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A Review of Adaptiveness in DSS: An Information Structuring Approach

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This paper identifies 59 journal articles and publications that have a primary focus on formulating, promoting, or providing adaptive characteristics in the design and application of decision support systems (DSS). In categorizing the literature we have taken the information Structuring approach of Toda et al.[1991] and developed a simplified research decision support systems (SRDSS). The paper first provides an understanding of the adaptive dimensions of DSS then describes the structure of SRDSS. It then presents a comprehensive review of adaptive DSS under the SRDSS categorization. The results of this review are presented in detail. We conclude that there has been some significant attempts in the development and application of adaptive characteristics in DSS or DSS related disciplines. The direction of the future research effort should be geared towards those least studied. or not yet explored areas as highlighted in this paper.

1. Introduction

The concept of Decision Support System (DSS) has been evolving for more than two decades since its first appearance brought by Scott Morton (1971) under the term "management decision systems". However, unlike traditional data processing and management information systems (MIS), there has been no established definition of DSS (Keen, 1987), for example see, Sprague, 1980; Alter, 1981; Ginzberg and Stohr, 1982; Watson and Hill, 1983; Stabell, 1983; Rockart and DeLong, 1988; Silver, 1991; and others. By and large, DSS have been described as computer-based aids for management decision-makers dealing with semi-structured problems (Keen and Scott Morton, 1978). DSS are differentiated from MIS in that they seek to establish a symbiosis of human mind and computer by allowing for a high degree of human-computer interaction, and by enabling the decision maker to maintain direct control over the computer's tasks and their outcomes. The first stage of support is to assist the decision maker in problem exploration and definition. The second stage aids in formulating alternative solutions, and final stage in selecting a strategy or plan (Young, 1983). These stages correspond to Simon's (1960) description of the three major stages of the decision process as Intelligence, Design, and Choice.

1.1 The Concept of DSS Adaptability

Longman's dictionary defines 'adaptability' as the '..ability to change so as to be suitable for new needs, different conditions, etc'. It also defines 'flexibility' as '..that can change or be changed to be suitable for new needs, changed conditions ,etc'. Sprague and Carlson (1982) are the first to offer a definition of a flexible DSS. They use 'flexible" as a generic term to indicate 'changeable', 'adaptable', modifiable', and 'evolutionary'. In fact, to a lot of DSS researchers, the terms 'adaptability' and 'flexibility' are interchangeable. Since the meanings of these two terms are very similar, we shall use the two terms interchangeably in this paper.

Looking from another angle, it is found that the subject of 'Flexibility' has been studied extensively in the arena of Flexible Manufacturing System (FMS). Consolidating ideas of other researchers, Gupta and Goyal (1989) define 'flexibility' as the ability of a system to cope with changing circumstances or instability caused by the environment. Flexibility types can be classified in various ways. One way is to examine flexibility from a short term or a long term perspective, another way is to focus on physical measures such as the capability of the system to overcome known changes in the environment. Most importantly, flexibility is a property of the system that indicates the system's potential behavior, rather than its performance.

In line with the thoughts of other researchers (e.g. Simon, 1960; Sprague and Carlson, 1982; Er, 1988; Gupta and Goyal, 1989), we define an adaptive DSS as a class of Decision Support Systems that:

> Possesses the ability to cope with changing decision environment, problem domains, and user characteristics over three time horizons:

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- In the short term, the system allows flexibility to perform intelligence, design, and choice activities, to allow for user preferences, and to provide alternative views and methods of solving a problem.
- In the intermediate term, the system learns about patterns of problem domain, task characteristics and user behavior. As a result, the system can adapt to new problem solving environment and user characteristics by modifying its capabilities and internal structure appropriately.
- In the long term, the system evolves to accommodate much different behavior, styles, or capabilities of the users (such as learning curve), and also changing information technology.

1.2 Reasons for Adaptability

Barki and Huff (1990) measured variables related to the characteristics of DSS in order to identify the critical factors affecting DSS use and user satisfaction. Their results indicate that DSS flexibility is the most important factor attributed to user satisfaction. Conventional DSS are designed to deal with well-structured or semi-structured problems. In many circumstances, conventional DSS require the problem solver: (1) to already know what the problem is, (2) to fit the problem to the available decision model, and (3) to adaptive himself (herself) to the system rather than to adapt the system to the user. Many researchers have pointed out that the general problem of the focus of conventional DSS design efforts is "the imposition of structure upon aspects of managerial problem solving rather than the discovery of a manager's pre-existing mental organization of a task" (Gorry and Krumland, 1983).

