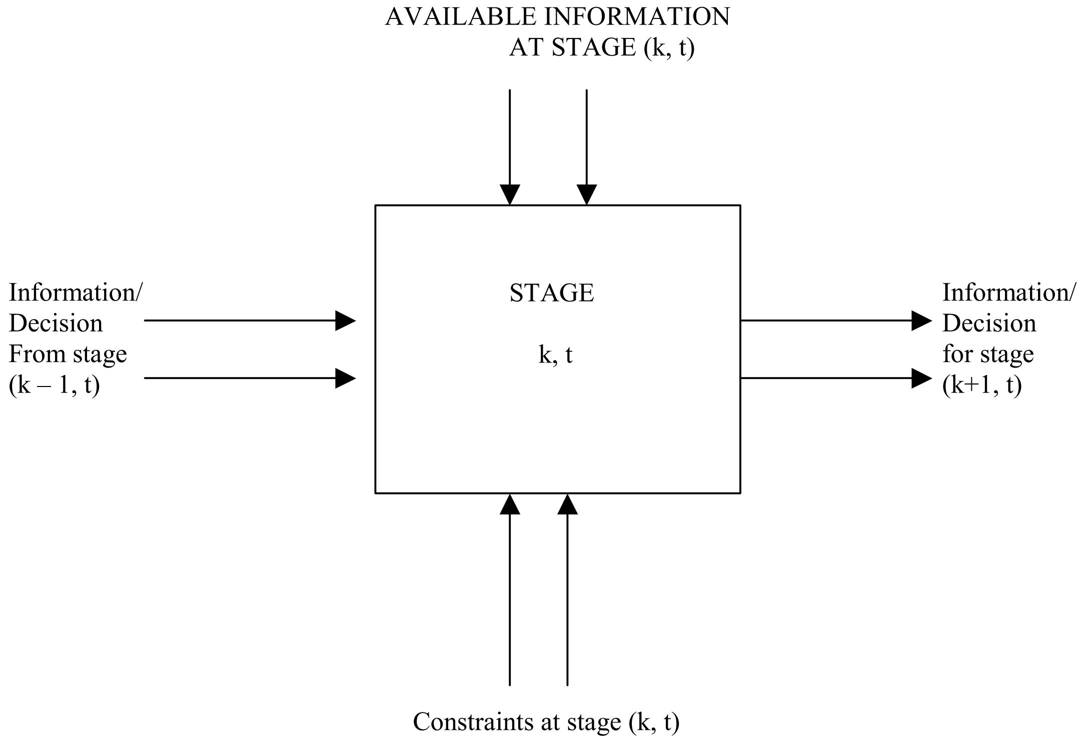


Figure 2(b): A Typical Parallel Stage

Note N is 1 for a single stage.

Where:

Dij = Decision made at parallel stage j and sub-stage I
0 = any parameter (summation, product.)
M = number of parallel stages
N = number of sequential stages in a parallel stage

Figure 2(b) shows factors involved in decision making at a typical stage k,t:

Dkt = f(Dk-1t, Ikt, Ckt)

Where
Dk-1t = information/decision from parallel stage t and sub stage k-1
Ikt = information available at stage k,t
Ckt = Constraints at stage k, t

Next section describes various sequential decision types.

Taxonomy of Sequential Decisions

A sequential decision whether deterministic or non-deterministic can have independent or interdependent stages. Deterministic is used here to include tasks for which analytical formulations and solutions are available and non-deterministic includes tasks for which analytical formulations and/or solutions are not (or only partially) available. Figure 3 relates sequential decisions to decision-making tools as they relate to deterministic environment. A single decision maker is assumed at each stage.

As seen in Figure 3, decisions can be classified at the following four levels:

The first level is based on the **scope** of stages,

- single stage
- multiple stages

For example, portfolio management involves single stage (or task), i.e., proportion of investment in various assets, whereas inventory management involves several stages like raw materials planning, production schedule and storage requirements.

