Journal of the Operational Research Society (1998) 49, 109–120

A survey of decision support system applications (1988–1994)

SB Eom[1], SM Lee[2], EB Kim[3] and C Somarajan[1]

[1] *Southeast Missouri State University,* [2] *University of Nebraska, and* [3] *Drake University, USA*

To extend a previous survey of specific decision support system (DSS) applications over the period (January 1971–April 1988), we have conducted a follow-up survey of DSS applications published between May 1988 and December 1994. Two hundred seventy-one published applications are identified. This survey reveals that there appear to be more creative applications of optimisation and suggestion model-based DSS than simulation-based applications. This is evidenced by a proportional increase of optimisation and suggestion models and a decrease of representation models. Moreover, group decision support systems, executive support systems, and knowledge-based systems applications are becoming more prevalent in many organisations. Although management science (MS)/operational research (OR) models continue to play critical roles, there is a clear observable trend in the DSS model area that three non-MS/OR tools are emerging as powerful DSS tools: graphics, artificial intelligence, and visual interactive modeling.

Keywords: decision support systems; applications; survey; management science models

Introduction

Since the early 1970s, scholars in the management information systems (MIS)/decision support systems (DSSs) areas have recognised the important roles computer-based information systems play in supporting managers in their semi-structured or unstructured decision making activities. For example, Gorry and Scott Morton[1] claimed that 'Information systems should exist only to support decisions.' Since then, there has been a growing amount of research in the area of DSSs.[2] This paper presents a new survey result based on the analysis of new data in a manner that follows on, and is consistent with, a previous survey paper which covered the period of January 1971 through April 1988.[3] We compiled a bibliography of 271 published DSS applications appearing in the literature, excluding those listed in conference proceedings and doctoral dissertations.[4]

Through this follow-up survey, our goal is to inform both academicians and practitioners about the areas in which specific DSS applications are reported. Our intent is to provide insight to DSS practitioners and researchers about major historical trends, implications of this study, future directions for new theoretical developments, and to compile a systematic reference for the burgeoning literature on DSS applications.

Correspondence: Dr SB Eom, Professor of MIS, Department of Management, Donald L. Harrison College of Business Administration, Southeast Missouri State University, Cape Girardeau, MO 63701, USA.
E-mail: sbeom@SEMOVM.SEMO.EDU

Selection criteria

Like the data complied in the previous survey, data for this survey was also collected using the ABI/INFORM database. Moreover, we searched the INSPEC database which is the highest ranked database in the DSS area.[5] To compare the trends between the two periods, the following same selection criteria used by the previous survey are used here to compile DSS applications.

A DSS is defined as a computer-based interactive system that

— supports decision makers rather than replaces them;
— utilises data and models;
— solves problems with varying degrees of structure—nonstructured (unstructured or ill-structured)[6]; semi-structured[7,8]; semistructured and unstructured tasks[9]; and structured, semistructured, and unstructured[10]; and
— focuses on the effectiveness rather than the efficiency of decision processes (facilitating decision processes).

The descriptor, 'decision support systems,' originally produced approximately 1600 articles. We used the following criteria in deciding which papers to include in our survey. They should include:

(1) A description of a semi- or unstructured decision;
(2) A description of the human-computer interface and the nature of the computer-based support for human decision makers' intuitions and judgments; and
(3) A description of a data-dialogue-model system.

Using these criteria, a very large number of published DSS applications did not make the cut, thus narrowing down the number of the bibliographies to two hundred seventy one applications for further analysis. Of these, approximately 52% of all DSSs are operational systems in use. About 32% of articles are concerned with prototype systems under various testing stages. The remaining 16% of all systems surveyed are in the conceptual design stages. But we have decided to include those systems because they present a novel approach that may be beneficial to the development of future generations of DSSs. Table 1 shows a list of journals publishing DSS application papers.

Analysis

To examine the development pattern of a specific DSS over time, we analysed and summarised the survey results according to: (1) the area of application; (2) the year of publication in each area of application; (3) the distribution of underlying models in DSSs; (4) a classification based on Alter's taxonomy; and (5) the management level (operational, tactical, or strategic) for which the DSS was designed. It should be noted that the published DSS applications are not a random sample of DSS applications in practice. Many DSS applications go unreported. Therefore, we should not interpret the result of this survey as if it has reflected the real world practice.

Classification by application areas

The application areas can be broadly divided into corporate functional management fields (72% of the total 271 applications articles) and other areas (28%) (Figure 1).

Corporate functional management area

There were 194 applications in the corporate functional management area. Of the corporate functional management applications, production and operations management (POM) contains the largest number of application articles published (41%), followed by management information systems (19%), marketing (13%), finance (10%), strategic management (6%), human resources (4%), multi-functional systems (3%), accounting (2%) and international business (2%).