On the other hand, very few DSS take into account an individual's decision style, though it is well known that personality influences one's decision style (Nutt, 1986). This view is shared by some other authors. For instance, Er (1988) has given examples that systematic decision makers prefer DSS that can support cost-benefit analyses of hard data, whereas speculative decision makers prefer DSS that can provide 'what-if' analyses. Thus the usual approach to providing all decision makers with the same DSS may not suit individuals' tastes, and hence decision making is less effective than it should be. Even worse is that an individual's cognitive style and personal characteristics are variable and task-dependent (Sage, 1981; Huber, 1983). Because of the variety of decision-making processes, a DSS is more likely to be useful and cost effective if it supports multiple processes. If a specific DSS is designed for only one type of decision, any change in the decision requires a change in the DSS to accommodate changes in information processing requirements. Therefore, designing a DSS for a specific decision reduces the number of decisions it can support (Sprague and Carlson, 1982). In line with this thought, we contend that in order to be of practical use within a business environment, an ideal DSS design should be flexible enough such that users can employ a variety of approaches to their decision tasks.

Since adaptability (or flexibility) in DSS has received so much attention, it will be of great benefit to discover where we are, and in what direction we are going ? This research will try to provide answers to the following research questions:

(i). What are the development, trend, and current status of adaptability in DSS?
(ii). What attributes of DSS adaptability have been promoted by researchers over the last two decades?
(iii). What attributes of DSS adaptability have not been studied, or have received little attention?
(iv). Are there signs of maturity in development, application and use of DSS adaptability?
(v). What are the direction and opportunities for future research efforts?

2. Data Collection and Methodology

There are three stages to this research. The ***first stage*** is the identification of information sources. It is indeed the establishment of a comprehensive bibliography of DSS related publications that have a primary focus on adaptiveness, flexibility and terms alike. The ***second stage*** is the classification and storing of information. It involves the isolation of attributes of adaptiveness and flexibility as perceived by various researchers, and to classify individual publication into appropriate categories of adaptiveness. To this end, an information structuring approach (Sugiyama and Toda, 1985; Toda et al., 1991) was adopted. The ***final stage*** is the analysis and discussion of overall findings in relationship with the questions posted above.

2.1 Identification of Information Sources

An intensive literature survey has been carried out on the following publications over the past 23 years (January 1971 to September 1993) in order to provide a list of bibliography for the purpose of this research:

1. Business Periodical Index
2. ABI/INFORM on CD-ROM
3. Various journals:
4. Books, dissertations, and proceedings to conferences
5. References cited in the identified information sources

The year 1971 was chosen as the starting point because it is commonly recognized that DSS was born in that year

under the term "management decision systems" (Scott Morton, 1971). Examples of some of the keywords used for searching are "adaptive", "flexible", "evolutionary", "variable", "plasticity", "pliancy", etc., including their counterparts such as verbs, adjectives, nouns, adverb and synonyms. All articles found were screened in accordance with a classification scheme described in the following section.

2.2 Classification and Storing of Information

To facilitate our classification and storing of information, a simplified version of the Research Decision Support System (SRDSS) was developed on an IBM PC using a window-based 4GL database management system called Microsoft Access®. A discussion of this SRDSS is included in this paper. For a full description of the original SRDSS see Toda et al. (1991).

In the process of problem solving, not all the available knowledge or information is relevant to solving the problem. The information structuring approach is a method for "integrating and transforming pieces of collected information into the one appropriate for solving the problem" (Toda et al., 1991). Innovative research and development activities generally require problem solving effort for a target setting problem. Seeking solutions to target setting problems involves resetting the present target to a higher level target, and resolving the gap between these two targets (Toda et al., 1991). Toda et al. (1991) contend that original scientific/technical papers usually contain descriptions on four elements (Figure 1), namely, motivation for R&D, existing R&D results, new results, and necessary future R&D topics/areas.

"The topic is the problem to be solved by the R&D activities. The problem can be rephrased as the ***need*** for the R&D. The new results usually constitute the main body of the paper, and offer solutions for the problem. The solutions, however, are usually partial ones for the problem, and necessary future research topics/areas are discussed or suggested for its future solution. Therefore, the new results can be considered as ***seeds*** for solving the problem completely." (Toda et al., 1991)

In the context of adaptive DSS, the ***need*** refers to a necessity of a system design element or an attribute that is required for solving the problem at hand. The ***seed*** refers to a possible solution to one or more needs.

