DECISION SUPPORT FOR MANUFACTURING

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This paper describes the development of a prototype decision support system which supports decision making in aerospace manufacturing environments. This system, referred to as ICAM Decision Support System (IDSS) Prototype 2, integrates various types of operations research models with a heavy emphasis on simulation modeling, utilizing computer graphics. This paper will discuss decision support system concepts, a series of decision support systems which will provide decision making aids to aerospace manufacturing and a particular system, IDSS Prototype 2, in detail.

As computer technology grew rapidly during the 1960's the use of computers expanded into many new areas. The development of mini-computers, micro-computers, desk-top computers, time-sharing systems and computer networks has greatly increased the availability of computer power to potential users. The development of timesharing systems allowed direct access to data and models, provided for the decentralization of the computer as a resource and increased the variety of applications possible. The use of computer graphics grew rapidly as a tool to display information. Software systems for managing vast amounts of data were also developed. In the early 1970's, systems began to be developed which combined these developments to aid decision makers in making better decisions.

The role of a decision support system has been well documented in the literature. It is generally agreed that such systems are not intended to actually make decisions, but rather to assist decision makers by supporting their judgment in making better decisions. They are intended to improve the effectiveness of decisions rather than their efficiency. In addition, they are targeted specifically to aid in decision making in tasks which can be partially automated, but require the experience of the decision maker to actually make the decision. Therefore, the impact of decision support systems is on decisions in which there is enough structure to use the computer and analytic tools, but the manager's judgment is essential.

Many types of decision support systems were developed during the 1970's to support decision making in various areas. These systems have combined many of the developments of the 1960's, including advances in computer hardware, data base management systems, computer graphics and computer modeling. They were applied to areas such as finance, marketing, planning, cartography and manufacturing.

There are several desirable characteristics of decision support systems, regardless of the type of decisions being supported:

1. Conversational, Interactive - The system should allow the user to interact with the system using English-like commands to come to a decision.

2. Flexible - The system should allow the user to combine different modules or segments of the system to solve his problem.

3. Adaptable - The system can be changed easily as the user's needs and capabilities change.

4. Helpful - The system should have simple operating procedures and be forgiving

of inexperienced users.

5. Quick - The system should respond to the user in a timely manner.

6. Reliable - The system should give correct answers to user queries and not break down in the middle of a user session.

These characteristics are desirable regardless of the type of user supported by the system or the specific area of application.

The conceptual structure illustrated in Figure 1 is typical of many decision support systems. The decision maker uses the command language of the User Interface Subsystem to access data from the Data Base Subsystem or models from the Modeling Subsystem. Data stored in the Data Base Subsystem may be user-defined information or the results of a model execution. The Data Base Subsystem also includes a data base management system which organizes and manages the data stored by the system. The Modeling Subsystem includes specific models, as well as modeling capabilities. In a successful system it is essential that these models are capable of obtaining performance measures of complex systems while still being flexible and easy to build. In addition, the User Interface must be able to display information in a useful manner for the user. Today's typical decision support systems take advantage of the most current developments to display data and model results to users. Computer graphics enables a user to view data in many forms, such as bar graphs, scatter plots, histograms, or pie charts. These capabilities are inducing greater acceptance of decision support systems by decision makers because data can be viewed in a convenient fashion rather than sorting through large quantities of computer printouts as has been done in the past.

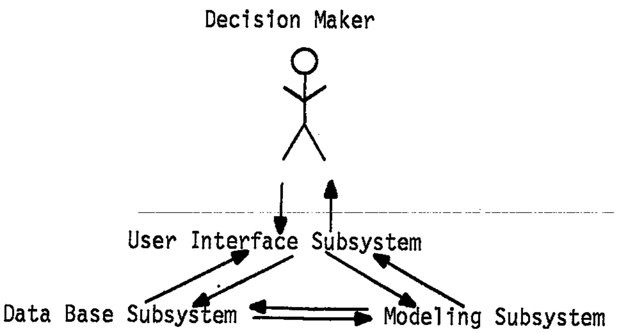

Figure 1. Conceptual Structure of a Decision Support System.