The second level describes the **dimensionality** of stages:

- sequential
- parallel

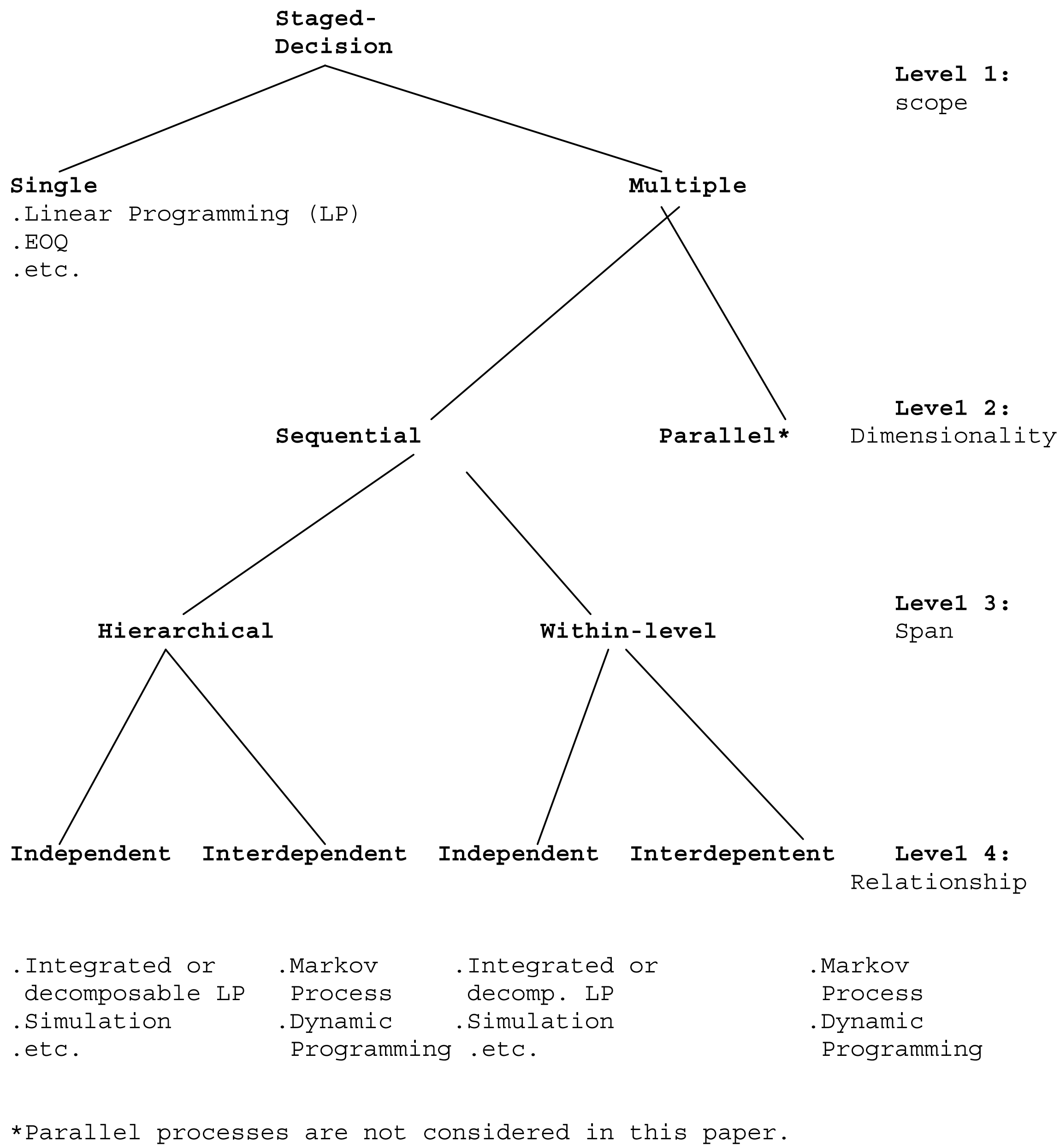


FIGURE 3: Relationship Between Staged Decision and Decision Tools

In a sequential process decisions are made in consecutive stages and in parallel process decisions are made simultaneously. A stage involves a single task and a single user.