2.3 A Framework of Adaptive DSS Need-Seed Keywords

A framework of adaptive DSS need-seed keywords were constructed in order to provide a basis for classifying information in the papers in terms of 'needs' and 'seeds' using an information structuring approach. This framework of adaptive DSS need-seed keywords is composed of two parts, namely, need trees (Table 1) and seed trees (Table 2). The trees are a kind of construction used to organize related individual needs and seeds into a hierarchy under the information structuring approach.

To start with, a preliminary version of the need trees was derived from the conceptual framework of adaptive DSS due to Lai and Quaddus (1993), and the seed trees were adapted from Toda et al. (1991). As this framework of need-seed keywords is dynamic, new categories of information (new needs and new seeds) had been kept adding to it during the course of this research. Table 1 and Table 2 represent the final version of the need and seed trees. However, as confined by the length of this paper, only a few levels of the tree structure are shown.

3 A Simplified Research Decision Support System (SRDSS)

For the purpose of this research, a simplified research decision support system (SRDSS) (Figure 2) was set up for storing, classifying, and analyzing information sources (journal articles and publications) and also their need-seed relationships. The need trees are stored in the Need database, while the seed trees in the Seed database (Figure 2).

Some major functions provided by the SRDSS are as follows:

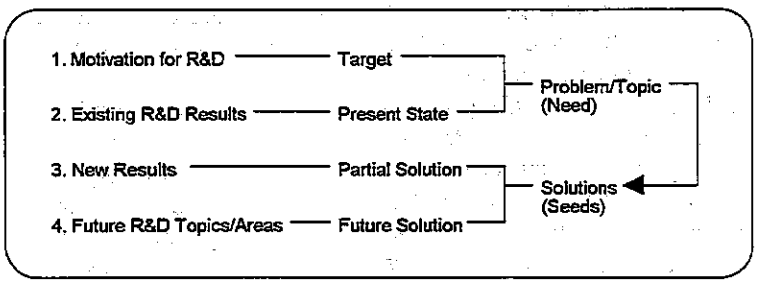

Figure 1: Elements of Original Papers (Source: Toda et al., 1991)

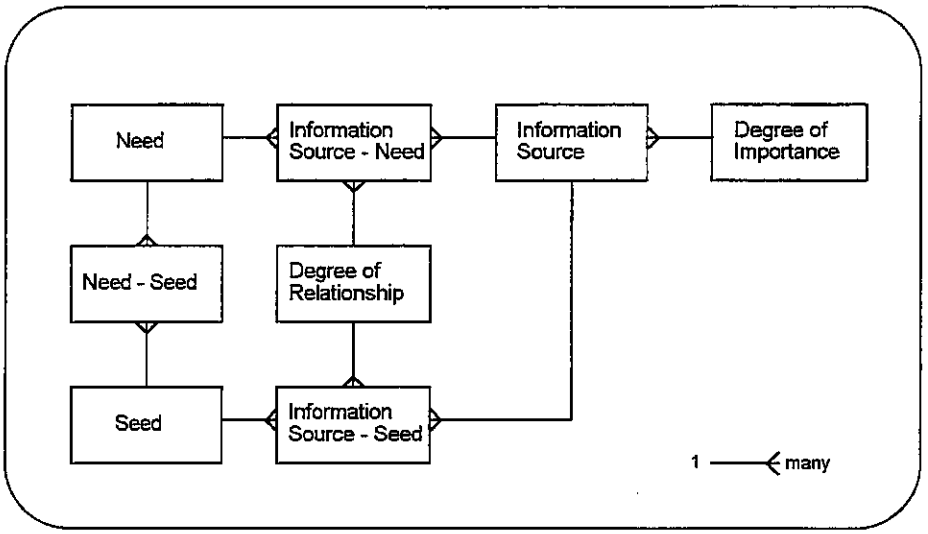

Figure 2: Entity-Relationship Model of the SRDSS

(i). Capturing and updating of adaptive DSS need-seed keywords
(ii). Capturing and updating of information sources (journal articles and publications)
(iii). Classifying information sources into appropriate topics (needs) and solutions (seeds)
(iv). Updating and restructuring databases as new need/seed information are added
(v). Analyzing need-seed relationships
(vi). SQL queries and reporting Facilities
(vii). Graphing and charting facilities

3.1 The Process of Classification

Every information source identified in section 2.1 was assigned with a unique reference number (key). Details of each article/publication, including author(s), year of publication, title, name of journal, publisher, and etc. were stored against their reference number in the Information Source database (Figure 2) for subsequent manipulation. Moreover, every information source was evaluated in terms of three categories of importance:

(i). Unimportant - Not relevant for the present interest
(ii). Important - Addressing limited area or a component of adaptive DSS design
(iii). Highly Important - Addressing large area or multiple components of adaptive DSS design

Only information sources belonging to categories (ii) and (iii) have been selected for further evaluation.