The data base management systems utilized to date have generally reflected state-of-the-art developments, as has the use of computer graphics. However, the weakest link to date in decision support systems has been the Modeling Subsystems. The models incorporated to date have been simple, general models such as time series analysis or return on investment calculations. To a great extent the modeling capabilities determine the real power and usefulness of a decision support system to decision makers. This is due to the fact that it is the modeling capabilities which provide the real "thinking power" of the system. Without good modeling capabilities, a decision support system is merely a sophisticated management information system with graphics capabilities.

It was mentioned earlier that decision support systems are intended to increase a decision maker's effectiveness. This can be done in five different ways. First, personal efficiency can be improved by automating the more clerical aspects of an analyst's job, which increases accuracy and timeliness of data. Second, decision support systems can increase a decision maker's effectiveness by expediting problem solving. This may be accomplished by permitting fast turnaround, improving consistency and accuracy, or by providing better ways of viewing or solving problems. A third way of increasing a decision maker's effectiveness is to facilitate his interpersonal communication. This can be accomplished by providing the decision maker with tools of persuasion or by standardizing vocabulary and providing for a common conceptual basis. A fourth and very important use of decision support systems is in fostering organizational and personal learning. The user of a decision support system develops a better understanding of his environment by experimenting with various models. It can often be used as a training aid to teach new employees the basic concepts behind the business which employs him. A fifth way of increasing a decision maker's effectiveness is to increase overall organizational control. A better understanding of the environment in which he works allows a decision maker to more easily control and make decisions affecting that environment. Each of these ways of increasing the effectiveness of decision making is noteworthy in that it allows a decision maker to extend his knowledge of his environment, solve particular problems and, in turn, have an opportunity to address new and more complicated issues.

This paper addresses the above issues as they relate to a particular decision support system, IDSS Prototype 2, which is being developed under the Air Force Integrated Computer Aided Manfacturing (ICAM) Program.

ICAM Decision Support Systems

The Air Force Integrated Computer Aided Manufacturing (ICAM) Program is a multi-million dollar effort to improve the productivity of aerospace manufacturing companies. As part of this program several efforts are ongoing in the area of decision support systems. These efforts can be divided into two areas. First, there are those whose goal is to develop a prototype in the near-term, which not only allows the evaluation of, and demonstrates the feasibility of, a decision support system for aerospace manufacturing, but also provides a tool for use in the aerospace manufacturing environment. The second area involves efforts to determine long range decision support requirements and to develop a preliminary design of a system to support aerospace decision making. The near-term prototype developments and the longer term system design efforts are ongoing simultaneously. They interface with each other to insure that lessons learned during prototype development are known by system designers and also that system structures and tools developed by prototype builders will be usable by the system designers.

The initial ICAM Decision Support System Prototype (0.0) was developed by Hughes Aircraft Company, assisted by a coalition of industrial and academic contributors. This initial version of IDSS provided for the automatic generation and analysis of simulation models from graphic model input. The system has been enhanced several times, the most current version being IDSS Prototype (1.4) which is operational on the Control Data Corporation CYBERNET time-sharing system. This prototype includes three functions: design, translate and analyze. The design function allows a user to graphically construct a model of his system and automatically stores it in the data base. The translate function retrieves the model from the data base and translates it into a SIMSCRIPT II.5 model. The analyze functions are invoked on command by the user while the translate function is invoked automatically by the analyze function. Reports to the user on the status of the simulation can be obtained in tabular form, line plots or histograms, and the user may select to view a subset of available outputs, avoiding a volume of possibly undesirable output. To date, the IDSS Prototypes (0.0 through 1.4) have been applied to several manufacturing problems, including a flexible manufacturing system, a ground laser locator designator facility, a sheet metal center, a group technology support software system and a manufacturing control-material management system.

The definition of long-term decision support system requirements and the preliminary design of the long-term system are being performed by Higher Order Software, Inc., who is assisted by a coalition of industrial and academic participants. Their goal is to develop a decision support system that will assist aerospace manufacturing managers at all organization levels and in all phases of manufacturing. The support system is being designed to support the following four types of users within the ICAM environment:

1. The type I user is the developer and maintainer of IDSS. He is the software engineer or software maintainer who uses IDSS as a support tool for developing and maintaining the IDSS software systems. IDSS development features will enable this user to accelerate the development process and streamline the maintenance process.

2. The type II user is the model builder responsible for providing manufacturing process models, decision scenario models, and analytic tool models. The manufacturing process model builder develops models of specific manufacturing processes, codes and classifies the decision problems, and selects the appropriate analytic tools from the support library. The analytic tool model builder codes and classifies new analytic tools and techniques and incorporates those new analysis capabilities in the IDSS support library. The software maintenance user develops models to support his maintenance functions needs and applies the analysis capabilities of IDSS to his problems.