For example, production process for canned goods where input is raw material and output is canned good, processing of can material and processing of items can be done in parallel before combining processed items and cans. Any scheduling and/or processing decisions related to the two processes can be made in parallel. On the other hand, lumber drying process consists of several sequential stages like pre-dryer drying, kiln drying and dry storage. Decisions related to kiln drying cannot be made unless decisions related to pre-dryer stages are made. In general, decisions at a stage can only be made after decisions at the previous stage have been made. Parallel decision processes are not considered any further since they are outside the scope of this paper; however, many concepts discussed here are equally valid for parallel decisions.

Third level is based on **span** of stages,

- hierarchical(across organizational levels)
- within-level.

Taxonomy Of Sequential DSS

Hierarchy is defined as lower, middle or upper level and a sequential hierarchical decision spans across several hierarchies (Sprague, 1993). For example, in an auto dealership involving salespersons quotas, salespeople set their goals (decisions) for the next year, this decision is then passed on to the next hierarchy, sales manager, who makes his decision on quotas based on the information available to him. A within-level decision involves decision makers at the same hierarchical level. For example, in a bidding process manager makes a decision to bid or not to bid, if bid, then the process is passed on for matching and selection of personnel to the next manager.

Fourth level classification is based on the **relationship** among stages,

- independent
- interdependent

Two stages are independent to the extent that decisions made at the previous stage do not affect decisions at the current stage, but current decision can not be made unless previous decision is made. For example, a bidding process consists of three sequential independent stages: policy requirements, matching and selection. Independent sequential decision process may be terminated at any stage, i.e., in the bidding process if the decision is not to bid at the policy stage then the decision process may be terminated. Production process depends on the following interdependent stages: sales projections, production scheduling and raw material requirements. In interdependent process decision-making cannot be terminated at an intermediate stage.

In summary, decisions, based on stages, can be classified as:

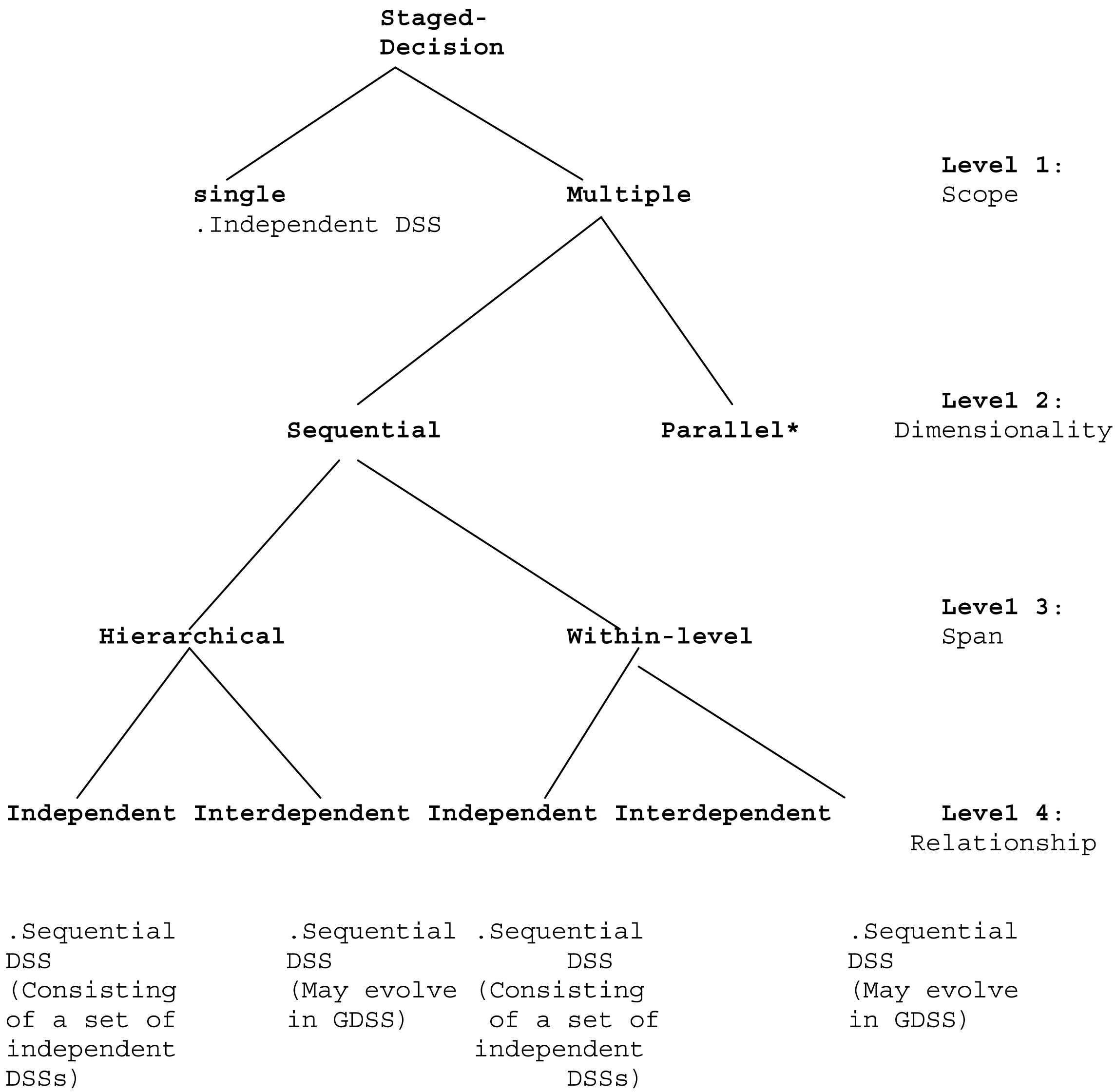
1. single stage
2. parallel multiple stages
3. sequential multiple stages
   3a. independent hierarchical
   3b. interdependent hierarchical
   3c. independent within-level
   3d. interdependent within-level

Sequential Decisions and Decision Tools

In general, in a deterministic environment analytical formulations and solutions are usually available (Bateman, 1986). However, selection of a technique depends on the decision involved. Following are some examples of analytical techniques that have been used for various sequential decisions. For a single stage decision, Linear Programming (LP), Economic Order Quantity (EOQ) or similar optimization technique have been used. Pfeifer (1989) uses an LP model to make discount fare allocation decision for an airline. In independent sequential-hierarchical and sequential-within-level, decisions can be made by using multiple but independent LPs (decomposable), integrated LP, simulation or any such optimization technique. Yan and Liu (1988) use a series of nested vector optimization technique to solve a multilevel (hierarchical), multi objective problem. Chern (1986) uses integer programming to combine decision-making at several hierarchical levels: decision maker at higher level minimizes pollution and the decision maker at the lower level maximizes reliability. Van Roy (1989) uses integer programming for multiple level production and distribution planning. For interdependent sequential-hierarchical or sequential-within-level decisions, markovian, simultaneous equations and simulation techniques are usually employed. Chong (1988) uses simulation techniques to integrate production and marketing systems. Several researchers use a set of equations to optimize sequential decisions in various business environments (Jenkins, 1987; Nowakowska, 1985).