The next step was the examination of needs (problem/topic) and seeds (solution) addressed by individual information sources. To begin with, the selected information source was read, any needs or seeds identified from the article/publication were evaluated in terms of three categories of degree of relationships:

(i). Slightly related - The need/seed is mentioned, but not a primary focus of this information source
(ii). Related - The need/seed is addressed as a subtopic of this information source
(iii). Highly related - The need/seed is a primary focus of this information source.

The identified needs/seeds were then matched against the need-seed keywords in Table 1 (and Table 2). If there was a new need (or new seed), the need (or seed) trees were updated accordingly. The examination results were stored in the Information Source - Need and Information Source - Seed databases (Figure 2). Finally, in accordance with the context of the selected information source, every need and seed identified from the paper is linked up and stored in the Need - Seed database (Figure 2). For instance, in one of the papers, three needs and two seeds have been identified (Figure 3).

Figure 3 implies that the need '04.01' can be satisfied by two seeds '01.01.02.09' and '01.01.02.10'. Similarly, the seed '01.01.02.10' is a possible solution to three needs '04.01', '04.05' and '06.01'.

Need Number	Need Description
01	**Environment of Decision System**
01.00	General
01.01	Task Characteristics/Problem Domain
01.02	Access Pattern
01.03	Information Technology
01.04	Multiple User Roles and System Functions
02	**Decision System Management Support**
02.00	General
02.01	Management of DS Functional Components
02.02	Selection of Decision Strategy
02.03	Selection of Human-Computer Interaction Pattern
02.04	Management of User Support Knowledge
02.05	Management of Decision Task Support Knowledge
02.06	Management of Decision Task Processes
03	**Problem/Opportunity Finding Support**
03.00	General
03.01	User Expectations and Standards
03.02	Problem/Opportunity Diagnosis
04	**Problem Structuring and Formulation Support**
04.00	General
04.01	Manipulation of Human Mental Model
04.02	User Characteristics
04.03	Multiple Uses
04.04	Debias Human Heuristics
04.05	Problem Formulation
05	**Decision Processing Support**
05.00	General
05.01	Support Human Information Processing
05.02	Debias Human Heuristics
05.03	Decision Choice
05.04	Decision Modelling
06	**Human Computer Interaction Support**
06.00	General
06.01	Adaptive/Flexible Human-Computer Interaction
06.02	Human Mental Model Artifacts and Terminology
06.03	User Characteristics
06.04	Learning Experience
06.05	Computer Literacy

Table 1: Need Trees (Only 2 levels are shown)

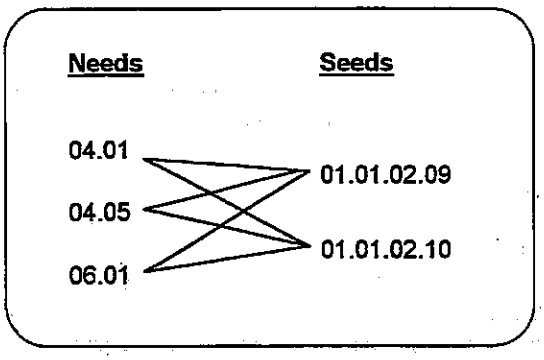

Figure 3: Need - Seed Relationships

4 Analysis and Discussion of Results

Although more than two hundred information sources have been identified having some bearing on adaptability, flexibility and terms alike, only 59 of them were classified as important (addressing some area or a component of adaptive DSS design) or highly important (addressing large area or multiple components of adaptive DSS design) that warrant detail analysis. There is also a couple of technical reports, dissertations and proceedings that are beyond reach, and therefore not included in this study (e.g., Rouse and Rouse, 1983; Sherman, 1986, 1987; Sherman and Treu, 1986; Tyler, 1986).