The POM applications (79 applications) are further subdivided into seven subareas: planning for demand, master scheduling, operations scheduling and control, operations design, capacity planning, inventory planning, and purchasing and supply management. For a systematic table of classification by application areas and correspond-

Table 1 A list of journals publishing DSS application articles

Rank	*Journals*	*Count*
1	Interfaces	60
2	Decision Support Systems	42
3	European Journal of Operations Research	28
4	Operations Research	12
5	Computers and Operations Research	8
6	Computers in Industry	7
7	Decision Sciences	6
	Information and Management	6
	Journal of Management Information Systems	6
8	Engineering Costs and Production Economics	5
	Journal of the Operational Research Society	5
	Omega	5
9	Computers and Industrial Engineering	4
10	International Journal of Production Research	3
	MIS Quarterly	3
	Naval Logistics Quarterly	3
	Production and Inventory Management Journal	3
	Project Management Journal	3
	Simulation	3
11	IEEE Transactions on Systems, Man, and Cybernetics	2
	INFOR	2
	International Journal of Physical Distribution and Logistics Management	2
	International Journal of Production Economics	2
	Journal of Applied Business Research	2
	Journal of Business Logistics	2
	Journal of Systems Management	2
12	All other journals	45
	Total	271

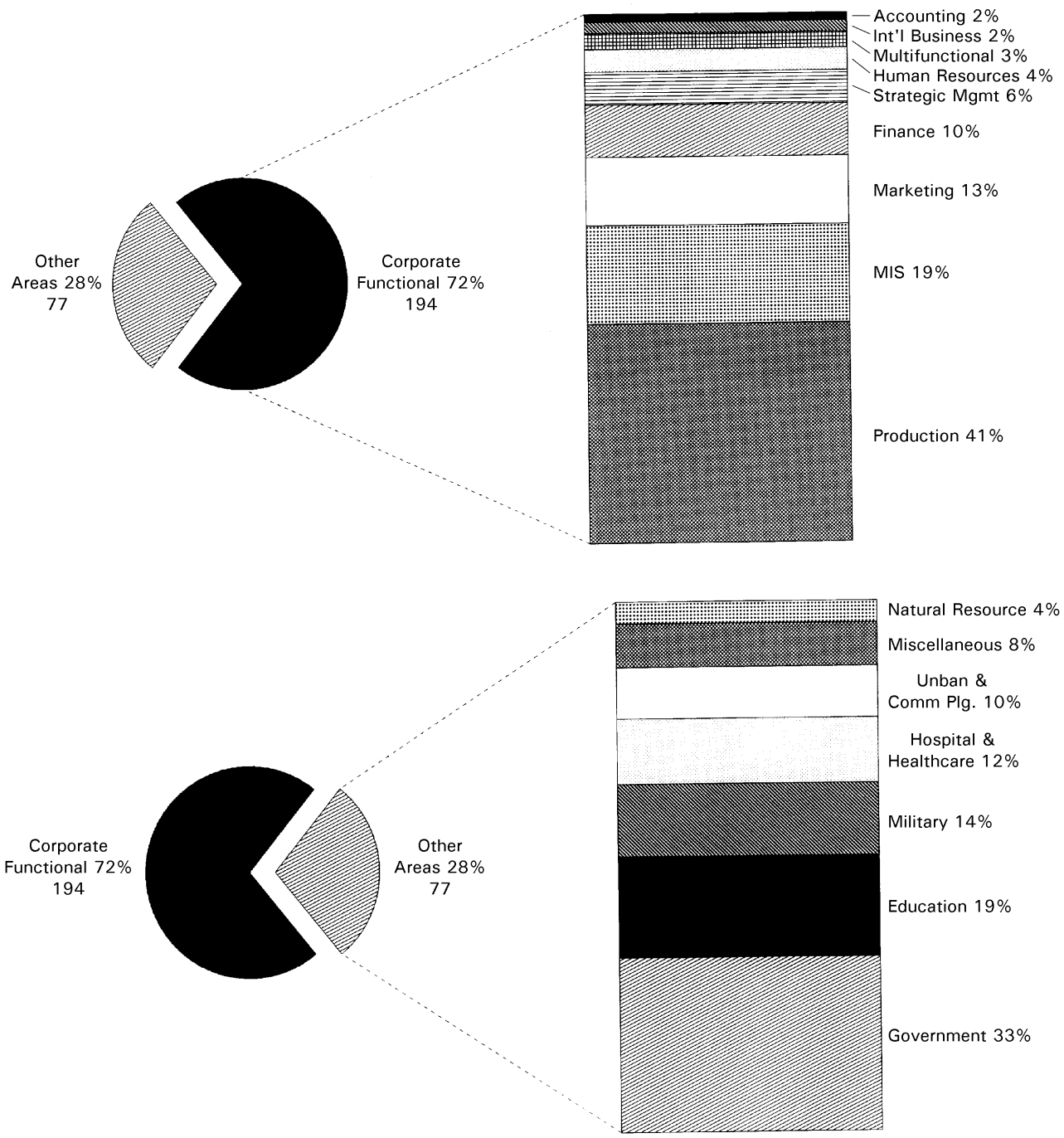

Figure 1 (a) All articles are broadly divided into corporate functional management (194) and noncorporate areas (77). Corporate functional management accounts for 72% of the application articles and is further divided into nine functional areas. (b) Twenty-eight percent of the application papers concern noncorporate subjects; this is subdivided into seven areas.

ing reference numbers in the bibliography, see Eom *et al.*[4] Planning for aggregate demand sets production and operations management in motion. Customer demands deserve to be managed effectively. DSSs are developed to help operations managers design sampling procedures for accurate estimation of electrical demand[11] and forecast rotatable aircraft parts demand.[12] To meet aggregate demand, capacity must be planned. Fixed capacity planning involves enhancing human potential through the use of high technology. DSSs have become effective tools for automating factories,[13] configuring/planning/controlling flexible manufacturing systems,[14–17] and for simplifying process technology using just-in-time production,[18] line-balancing[19,20], and quick setup.