Sequential Decisions and Decision Support

In general, in a non-deterministic environment analytical tools are not applicable. The reason is lack of algorithmic structure, uncertainty and complexity of task. These tasks are typically faced by top managers (Watson et al, 1997). Diversification of existing lines, merger and acquisition are some examples of non-deterministic tasks. since analytical techniques can not provide solutions, in many cases, they can be embedded in DSS to provide decision support. To be successful, however, systems (DSS) that provide this support must have decision focus. Figure 4 relates decision types to various DSS.



*Parallel processes are not considered in this paper.

FIGURE 4: Relationship between DSS and Staged Decision

Figure 4 shows that different DSSs are needed to support decisions at different levels. Following is a discussion of sequential DSS in the context of data-dialog-model-communication capabilities. Note that we need an extra component, communication, since decisions across levels and within-level involves several people.

A single stage decision can be supported by a traditional PC-based DSS. Systems built are traditionally, user oriented, data intensive and customized. There is very little communication involved. Blakely and Evans (1985) describe a DSS built for senior executive to manage supplier/distributor relationship).Pfeifer (1989) describe a DSS for a senior airline manager to formulate discount policies. They are part of first, second and third generation DSS.

For independent hierarchical or within-level decisions, a sequential DSS consisting of a set of independent DSS's is needed (maybe, one DSS for one stage). The DSS's are independent to the extent decisions are independent. The only dependency is that stages are sequential and a 'no' go decision at a stage may terminate the decision process. In a bidding process, (see figure 5) a bid/no bid decision involves three sequential independent stages: policies, matching and selection. Policy must precede matching and matching must precede selection. Decisions at each stage are independent of decisions at the previous stages. A system that supports bid/no bid decision could consist of three independent DSS (policy, matching and selection) if there are three different users. Data requirement at each stage will probably be the same since users are working on different phases of the same task, however modeling requirements will be quite different. For example, policy decisions may require expert system, matching may require data base/querying and selection may require heuristics. Since decision makers are at the same hierarchical level it is likely that the dialog component will have similar style and sophistication. Communication is required to the extent that yes/no, go/no-go types of decisions are passed from one stage to the next, hence, communication costs are negligible.

Independency among DSS is more pronounced if the decision makers are at different hierarchical level. For example, In R&D department scientists need decision support in developing new products and department manager needs decision support to examine the patentability of the product. The two stages are independent but sequential in the sense that a new product must be developed before patentability can be examined. R&D needs two independent DSS with different capabilities. Data-model requirements will be different for different levels since decision focus is different, i.e., scientist will need data and models that will provide information on chemical compositions, chemical reactions etc., whereas manager will require information related to product differentiation, legal procedures etc.. Dialog styles will be very different since users at different hierarchy are involved. The higher we go the more user friendly the system will have to be (Reck et al, 1984). Communication requirements are little more than within-level, scientists not only have to pass new products but the salient features of the product to the manager. An web-based e-Mail type communication will suffice. Currently, there are no examples of DSS that support the sequential aspects of the decisions. Next millennium generation DSS that capture the sequencing of decision making are needed.

For **interdependent hierarchical or within-level** decisions, a sequential DSS which captures the dependency among stages is needed. Stages are interdependent because decisions made or information generated at one stage is used in decision making at the next stage. Since several stages are involved DSS must capture the interrelationship among decisions. This can be achieved through modeling and/or data subsystem since dependency requires passage of data and/or models from one stage to the next. In a budgeting process, (see figure 6)where hierarchical interdependency exists, a unit makes its budgeting decisions and passes its requirements to the next hierarchy, department manager. Department manager needs units input/decision before making his/her decision. Data require-

Decision Support	Project in Policy Domain	"Critical" vs "Non-critical" Matching	"In-house" vs "outside Consultants" Congeniality, Presentability
Communication:	bid/no-bid	bid/no-bid	bid/no-bid
Dialog:	Question/ Answer	Question/ Answer	Question/ Answer
Model:	Expert System	Data Base/ Adhoc Query	Heuristic
Data	Policy Data	Historical Data	Selected Data