Seed Number	Seed Description
01	**Theory/Methodology**
01.00	General
01.01	Concept
01.01.01	Framework
01.01.02	Approach
01.02	Decision Theory/Analysis
01.02.01	Models of DM
01.02.02	Multiple Objective Decision Analysis/MCDM
01.02.03	Utility Assessment
01.03	Management Science/Operations Research
01.03.00	General
01.03.01	Mathematical Programming
01.04	System Analysis, Design and Development
01.04.00	General
01.04.01	Structural Modeling/Analysis
01.04.02	Adaptive/Evolutionary Design Process
01.04.03	Exploratory Systems Development
01.04.04	Interactive Design
01.05	Mathematical Model/Theory
01.05.00	General
01.05.01	Multivariate Analysis
01.05.02	Graph Theory
01.05.03	Logics
01.05.04	Statics
01.06	Programming
01.07	Artificial Intelligence
01.07.00	General
01.07.01	Automatic Programming
01.07.02	Deduction and Theorem Proving
01.07.03	Knowledge Representation
01.07.04	Knowledge Acquisition
01.07.05	Knowledgebase Detection of Deficiencies & Refinement
01.07.06	Natural Language Processing
01.07.07	Problem Solving, Control Methods and Search
01.07.08	Application Modelling
01.07.09	General User Modelling
02	**Software**
02.00	General
02.00.01	Flexible System Objects and Behavior
02.00.02	Parametrized System Behavior
02.00.03	System Integration
02.00.04	Tailorable and Extensible System
02.01	Adaptive/Evolutionary/Flexible DSS
02.01.00	General
02.01.01	Conceptual Architecture
02.02	Data Base Management
02.02.00	General
02.02.01	Relational Data Model
02.02.02	Relational Calculus and Database Management
02.02.03	Storage of Ill-Structured Data
02.03	Model Base Management
02.03.00	General
02.03.01	Model Base Representation
02.03.02	Model Manipulation
02.04	Knowledge Base Management System
02.04.00	General
02.05	Inference Engine
02.05.00	General
02.06	Self-Adaptive/Flexible/Intelligent User Interface
02.06.00	General
02.06.01	Multimodal Response
02.06.02	Task-Oriented Parsing
02.06.03	Command Language Grammar
02.06.04	Self-Regulating
02.06.05	Conceptual Modeling Language
02.06.06	Blackboard Architecture
02.06.07	Personalized Interface
03	**Hardware**
03.00	General
04	**Communication**
04.00	General

Table 2: Seed Trees (Only 3 levels are shown)

4.1 Analysis of Results

In this section, the collected data is presented and analyzed. It includes categorization of information sources (articles, papers, publications; hereunder they are all referred as articles), participation rate of authors, countries, institutions, and also the needs and seeds that have been discussed by various researchers.

4.1.1 Degree of Importance

Table 3 shows the distribution by degree of importance from 1971 to September 1993. It appears that 36 (61%) articles were written in the mid-80s (1983 to 1987), while 11 (19%) articles were contributed in 1987, that single year alone. Moreover, 36 (61%) articles addressed only a limited area or a component of adaptive DSS design (degree of importance equals 2). The remaining 23 (39%) of them have a wider coverage, addressing large area or multiple components of adaptive DSS design (degree of importance equals 3).

4.1.2 Leading Countries

With 57% (69) author appearances (Table 4), the USA has dominated the scene. It means that the USA has the highest participation rate in the research and application of DSS adaptability. The next significant country is UK, having 20% (24), then followed by Canada (2%), Germany (2%), Hong Kong (2%), Israel (2%), France (1%) and Switzerland (1%).

4.1.3 Frequent Contributors

During the period studied, 105 different scholars have authored or co-authored 59 articles that are related to adaptive DSS design and its applications. The total number of author appearances is 121, or on the average, 2 authors per article. The result agrees well with Table 3 - a majority of 70 (58%) author appearances were found within the five year period from 1983 to 1987.

Table 5 shows that there are 88% (92) authors appeared once, 10% (11) authors (Benyon, D.; Croft, W.B.; Gargan, R.A.; Innocent, P.R.; Keen, P.W.G.; Liang, T.P.; Sullivan, J.W.; Treu, S.; Trevellyan, R.; Tyler, S.W.; Whinston, A.B.) appeared twice, one (1%) author (Holsapple, C.W.) appeared three times, and one (1%) author (Browne, D.P.) appeared four times. Although there is not much clue to the question of why not many people have multiple appearances, we speculate some possible explanations:

(i). Some research projects were relatively short-term and small-scaled, therefore multiple publications could not be justified.

(ii). Some research topics were only a small part of a formal body of research. For example, the study of adaptive human-computer interface may be a small part of a big system or project. Once this interface design is completed, the research effort will be diverted to other more important areas.

4.1.4 Leading Institutions

We analyzed the institutions to which the authors are affiliated (Table 6 and Table 7). It is found that in terms of number of institutions, 66% (46) are academics, 13% (9) are professionals, and 21% (15) are unknown. In terms of number of author appearances, 64% (78) are academics, 24% (28) are professionals, and 12% (15) are unknown. In addition, among the top seven institutions (Table 7), two professional organizations (Data Logic Limited and Lockheed - AI Center) take the lead, then followed by other universities and polytechnics.