Meeting customer demand for each item requires careful planning to produce, specified by item, by period, and by capacity group (master schedule). Master scheduling cannot be managed without careful planning of control of inventory and material requirement planning (MRP). This survey identified a large number of DSSs for master scheduling,[21–26] MRP,[27] and inventory planning and control.[28–30] Master scheduling must be executed to produce the products for meeting customer demands through the operations design, scheduling, and control. Almost 30% of the POM applications are developed to support managers in planning and controlling manufacturing operations such as refinery operations (gasoline blending),[31] managing quality-control process[32], designing product,[33,34] selecting machines in integrated process planning, evaluating personal and machine productivity, managing manufacturing logistics and dispatch,[35,36] planning offshore drilling, and scheduling and terminating projects. The transportation industry has been dependent on DSSs in managing fleet, dispatching trains, scheduling courier vehicles, flights, and airlines cockpit crews, and allocating airline arrival slots.[37,38] Operations scheduling and control also involves effective resource management including purchasing and materials management. In doing so, DSSs are used to design materials management processes and manage procurement in business volume discount environments.

The MIS area is the second major DSS application area with thirty-seven applications in the following subareas—data communications, systems analysis/design/evaluation, information resources management, and DSS generators. In the data communication area, DSSs support the user in designing a fiber optic wide area network[39] and evaluating local area network topologies.[40] The process of information systems analysis, design, development, and evaluation are supported by DSSs in the following areas: designing online retail banking systems, evaluating MIS effectiveness, joint application development, optimising MIS project portfolio mix, systems analysis and planning, and strategic planning of system development. DSSs have become effective tools for managing information resources such as planning information systems security and supercomputer acquisition.[41,42] A notable development during the survey period is the development of a large number of application (domain)-independent systems for supporting group decision making,[43] massive data retrieval and extraction,[44] multiple criteria decision making problems,[45] consensus reaching processes, decision conferencing, multicultural/multilingual communication, and modeling tasks.[46]

Thirteen percent (25 out of 194) of the applications in corporate functional management dealt with marketing in the following: Allocating retail space in retail outlets, measuring direct product profitability in retail merchandising, competitive pricing and market share, designing freight networks and distribution systems, planning logistics, scheduling vehicles, and managing hazardous material shipments. The advertising-related applications include media-planning for advertising agencies and selecting telemarketing sites.

Financial DSSs include applications in corporate financing like the management of asset-liability and cash, debt planning, capital budgeting, evaluating financial risk and financial analysis.[47] Funding strategic product development, locating banks, planning mergers and acquisitions, and selecting research and development projects[48] were the areas of application dealing with financial institutions. In other finance area applications, DSSs are used to set interest rates for money market deposit accounts, manage portfolios, structure optimal leases, appraise real estate values, and plan small business finance.

In the strategic management area, DSSs are developed to support in analysing external environment and industry trends[49], mergers and acquisitions, product/market position, and planning multi-level (corporate, division, department) and multifunctional corporations, selecting grand strategy, managing a portfolio of new product development research projects, evaluating strategy, supporting integrated strategic planning process, and managing organisational crisis.[50]

In the human resources management area, the majority of DSSs help the user to plan manpower, resolve labor management disputes, and to track critical human resources information[51]. Four applications in international business are in allocating investment funds in multinational corporations (MNCs), analysing international investment options, planning global logistics, and planning global marketing/production/distribution. In the accounting/auditing area, DSSs are applied to audit health insurance claims[52], estimate pencil manufacturing cost[53], and analyse stochastic cost-volume-profit. Multifunctional management DSSs aid the user in the following: multi-refinery, multi-period capital investments planning for expanding refining capacity, budgeting and manpower planning, strategic production and distribution planning, manpower and vehicle scheduling, integrated multifunctional systems for chemical production, and supporting reciprocally interdependent decisions.

Other areas

In non-corporate areas, government appears to be the dominant domain for DSS applications (36%), followed by education (22%), military (13%), hospital and healthcare (12%), urban/community planning and administration (9%), and miscellaneous (8%). The natural resources sector accounts for only 4% of the 77 application articles.

Ten percent of all applications (twenty-eight) were in the government sector. These twenty-eight were distributed among allocating inspection resources, analysing energy policy[54], assessing flood risks, cost-benefit-risk analysis of safety back fit for nuclear power reactor, decision conferencing for systems planning, designing a service territories network, developing national economic policy[55], environ-

mental planning, evaluating multistage investment in coal production, evaluating motor vehicle taxation legislation, facilitating the quality improvement process, facility and equipment planning, hurricane mitigation planning, improving youth probation service, managing pavement rehabilitation, manpower planning and scheduling, planning nuclear emergency evacuation, planning statewide highway networks, planning and evaluating NSAS space projects,[56] proactive debt management, scheduling the Olympic games,[57] strategic decision and information system for government cabinet, and tracking criminal histories.