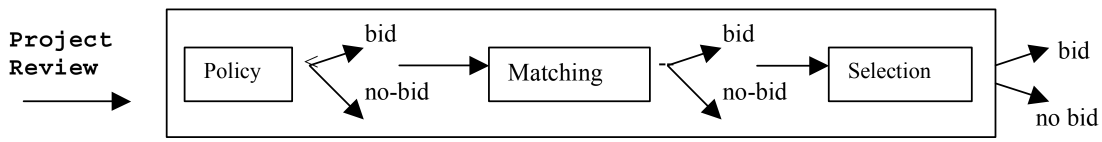


FIGURE 5: A Sequential DSS for Bidding Process

ments at the unit level will include past, current and projected unit data. At the department level data requirements include relevant data of all units, past, current and possible future relation to other departments and organization goals. Modeling and analysis requirements will be different; unit level requirements include forecasting models, historical trends and department requirements include trade-off analysis, allocation models and 'what-if' analysis. Dialog requirements will also be different because of difference in hierarchy. A menu-driven dialog is more suitable at department level and may be question/answer type at the unit level. Communication between hierarchical stages is very important because of the dependency. Communication costs could be substantial if two hierarchical stages are physically far apart. In an extreme case, this may require long distance communication capabilities. Sideridis (1988) discusses A DSS for Greek municipalities that may eventually span across various levels.

Inventory management includes several within-level interdependent sequential stages like sales forecasting, production scheduling and raw material planning. Stages are dependent because production scheduling can not be planned unless sales forecasts are known and raw material requirements can not be planned unless production schedule is known. Data requirements are different at each stage: sales stage requires past and economic data; production stage requires projected sales, process and labor data; and raw material stage requires product requirements, product availability and lag times. Modeling requirements are different; sales requires forecasting models; product requires multistage scheduling models; and raw material requires economic order quantity (EOQ) models. Dialog styles may be similar because of same hierarchy. Substantial communication is required among stages. Information from one stage needs to be passed on to the next stage. This may also require long distance communication capabilities, especially if the stages are at remote locations. In this case, we will need fourth generation DSS with high communication capabilities to support sequential decisions.

An interesting point to note here is that interdependent hierarchical and within-level sequential decisions may evolve into group decision making requiring group decision support (GDSS) if the task sequencing breaks down because of unacceptable output from one stage to the next. For example, if production planner is not satisfied with sales projections (this is possible since both have different objectives; sales department wants to minimize stockouts and production department wants to minimize inventory carrying costs) he may want to negotiate with the sales department and not take sales figure as given. This can extend to raw materials planner which, in an extreme case, may involve negotiation for all three stages: acceptable sales, production