3. The type III user has been referred to by many titles such as direct user, end user, and manufacturing decision maker. This user applies IDSS in the normal execution of his job, using models that have already been built in order to solve problems in the manufacturing environment. IDSS supports this user by manipulating the required data and providing the output to him in a useful form.

4. The type IV user is the indirect user. This individual is basically one who uses IDSS by directing or contracting for the services of types I, II or III. This user is supported by IDSS, but does not become personally involved with the system.

The long-term decision support system is being designed considering the differing needs of each user type.

The long-term decision support system design is focusing on the needs of the ICAM program and taking advantage of technology developed within ICAM. In the beginning of this project, attention was focused on supporting a subset of possible decisions with a subset of available analytic tools. The processes of developing a production schedule, developing a tooling plan and tentatively deciding to make or buy were defined, and potential areas for decision support were identified. This was done by identifying the functions performed to accomplish each of these processes, as well as defining the information required to support each of the functions. In addition, seven groups of analytic tools were identified and defined. Again, this was done by identifying the functions performed in using the analytic tools and by defining the information associated with using them. The seven groups of analytic tools include mathematical programming, stochastic modeling, statistics, simulation, scheduling, economic models and product assurance models. As the design progresses additional manufacturing processes and analytic tools will be considered.

As the definition of requirements for and preliminary design of the long-range IDSS progressed, it became apparent that there were many basic decision support concepts which had not been tested or evaluated in the aerospace manufacturing environment. Therefore, the development of IDSS Prototype 2, a second prototype with greatly enhanced capabilities, was begun. The concepts to be evaluated by the IDSS Prototype 2 include the following: the integration of multiple types of analytic tools within one problem solving framework, the addition of a more powerful simulation capability, the development of an integrated data base to support the expanded system, the development of a more flexible report generation capability, and the development of a user-defined computational capability. The IDSS Prototype 2 was designed to be user friendly, extensible, flexible, and as computer hardware independent as possible. Each of the IDSS Prototype 2 capabilities will be discussed in greater detail in the next section.

IDSS Prototype 2

The intent of the development of IDSS Prototype 2 is to extend previously developed and proposed decision support systems by providing flexible and interactive input and output procedures and by integrating the modeling support. This goal will be accomplished primarily through the development of a Decision Support Language (DSL). The DSL will aid the IDSS user by providing the tools required to construct decision support scenarios. These scenarios will facilitate the performance of operations in the IDSS Prototype 2 environment.

The IDSS Prototype 2 system consists of three primary subsystems, shown in Figure 1. The modeling subsystem consists of three subsystems consistent with the ICAM philosophy of segregation of model building, model analysis and model reporting. The Model Build Subsystem will allow users to select modeling approaches and develop model descriptions in an interactive environment. The Model Execute Subsystem will allow users to execute desired scenarios of a selected model analysis vehicle. The Report Generation Subsystem will allow the users to develop detailed and tailored reports, independent of model analysis. In addition, a scratch pad calculator function is provided.

Model Integration

One of the most important concepts to be demonstrated in IDSS Prototype 2 is the integration of models and modeling tools. Selected analysis techniques include a network queueing analysis program, linear and nonlinear mathematical programming, economic analysis programs, linear and nonlinear regression, and simulation. One means of integration of these techniques will be by sequential algorithm execution, that is, one analysis technique completes execution and data is prepared from this output to provide input to another analysis technique. Another approach to integration of models is concurrent algorithm integration. Concurrent integration would occur when, in the midst of its processing, one analytic technique requires another analytic technique to be processed. Particular cases of this type of integration would be the iteration of submodels or algorithm use during a simulation.

$IDEF_2$

The $IDEF_2$ modeling language takes a new and innovative approach to modeling which decomposes a manufacturing system into four submodels. The submodel which describes the components of the system or facility under consideration is referred to as the Facility Submodel. The submodel which describes the logical processing performed by the system on the entities flowing through the system is referred to as the Entity Flow Submodel. The Resource Disposition Submodel is used to describe procedures for determining the disposition of, or reassignment of resources when they complete assigned tasks. The last submodel is the System Control Submodel, in which modelers describe events which affect the processing of entities, such as the effect of the external environment on the system. These four submodels combine to completely describe the manufacturing system under consideration. They are generic in nature to allow the representation of many types of manufacturing situations.