In the education area, DSSs are used in allocating interview slots of campus recruiters, assigning students to group projects, designing a master of business administration program, negotiating teacher union contract, designing university admission policy, managing university funds,[58] scheduling general examinations/academic courses/instructors, deciding school districts,[59] and strategic planning support for school managers.

Military DSS applications are developed to allocate military units to tasks, assess the combat capability of air force weapon systems,[60] forecast the army's enlisted personnel, manage the army's facility/naval electronic warfare, plan housing supply, modernise helicopter fleet, procure military equipment, support army's group decision process via teleconferencing systems,[61] and schedule the operation desert storm airlift.[62]

In the health-care industry, DSSs help health care administrators assign family practice residents to clinics[63], allocate resources in public health organisations, control health care costs, plan and locate health facilities, plan district health care services, and plan resource requirements for HIV/AIDS population.[64] Urban and community planning DSSs are applied to manage mass transit personnel and resources, plan a large-scale event in a local public sector, budget public library, and schedule sanitation vehicles.[65] In the area of natural resources, DSSs are developed to allocate pelagic fish quota, evaluate an area for landslide favorability, and declare wildfire disaster.[66] Other miscellaneous applications include assigning referees for editors, planning pot plant nurseries, preparing/dispatching telegrams, scheduling for a sport league, and selecting a tenant.

Distribution of entries by classification and year of publication

The annual count of published DSS applications shows that the number has increased eash year (Table 2 and Figure 2). Figure 2 depicts a clear trend of an increasing number of DSS applications over the period of 1971 through 1994. As conjectured in the earlier survey,[3] the number of articles has continued to increase each year.

Several interesting trends in the development of DSS applications are apparent. First, the most significant change in the corporate functional areas is that production and operations management and management information systems areas have emerged as the dominant DSS application fields, while the remaining areas of application have been holding steady. Some areas are less explored: accounting, international business, and human resources. Also a notable change in the non-corporate areas is that approximately 60% of applications are in government and educational institutions.

Table 2 Distribution of entries by application areas and year of publication

Area	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*Total*
Corporate functional area								194
Accounting/auditing				1		2		3
Finance		5	1	6		1	6	19
Human resources	2	1		1		3	1	8
International business	1			2			1	4
Management info. systems	4	1	6	5	8	4	8	36
Marketing/transportation	4	2	6	1	5	3	4	25
Production/operation	7	12	7	14	19	15	7	81
Strategic management	1	1		2	3	3	2	12
Multi-functional application		1	3			2		6
Non-corporate area								77
Education	1	2	2	1	2		6	14
Government	3	7	3	6	5	3	1	28
Hospital/health care		2	1	2	2	2		9
Military	1			5	2	2		10
Natural resources	1		1	1				3
Urban/community planning		1	1	2	1	1	1	7
Miscellaneous	1			3		1	1	6
Yearly total	26	35	31	52	47	42	38	271