4.1.5 Problems/Topics (Needs)

In the original SRDSS database, the need trees and seed trees have reached six levels (see example in Table 8). But for illustration purpose in this paper, we have consolidated the need trees into two levels, and the seed trees into three levels (refer Table 1 and Table 2). This capability of information consolidation is a valuable feature of the information structuring approach.

In total 53 articles have contributed to 110 need counts. Thus on the average, one article addresses two needs. The most outstanding articles are due to Weisbrod et al., 1977 and Remus, W.E. and Kottemann, J.E., 1986. They scored 10 (9%) and 7 (6%) need counts respectively. It is observed also that the following three needs have received the most attention by the researchers:

(i). '06.01' - Adaptive/Flexible Human-Computer Interaction, scored 28 (25%)

(ii).'02.04' - Management of User Support Knowledge, scored 12 (11%)

(iii).'06.03' - User Characteristics, scored 12 (11%)

Table 9 analyzes the distribution and trend of research problems/topics (needs). It is observed that the past research concentrates most in the area of '06' (Human-Computer Interaction Support) (48%), then '02' (Decision System Management Support) (19%), '05' (Decision Processing Support) (13%), '04' (Problem Structuring and Formulation Support) (11%), '01' (Environment of Decision System) (11%), and least in '03' (Problem/Opportunity Finding Support) (3%).

In Table 9, no more research topics having a primary focus on '01' (Environment of Decision System) is found after 1987. The trend of research in '02' (Decision System Management Support) dropped after 1987, in '03' (Problem/Opportunity Finding Support) is scarce, in '04' (Problem Structuring and Formulation Support) and '05'

Importance	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	Total
2	0	0	0	0	0	2	0	0	0	0	0	2	4	5	3	4	6	4	2	1	2	1	0	36 (61%)
3	0	0	0	0	0	0	1	0	0	1	1	0	3	1	5	0	5	0	1	2	2	0	1	23 (39%)
Total	0	0	0	0	0	2	1	0	0	1	1	2	7	6	8	4	11	4	3	3	4	1	1	59 (100%)

Table 3: Distribution by Degree of Importance

Year / Country	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	Total
Canada	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	3 (2%)
France	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1 (1%)
Germany	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	3 (2%)
Hong Kong	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2 (2%)
Israel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2 (2%)
Switzerland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1 (1%)
UK	0	0	0	0	0	0	0	0	0	0	0	1	0	0	8	4	8	0	0	3	0	0	0	24 (20%)
USA	0	0	0	0	0	1	3	0	0	1	3	0	4	10	3	4	12	9	2	2	10	2	3	69 (57%)
Unknown	0	0	0	0	0	1	0	0	0	0	0	0	7	0	2	0	4	0	0	0	0	0	0	16 (13%)
Total	0	0	0	0	0	2	3	0	0	1	3	1	12	10	15	8	25	11	6	7	10	2	3	121 (100%)

Table 4: Distribution by Country of Authors

	No. of Appearances				Total
	1	2	3	4	
No. of Authors	92 (88%)	11 (10%)	1 (1%)	1 (1%)	105 (100%)

Table 5: Analysis of Frequency of Appearances

	Academic	Professional	Unknown	Total
No. of Institutions	46 (66%)	9 (13%)	15 (21%)	70 (100%)
No. of Author Appearances	78 (64%)	28 (24%)	15 (12%)	121 (100%)

Table 6: Distribution by Nature of Institutions

(Decision Processing Support) seem consistent, whereas in '06' (Human-Computer Interaction Support) appears like a 'roller coaster' - with a lot of ups and downs.

4.1.6 Possible Solutions (Seeds)

Cross tabulation revealed that 58 articles have contributed to 106 seed counts. On the average, one article addresses two seeds. Articles due to Trigg et al., 1987, Liang and Jones, 1987, and Piramuthu, et al., 1993 are important, as they accounted for 17% (18) of the total seed counts. On the other hand, the following three seeds have received the most attention by the researchers:

(i). '01.01.02' (Conceptual Approach), scored 30 (28%)
(ii). '02.06.00' (Self-Adaptive/Flexible/Intelligence User Interface in General), scored 18 (17%)
(iii).'01.01.01' (Conceptual Framework), scored 12 (12%).