To understand the characteristics of manufacturing systems, modelers usually find it useful to begin by making a sketch of the system, including all of the components which they will include in their model. For this reason, the $IDEF_2$ Facility Submodel includes a graphic representation of the system being modeled, as well as additional supporting information. If the system being modeled is the actual production system, the components identified and described in the Facility Submodel would be such things as the machines, operators, and material handling equipment used by the system. These components are described graphically in the Facility Diagram, which identifies each component and its relative location to other components. If the system being modeled is not the production portion of a system, the facility components identified may be such things as elements of a computer hardware system, pieces of computer software, documents, people, or even procedures.

The $IDEF_2$ submodel which describes the logical processing performed by the system is the Entity Flow Submodel. Entities represent the parts, subassemblies, assemblies, information, messages, signals, etc. which are processed by the system. $IDEF_2$ may be used to describe the manner in which entities flow through the system and the reaction of the system to entity flow. For example, a part is said to flow along a production line as operations are carried out on it. When the production line is the system being modeled, the parts can be seen as entities flowing through the system. The graphic portion of the Entity Flow Submodel is referred to as the Entity Flow Network. Activities in which entities engage are described graphically with arrows. Activities are separated by nodes which represent milestones or decision points. Probabilistic and conditional branching may occur, and a flexible set of rules is available to allow selection among competing elements, such as parallel queues, alternative resource sets, or alternate activities.

The $IDEF_2$ Resource Disposition Submodel is used to describe the disposition of resources when they become available. A resource in $IDEF_2$ is any part of the system which must be present to perform an activity. The $IDEF_2$ modeler uses tree structures to ask questions concerning the status of the system and then to specify what actions should be taken with respect to the available resource. A resource may become available within the model in several ways. For example, it may complete the performance of an activity, complete repair, or be introduced into the model as a new resource. In all of these cases, the logic which the modeler describes in the Resource Disposition Tree for the resource will determine what action will be taken with respect to the resource. There is a Resource Disposition Tree created for each type of resource used in an $IDEF_2$ model.

The last $IDEF_2$ submodel is the System Control Submodel, which is used to describe the occurrences of events which control or affect, but do not prescribe, the processing of entities. The graphic portions of the System Control Submodel are referred to as System Control Networks. They can be used to create entities, alter the attributes of entites, alter the capacity of resources, or cause the unavailability of resources used to process entities. The activities or conditions represented in System Control Networks are triggered by events. These happenings, occurrences, milestones, or decisions are the instants in time when the status of the system changes.

The approach to build $IDEF_2$ models is to create each of the four submodels which combine to describe the dynamic or time-varying behavior of the manufacturing system. This may be done using an interactive graphics input mechanism, as with the other analysis techniques provided in IDSS Prototype 2.

Report Generation

The report generation capabilities of IDSS Prototype 2 provide the user with the ability to develop customized reports based on interactive inputs indicating report format and contents. Report generation is aided through techniques employing computer graphics to illustrate and aid in editing the general format of the report. Any data element accessible to the system may be included in any report. In addition, for each analysis technique a selection of standard reports is available. The segregation of report generation from model analysis makes the generation of tailored reports much easier.

Personal Computer

A scratch-pad-like calculator is also included in the IDSS Prototype 2 design. Calculations may be made not only using explicitly defined constants, but also with variables read in from an external source or data elements extracted from an accessible applications data base. This feature will allow the user to include in his models the most current data from the system being modeled. All commonly used computational functions are available in the personal computer.

IDBMS

The data base management system supporting IDSS Prototype 2 is the ICAM Data Base Management System developed by Control Data Corporation. IDBMS was conceived as a subset of the CODASYL 1971 standards for data base management systems. As such, an IDBMS data base is interpreted as a collection of sets, records, and items. An item is a unit of data and is the smallest unit that IDBMS manipulates. Records are named groups of items which are accessed together. Sets are named relationships between records. In a set, one record participates as the owner, and zero or more records participate as members. The collection of set types and record types is defined, described and maintained as a unit separate from the application programs. Each program works only with the portion of the data base which it needs. The required data is transferred to and from the data base by IDBMS. The operations and manipulation criteria are provided by the application programs but the definition, description, and control of the data base itself is kept within IDBMS.