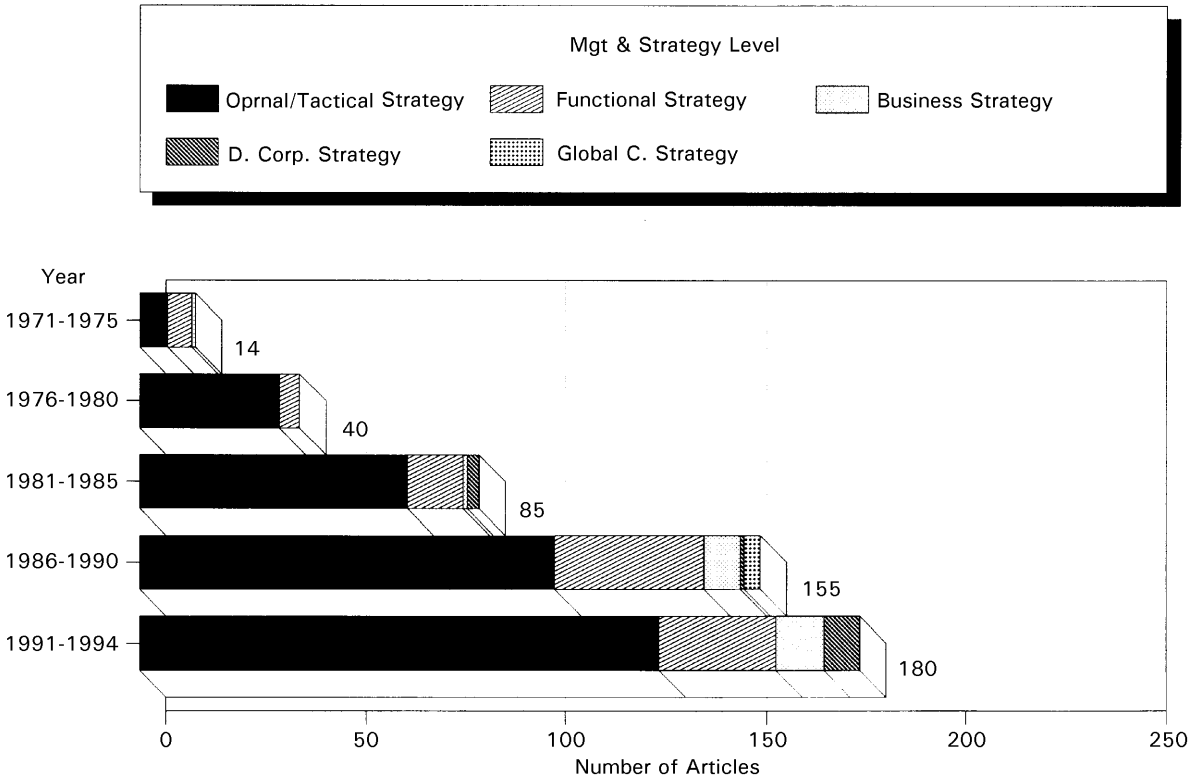

Figure 2 The proportions of DSS papers concerning operational, tactical, and strategic decisions changed during different periods in the 1970s, 1980s, and 1990s.

Distribution of underlying models in DSSs

Management science/operations research (MS/OR) models have been essential elements of DSSs as Table 3 indicates. As shown in the previous survey[3], forecasting and statistical models, simulation, integer programming, linear programming, and network models have been powerful MS/OR tools that have been increasingly embedded in the model base of DSSs (Table 3). There are several notable changes in the distribution of models in this survey.

Firstly, MS/OR models are still essential elements of many DSSs. However, this survey clearly shows that other models have been increasingly embedded in the decision support systems including graphics, visual interactive modeling, artificial intelligence tools such as AI languages, expert systems, voice recognition, neural networks, and heuristics. There is a clear observable trend in the DSS model area that three non MS/OR tools are emerging as powerful DSS tools: Graphics, Artificial Intelligence, and Visual Interactive Modeling. Artificial intelligence and Graphics are the tools most frequently embedded in DSSs, more often than all other MS/OR models except multiple attribute decision making (MADM) models. Visual Interactive Modeling is another emerging DSS tool and permits a decision maker to generate and modify various visual representations of decision alternatives. Many commercial software now include visual interactive sensitivity analysis capabilities. In their DSS prize paper sponsored by INFORMS, Angehrn and Lüthi[67] introduced a DSS generator, Tolomeo, that supports visual interactive modeling and that allows the user to interact with both model and the interface. Other recent developments in this area include graph-based modeling using graph grammars.[68] DSS researchers such as Loy[69] found that the user's ability to create and use visual images is positively related to better problem-solving and problem-structuring performance using an interactive graphics-based problem-structuring aid such as the Graphical Interactive Structural Modeling Option (GISMO). Moreover, query languages and other models including genetic algorithms, fuzzy sets models, and tele-conferencing systems are becoming integral parts of many DSSs.

Secondly, multiple criteria decision making (MCDM) models, especially MADM models have become the most widely embedded MS/OR tools in the DSS application articles surveyed. Thirdly, use of deterministic models in DSSs is increasing while that of stochastic models is proportionally decreasing (see Table 3). Nemhauser[70]

Table 3 Distribution of models

	Previous survey	*Current survey*
Deterministic models	85	132
Linear programming	18	28
Goal programming	9	5
Transportation model	6	18
Network models	15	23
Inventory models	8	7
Integer Programming	19	32
Nonlinear programming	6	11
Dynamic programming	4	8
Stochastic models	58	57
Queuing models	3	1
Markov process models	6	4
Simulation models	41	41
Decision trees	8	11
Game theory	1	0
Other stochastic models		3
Forecasting and statistical models	40	47
Others	104	345
Other MCDM models	11	67
MADM	5	43
MOLP	5	10
AHP	1	12
Nonlinear goal programming	0	2
Spreadsheet modeling	24	22
Graphics	46	81
Artificial intelligence	12	73
Visual interactive modeling	0	40
Query language or 4GL	0	21
Others	0	41

The numbers indicate the frequency with which each technique appears in each specific DSS. The first column numbers come from the 1990 survey of Eom and Lee and the second column numbers represent the result of this survey.

points out that due to new advances in algorithms such as the new interior point, branch-and-bound algorithms and simplex methods as well as computer technology, and advanced implementations of optimisation algorithms that have been incorporated in commercially inexpensive software make it possible for unsophisticated users to obtain readily understandable outputs.

Our earlier survey reported that linear programming and integer programming are MS/OR tools that are frequently embedded in DSSs. The current survey reconfirms our earlier observations of the frequent use of linear programming and integer programming in mathematical programming systems. As observed by Nemhauser[70], integer programming has assumed much more important roles in supporting decisions such as scheduling flexible manufacturing systems, manpower assignment, and course and instructor, planning computer capacity, media allocation, fleet mix, designing freight/distribution networks, and so on.