Year / Institution	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	Total
Data Logic Ltd. UK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	7	0	0	0	0	0	0	10
Lockheed - AI Center, USA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	4	0	0	7
Purdue University, USA	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	4	0	0	0	0	0	7
Leicester Polytechnic, U	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4	0	0	0	0	0	0	0	0	5
University of Illinois, USA	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	1	4
University of Massachusetts, USA	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	4
Virginia Polytechnic, USA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	0	0	0	4
Total	0	0	0	0	0	0	0	0	0	0	3	1	0	3	4	3	11	7	1	2	4	1	1	41

Table 7: Distribution by Institution of Authors (Top 7 Institutions)

Seed Number	Seed Description	Example of Scores
01	Theory/Methodology	75
01.01	Concept	75
01.01.00	General	30
01.01.01	Framework	45
01.01.01.01	Adaptive Decision Aid/Model	20
01.01.01.02	Adaptive/Evolutionary/Flexible DSS Framework	10
01.01.01.03	Adaptive Model Management System Framework	15
01.01.01.03.01	Model Representation	15
01.01.01.03.01.01	Predicate Calculus and Production System	1
01.01.01.03.01.02	Graphs	2
01.01.01.03.01.03	Semantic Networks	3
01.01.01.03.01.04	Frames	4
01.01.01.03.01.05	Relational Database Theory	5

Table 8: Example of a 6-Level Seed Tree

In the context of providing solutions (seeds) to DSS adaptability, most of the past research effort is in the area of '01' (Theory/Methodology) (63%) and '02' (Software) (37%), but none in '03' (Hardware) and '04' (Communication) (Table 10). Table 10 shows that the trend of research in '01' (Theory/Methodology) remains consistent, but that of '02' (Software) dropped after 1987.

4.1.7 Need-Seed Relationships

Our SRDSS is capable of presenting a road map showing the relationships between needs and seeds. Such a road map is most useful when one wants to find out the possible solutions (seeds) to a problem/research topic (need), or all problems/research topics (needs) that are related to a particular solution (seed). To a certain extent, all the needs and seeds are inter-related because a need is related to many seeds, and every one of these seeds is related to many needs. For instance, the need '04.05' (Problem Formulation) can be satisfied by seven seeds, namely, one 'Framework' ('01.01.01') and six different 'Approaches' ('01.01.02', including sub-level seeds). If we now want to know the details of those six 'Approaches', the table can be re-run immediately by modifying the SQL (Sequential Query Language) script or the QBE (Query-by-example).

Table 11 highlights the needs and seeds in descending order of frequency counts. Items at the top of the list are important because they represent areas of contemporary research interest of most people in relationship with DSS adaptability. On the other hand, items down at the bottom of the list are of equal significance because either they have not yet been studied, or they have not been discussed too much. They represent 'holes' that require additional knowledge to be filled in, and are in effect opportunities for future research.

5 Conclusions

The literature on DSS and its related disciplines is undoubtedly abound. However, our findings indicate that the research on DSS adaptability still has much ground for improvement. Although thousands of articles, papers, and publications have been reviewed over a period of 23 years in this study, only 59 of them can be considered having a primary focus on formulating, promoting, or providing adaptive characteristics to the design and application of decision support systems. To save space this list of 59 articles is not included in this paper. But it is available from the authors.

In terms of research problems/topics (needs), we can see that the past research effort concentrates most in the area of 'Human-Computer Interaction Support', then 'Decision System Management Support', 'Problem Structuring and Formulation Support', 'Environment of Decision System', and least in 'Problem/Opportunity Finding Support'. But in terms of providing solutions (seeds), most of the past research effort is in 'Theory/Methodology', less in 'Software', and none in 'Hardware' and 'Communication'.

By and large, the research in DSS adaptability began to boom in early 1980s, and reached its peak in 1987. Apart from some individual research topics still receiving consistent attention (e.g., 'Theory/Methodology', 'Problem Structuring and Formulation Support', and 'Decision Processing Support'), the general trend is declining. Such a decline may be due to a shifting of research interest, saturation of knowledge, lack of new research opportunities, lack of funds, lack of supporting information technology, etc., which all pose questions for future research.

We contend that the need for providing adaptive attributes in DSS is there. On the one hand the user community is not homogeneous. On the other hand plenty of business settings are versatile in nature. Their decision making processes can be extremely ad-hoc and ill-structured. In order to be 'of practical use within a business environment, an ideal DSS design should be flexible enough such that users can employ a variety of approaches to their decision tasks' (Lai and Quaddus, 1993). There are already research that demonstrate high degree of maturity in the field of theory/methodology and human-computer interface. The direction for future research effort should be geared towards those least studied, or not yet discovered areas as highlighted in this paper.

Our current effort is consolidating the findings of this study with the conceptual framework of adaptive decision support system (Lai and Quaddus, 1993). Eventually an adaptive decision support system prototype, having most of the adaptive characteristics required by a business environment, is expected to be built in order to study in depth the benefits, theoretical, technical, and practical viability of providing such a system.