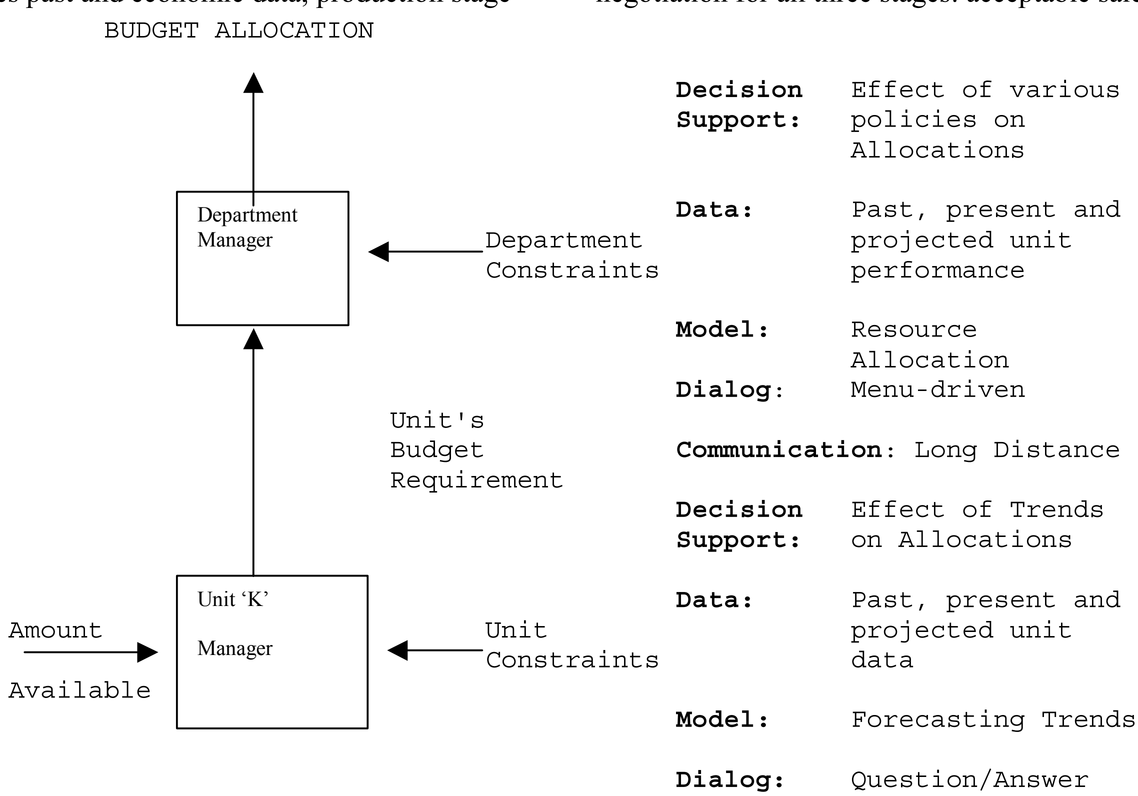


FIGURE 6: A Sequential DSS for Budget Allocation Process

Taxonomy Of Sequential DSS

DEC. / SEQ. DSS	SINGLE STAGE	SEQUENTIAL MULTIPLE STAGES			
		Hierarchical		Within-level	
		Independent	Interdependent	Independent	Interdependent
DECISION	Single, Independent	Across level Independent	Across level Interdependent	Same level Independent	Same level Interdependent
USER	Single	Multiple Across levels	Multiple Across levels	Multiple Within level	Multiple Within level
DSS BUILDING BLOCK	User, Data, OR Model	Decision	Dependent Across levels	Decision	Dependent Within levels
COMMU-NICATION	None	Some Across levels	High Across levels	Some Within levels	High Within levels
DATA	Task Specific	Different Across levels	Different Across levels	Similar Within levels	Similar Within levels
MODEL	Task Specific	Different Across levels	Different Across levels	Different Within levels	Different Within levels
DIALOG	User Oriented	Different Across levels	Different Across levels	Similar Within levels	Similar Within levels
COMMENTS	-	-	**	*	**

* Decision process can be stopped at an intermediate stage.

** Decision process may evolve into group negotiations if sequencing breaks down.

TABLE 1: Sequential Decisions and Sequential DSS

schedule and raw material shipments. This implies that fourth generation sequential DSS may also need/require teleconferencing capabilities.

Table 1 summarizes sequential DSS requirements for different sequential decisions.

Summary

This paper has addressed a major class of decision problems, sequential decisions, which have largely been ignored in the literature. The taxonomy presented in the paper is needed because of the complexity of decisions next generation DSS are trying to support. It is argued that the new generation of DSS will have to focus on decision, decision flow and decision dependency. Next millennium DSS must use decision as the building block and provide support in the context of data-dialog-model-communication. Communication is an important part of sequential DSS, especially if the stages are dependent.

The taxonomy presented here has major implications for the DSS builder who in the future will be moving from a single user DSSs to multi user DSSs with task dependencies. We feel, the taxonomy of decisions and the structure of sequential DSS provided here is an excellent starting point.

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Biography

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