Classification based on Alter's taxonomy

Alter[71] suggested a classification scheme, based on the 'degree of action implication of system outputs (that is, the degree to which the system's output could directly determine the decision).' In this survey, none of the 271 published DSS applications belong to *file drawer systems*, which allow on-line access only to particular data items. Care must be exercised when interpreting the result of this survey. The nature of published DSS applications is very much different from that of implemented DSS applications. For example, Pearson and Shim[72] in an empirical study of DSS applications find many file drawer systems. Approximately 7% of all applications (18 articles) concern *data analysis systems*. They allow on-line data retrieval, manipulation, and display of current and historical data by means of such operations as pictorial representation, summarisation, and calculation of data. About 17% of all applications (47 articles) represent *analysis information systems*, which are capable of manipulating the internal data from transaction processing systems and augmenting the internal data with external data using statistical packages and other small models to generate management information. The next type of system, *accounting models*, occupies approximately 3% of the total applications (7 articles). Accounting systems facilitate planning by calculating the consequences of planned actions on the estimate-of-income statements, balance sheets, and other financial statements. Accounting models are based on definitional relationships and formulas, unlike other types of MS/OR models. Twenty five percent of all applications (68 articles) utilise *representational models* to estimate the future consequences of actions on the basis of partially nondefinitional models, including all simulation models. Thirty eight percent of all applications (104 articles) are classified as *optimisation models* which generate the optimal solutions consistent with a series of constraints. Finally, 10% of all applications (27 articles) are categorised as *suggestion models* which lead to a specific suggested decision for a fairly structured task. Such systems perform mechanical calculations and leave little room for managerial judgment.

We find that three model types dominate; optimisation (38%), representation (25%) and analysis information systems (17%). When compared to our previous survey of 1990, we are witnessing the continued importance of optimisation systems and suggestion models which lead to a specific suggested decision. There is a definite proportional increase of optimisation and suggestion models and a decrease in the number of representation models embedded in DSSs, as shown in Table 4. It appears that application of optimisation models are increasingly dependent upon DSS front ends to make them more easily accessible to end users (decision makers).

We conducted further analysis to examine the management levels (operational, tactical, or strategic) for which

Table 4 Classification based on Alter's taxonomy

Alter's taxonomy	*Number of proportion articles*			
	Previous survey		*Current survey*	
Suggestion models	13	6%	27	10%
Optimisation models	57	28%	104	38%
Representation models	81	40%	68	25%
Accounting models	14	7%	7	3%
Analysis information systems	23	11%	47	17%
Data analysis systems	15	7%	18	7%
File drawer systems	0	0%	0	0%
Total	203		271	

DSSs are designed. Decision support systems should provide decision making support for decision makers at all organisational levels[9].

Figure 2 shows the number of specific DSS applications and their composition among operational, tactical, and three levels of strategic decisions for different periods in the 1970s, 1980s, and 1990s. During the first five-year period (1971–1975), only fourteen papers on DSS applications were published; seven about operational or tactical decision making, six on functional level strategic decision making, and one on business level decision making. During the next period (1976–1980), forty papers on DSS applications were published; five concerning functional level strategic decision making, and thirty-five on tactical or operational decision making. In other words, for this period 87.5% of the published DSS applications were concerned with operational or tactical decisions. This survey shows that approximately 28.7% of the DSS applications (78 articles) were developed to support strategic decisions; and 71.2% were developed for tactical or operational levels of decisions. Still, the majority of DSSs are being applied to support operational and tactical decisions. Supporting strategic decisions should be the focal point of DSS research as we pointed out earlier[3].

Emergence of ESS

This survey exhibits the use of executive support systems (ESS) by major corporations to assess market shares, project rental volumes, set rental prices, determining long-term effect of pricing trends, respond to competitors' price change, and restructure and downsize organisations.

Emerging trends of expert decision support systems (knowledge-based decision support systems, intelligent DSSs)

An increasing number of systems are incorporating domain knowledge, modeling, and analysis systems to provide users the capability of intelligent assistance. Knowledge base modules are being used to formulate problems and decision models, and analyse and interpret the results. Some systems are adding knowledge-based modules to replace human judgments. Managerial judgments have been used to ascertain (assess) future uncertainty and to select assumptions on which decision models can be based. Some decisions are both knowledge and data intensive. Consequently, a large amount of data usually requires considerable efforts for their interpretation and use. Knowledge-based systems are effective tools for interpreting these data to diagnose the cause of unsatisfactory results in the manufacturing processes, for example. The need to deal with a large amount of uncertain data necessitates the development of a knowledge-based DSS[73].

Real-time decision support systems

These systems are emerging due to the new development of artificial intelligence techniques such as machine learning, case-based reasoning and learning, and the improvement of computer hardware and mathematical programming packages in terms of speed of CPU and the problem size. As the survey indicates, a large proportion of DSSs involves optimisation systems. Ever increasing computing power makes it possible to solve a large scale mathematical optimisation model in a fraction of a second. Moreover, the machine learning approach and case-based reasoning and learning are a new class of emerging tools. These tools can obtain knowledge from prior data, decisions and examples (cases), and contribute to the creation of DSS to support repetitive, complex real-time decision making in the flexible manufacturing system scheduling and control[74].