Year / Needs	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	Total
01	0	0	0	0	0	1	2	0	0	0	0	3	0	2	1	0	3	0	0	0	0	0	0	12 (11%
02	0	0	0	0	0	0	3	0	0	0	0	0	4	6	0	2	3	0	1	0	1	0	1	21 (19%
03	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	3 (3%)
04	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	1	3	0	0	2	2	0	1	12 (11%
05	0	0	0	0	0	0	2	0	0	1	1	0	2	1	0	1	0	0	0	3	2	0	1	14 (13%
06	0	0	0	0	0	2	0	0	0	0	0	1	1	5	8	8	12	5	1	2	3	0	0	48 (43%
Total	0	0	0	0	0	3	10	0	0	1	1	4	7	14	10	12	22	5	2	7	8	0	4	110

Table 9: Distribution of Research Problems/Topics (Needs)

Year / Seeds	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	Total
01	0	0	0	0	0	1	3	0	0	1	3	3	9	2	7	3	14	1	0	5	7	2	6	67 (63%
02	0	0	0	0	0	1	0	0	0	0	0	1	1	6	5	4	12	4	4	0	1	0	0	39 (37%
03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	2	3	0	0	1	3	4	10	8	12	7	26	5	4	5	8	2	6	106

Table 10: Distribution of Research in Solutions (Seeds)

Needs	Seeds
1. '06.01' - Adaptive/Flexible Human-Computer Interface	1. '01.01.02' - Approach
2. '02.04' - Management of User Support Knowledge	2. '01.01.01' - Framework
3. '06.03' - User Characteristics	3. '02.06.00' - Self-Adaptive/Flexible/Intelligent User Interface in General
4. '01.01' - Task Characteristics/Problem Domain	4. '02.04.00' - Knowledge Base Management System in General
5. '04.05' - Problem Formulation	5. '01.07.07' - Problem Solving, Control Methods and Search
6. '02.05' - Management of Decision Task Support Knowledge	6. '01.07.09' - General User Modelling
7. '05.01' - Support Human Information Processing	7. '01.07.03' - Knowledge Representation
8. '04.02' - User Characteristics	8. '01.02.02' - Multiple Objective Decision Analysis/MCDM
9. '06.02' - Human Mental Model Artifacts and Terminology	9. '01.02.03' - Utility Assessment
10. '01.02' - Access Pattern	10. '01.04.04' - Interactive Design
11. '04.03' - Multiple Uses	11. '02.01.00' - Adaptive/Evolutionary/Flexible DSS in General
12. '05.03' - Decision Choice	12. '02.06.01' - Multi-Modal Response
13. '06.04' - Learning Experience	13. '02.06.07' - Personalize Interface
14. '01.04' - Multiple User Roles and System Functions	14. '01.07.04' - Knowledge Acquisition
15. '03.02' - Problem/Opportunity Diagnosis	15. '01.07.05' - Knowledgebase Detection of Deficiencies & Refinement
16. '04.01' - Manipulation of Human Mental Model	16. '01.07.06' - Natural Language Processing
17. '05.04' - Decision Modelling	17. '01.07.08' - Application Modelling
18. '02.02' - Selection of Decision Strategy	18. '02.00.01' - Flexible System Objects and Behaviour
19. '04.04' - Debias Human Heuristics	19. '02.00.02' - Parametrized System Behaviour
20. '05.02' - Debias Human Heuristics	20. '02.00.03' - System Integration
21. '06.05' - Computer Literacy	21. '02.00.04' - Tailorable and Extensible System
22. '02.00' - Decision System Management Support in General	22. '02.01.01' - Conceptual Architecture
23. '03.01' - User Expectations and Standards	23. '02.02.03' - Storage of Ill-Structured Data
24. '05.00' - Decision Processing Support in General	24. '02.03.01' - Model Base Representation
25. '06.00' - Human Computer Interaction Support in General	25. '02.06.02' - Task-Oriented Parsing
26. '01.00' - Environment of Decision System in General	26. '02.06.03' - Command Language Grammar
27. '01.03' - Information Technology	27. '02.06.04' - Self-Regulating
28. '02.01' - Management of DS Functional Components	28. '02.06.05' - Conceptual Modelling Language
29. '02.03' - Selection of Human-Computer Interaction Pattern	29. '02.06.06' - Blackboard Architecture
30. '02.06' - Management of Decision Task Processes	
31. 03.00' - Problem/Opportunity Finding Support in General	
32. '04.00' - Problem Structuring and Formulation Support in General	

Table 11: The Needs and Seeds (in decending order of frequency counts)

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