Group decision support systems (GDSSs)

GDSSs are slowly gaining acceptance. They are used to facilitate knowledge acquisition from multiple experts. Group DSSs, including video conferencing systems, have been implemented in many corporations and government organisations to facilitate group decision making in a geographically distributed environment.

A new set of DSS tools and approaches are adding new capabilities to DSSs to effectively deal with the problems that could not be dealt with previously. The majority of these tools are being used to make decision support systems more intelligent by providing them with a new capability. The new capability includes machine learning which refers to computational methods/tools of a computer system to learn from experience (past solutions), data, and observations, and consequently alter its behavior, triggered by a modification to the stored knowledge. Artificial neural networks and genetic algorithms are the most notable approaches to machine learning. Other tools include fuzzy sets, modeling by example, geographical information

system (GIS), logic modeling, and visual interactive modeling (VIM).

Implications and suggestions for future DSS applications research

This survey clearly indicates that DSSs are increasingly being implemented in many organisations and that studies report that there have been significant financial and non-financial benefits of DSS application. During the period of May 1988 through 1994, two hundred seventy one DSS applications were published. When compared to our previous survey of the past two decades (1971–1988), this is indeed a significant increase from approximately 12 annual applications to 48 annual applications. Still, the majority of DSS are being applied to support operational and tactical decisions. We believe that supporting strategic decisions should be the focal point of DSS research. The same should be true for the application of DSSs to global management decision making.

The distribution of DSS applications has changed significantly between the 1980s and the first half of the 1990s. The most striking differences are that POM and MIS areas have become the two predominant fields, followed by finance. In the non-corporate area, government and educational institutions are two not-for-profit organisations that have widely used DSSs.

The nature of DSS tools have changed significantly. Today's DSSs are equipped with a variety of tools such as graphics, visual interactive modeling, artificial intelligence techniques, fuzzy sets, and genetic algorithms. Nehauser[70] stated that 'The combination of remarkable advances in algorithms and computers has made it possible to solve linear and integer programs of sizes and with speeds that we did not even dream possible a decade ago.' Indeed, the age of large scale optimisation has arrived, according to the two recent surveys[75,76] of linear programming and mixed integer programming applications. Both surveys reported that the size of the problem solvable by commercial software is virtually unlimited, only dependent on the size of random access memory of computers and the user's patience. Moreover, several solvers are built into the spreadsheet programs such as Microsoft Excel and Borland's Quattro-Pro, along with the capabilities of linking to databases and graphical user interfaces.

A host of new tools that are emerging in the DSS area are becoming an integral part of a set of recent developments in data management, DSSs, and executive information systems. These tools are and will reshape DSS developments in organisations. In addition to management science/operations research tools as identified in this survey, these emerging tools include the data warehouse/multidimensional databases (MDDB), data mining, on-line analytical processing (OLAP), intelligent agents, World Wide Web technologies, the Internet, and corporate intranets. These new tools are a set of inseparable tools that adds new capabilities to decision support systems and executive support systems. In a nutshell, data mining refers to a technology (or process) of discovering meaningful information/patterns/trends about a business from the data warehouse/MDDB using various techniques including OLAP and intelligent agents.

According to Gray,[77] the data warehouse is a relational/multidimensional database which is separated from operational databases. It is a subject oriented, integrated, time-variant, and nonvolatile (read only) collection of databases optimised for decision support. MDDB organises data as an n-dimensional cube so that users deal with multidimensional data views such as product, region, sales, time, etc. with a faster query response time. Data mining, also known as Knowledge Data Discovery, refers to discovering meaningful information/patterns/trends about a business from the data warehouse that queries and reports do not reveal effectively using various techniques.[77]

The data mining technologies utilise a plethora of tools such as artificial intelligence (expert systems, neural networks, pattern recognition, machine learning, and fuzzy logic), statistical analysis, multidimensional data analysis, visualisation including geographical information systems, and database monitoring technologies to discover new information, patterns, and trends from a company's databases. OLAP, also known as multi-dimensional analysis, is a technology that allows manipulation of enterprise aggregate data across many dimensions such as product, time, and location, etc.[78] Database monitoring uses various tools such as intelligent agents, machine learning, database triggers, and web crawlers to automatically identify data and events to be monitored, the specific thresholds that will trigger an alert, and present the results of monitoring to the user.

Intelligent agents (known also as intelligent interfaces, adaptive interfaces) research is an emerging interdisciplinary research area involving researchers from such fields as expert systems, decision support systems, cognitive science, psychology, databases, etc. According to Riecken,[79] the primary purpose of agent research is to 'develop software systems which *engage and help* all types of end users' in order to reduce work and information overload, teach, learn, and perform tasks for the user.

In the 1992 Franz Edelman DSS prize-winning paper, Angehrn[80] introduced the conversational framework for decision support. The conversational framework is the basis of a new generation of active and intelligent decision support systems and executive information systems. The active DSS will be equipped with the tools (stimulus agents) that will act as experts, servants, or mentors to decide when and how to provide advice and criticism to the user, while the user formulates and inquires about its problems under the continuous stimulus of electronic agents. This kind of

active DSSs promotes use, creativity, exploratory learning, and adaptability. The essence of active decision support activities includes monitoring decision making processes and stimulating creative ideas through carrying out insightful conversations with decision makers.

World Wide Web-based DSS is another emerging topic in the DSS area. The World Wide Web is increasingly being used as the client/server platform of many business organisations due to its network and platform-independence and very low software/installation/maintenance costs. The web-based solutions are low cost vehicles for easily accessing, analysing, and distributing timely business information from corporate databases through OLAP. The Internet and corporate intranets opened a wide possibility of building decision support systems to deal with problems of global natures. As we enter the age of the global village where geographical and temporal boundaries are shrinking rapidly, global decision support systems are emerging as the new frontiers in management information systems area. Eom[81] defined a global management support system as a management support system to support managers of multinational corporations in their decision making processes to deal with one or more variables that constitute the multidimensional complexities of global decision making. This multidimensional complexity stems from the multiplicity of the global environments in which MNCs operate. The global environment consists of legal (patent and trademark laws, laws affecting multinational operations, etc.), cultural (languages, customs, value systems, religious beliefs, etc.), economic (currency, tax, inflation, interest rates, monetary and fiscal policy, etc.), and political (form and stability of government, governmental policy toward MNCs, etc.) forces. Global management support systems have indeed become a real world technology to deal with the real world managerial complexities of global corporations. Federal Express Corporation has developed an integrated decision support and information system, the Global Operations Control Center (GOCC) system. The system uses the World Wide Web and intranets to support critical decision making concerning future operations of the 2500 trucks, 252 jet transports, and approximately 200 feeder aircraft, as well as keep track of what is happening in the far-flung courier and freight operation. The core of the GOCC system includes Total Airspace and Airport Modeler to optimise all cargo loading (weight and balance) operations, and a decision support module for fast and real-time simulations of aircraft and airport operations. The GOCC system will be a strategic decision making tool to quickly and accurately evaluate the impact of operational, tactical, and strategic management decisions.[82] Many multi-million dollar research projects are being launched to develop, implement, and evaluate WWW-based decision support systems in the health care area.[83]

The urgent challenge in the DSS field is bridging the gap between practitioners and DSS researchers. Over the last two and a half decades (1970–1995), DSSs research has mainly concentrated on DSS components (for example, data, model, dialogue, and decision maker). The future DSS research should redirect its attention to underdeveloped subspecialties to provide useful guiding principles for practitioners in the integrated processes of design, implementation, and evaluation. In the area of model/data management, much progress has been made in the subareas of model representation, model base processing, model integration, and the application of artificial intelligence to model management. Some researchers in the model management area believe a theory of models is imminent. Nevertheless, Dolk and Kotteman[84] further believe that model management needs to see some effective implementations, much like relational theory needed ORACLE and other commercially viable products. The expense of building such systems is high, however, and it is not clear that there is a market support for such a product.

The important question still remaining to be answered is: What DSS theories concerning design, implementation, and evaluation have been developed for the practitioner? *Have we developed theories*, *concepts*, *frameworks*, *methods*, *techniques*, *and tools that are being applied in practice*? *Has our DSS research been relevant to meet the needs of managers*? The increasing level of DSS implementation in organisations over the past two decades is a strong evidence to show that DSS is indeed a viable and well-accepted managerial tool. Most DSS applications have resulted in substantial financial and nonfinancial benefits to many organisations as indicated by the winners of the prestigious Franz Edelman Awards for Management Science Achievement, sponsored by INFORMS. To quote Murphy,[85] p 5, developing DSSs theory for practice depends on 'maintaining a constructive tension between the immediate needs of managers and the research interests of professors.'

DSSs have made meaningful progress over the past two decades. As a field of study, DSS is in the process of solidifying its domain and demarcating its reference disciplines including organisational sciences, artificial intelligence, systems science, cognitive science, and management science/multiple criteria decision making. A recent study provides us with concrete evidence as to the existence of a cumulative DSS research tradition, a prerequisite to the scientific progress of an academic discipline[2]. The DSS community has passed the stage of consensus building about the existence of a body of phenomena that is worthy of scientific study. An increasing number of researchers are conducting empirical study of the phenomena to establish a particular fact or a generalisation. The DSS community is approaching the stage of articulating theories to provide a unified explanation of established empirical facts and generalisations. This will eventually lead to the paradigm building stage to reach a consensus on the set of elements possessed in common by practitioners of the discipline.

Acknowledgements—We are grateful to the Editor and the anonymous referee whose suggestions improved the quality of the paper. This research is supported in part by a Research Grant of the Dean of Donald Harrison College of Business, Southeast Missouri State University. Special thanks go to Ronghua Shan and Jeong-Gon Yang, both are graduate students in the doctoral program in the department of management, University of Nebraska-Lincoln, for their essential assistance in analysing research data.

Editor's note: These DSS application references are on the author's web site: http://economics.semo.edu/com/.

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Received March 1997;
accepted October 1997 after one revision