IDBMS provides a Data Definition Language (DDL) for a user to define his data base for IDBMS's organization and management. After the DDL statements describing a data base with its components and their associations are completed, the DDL Processor must be used to convert the DDL statements into tables which will constitute the Data Base Tables. At the same time, the storage area of the data base must be formatted according to the physical requirement of the data base. A Data Management Language (DML) is provided by IDBMS to access and manipulate the data base. DML commands are issued from FORTRAN application programs using call statements. The functions of the DML commands include the opening and closing of data bases, the accessing and manipulation of data records, and special functions such as the number of operations performed on the data base.

Overall Design

The incorporation of all the features described above result in the design shown in Figure 2. This approach applies to all the analysis techniques to be included in IDSS Prototype 2. The integration of modeling techniques occurs at the data base interfaces. The segregation of report generation from model execution is made possible by the data base interface. The segregation of model building, model execution and report generation functions will make the utilization of the Decision Support Language much more effective.

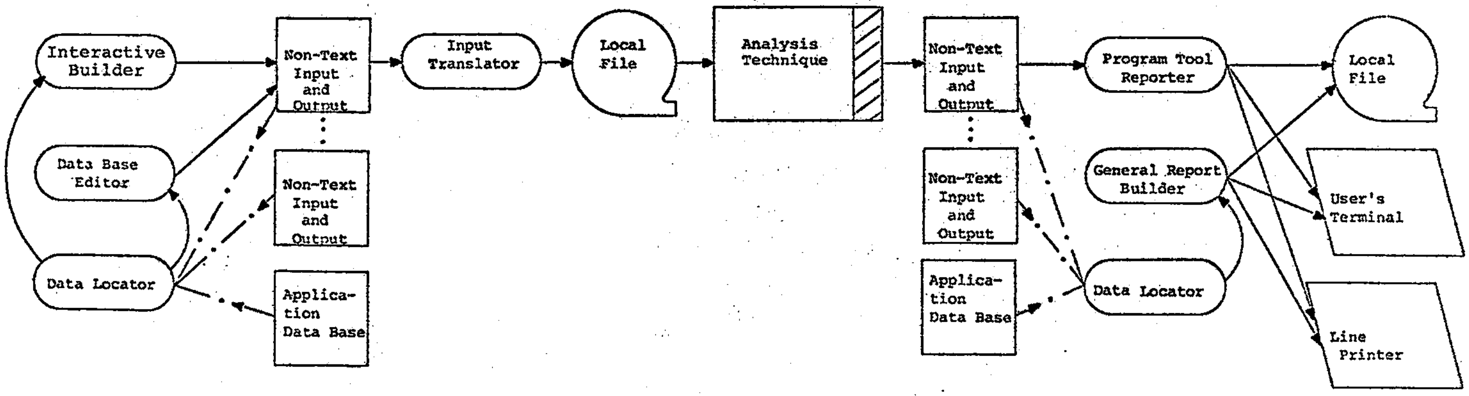

Figure 2. IDSS Prototype 2 Design

Future Plans

The initial design for IDSS Prototype 2 was referred to as IDSS Prototype (2.0). As its design progressed, it was determined that a more advanced prototype could be developed and built using enhanced data base and scenario definition concepts. Thus, a new design evolved which is referred to as IDSS Prototype (2.5). The features described in this paper reflect the IDSS Prototype (2.5) design. This design will be implemented by September, 1982.

The IDSS prototype efforts were initiated to provide an interim capability for the aerospace industry and to test such design concepts as data base use to store models, use of graphics as an input medium, and use of multiple analytic techniques on a common model data base. The next step will be the development of a production version of IDSS for the support of manufacturing operations planning and control. This IDSS will ultimately be incorporated into an integrated sheet metal center and included in a 1985 demonstration of all ICAM developments.

Bibliography

1. Alter, S.L. (1980) Decision Support Systems: Current Practice and Continuing Challenges. Reading, Massachusetts: Addison- Wesley Publishing Company.

2. Keen, P.G.W., and M.S. Scott Morton. (1978) Decision Support Systems: An Organizational Perspective. Reading, Massachusetts: Addison-Wesley Publishing Company.

3. O'Reilly, J., et al. (1980) IDSS Version 2.0 Preliminary User's Manual. West Lafayette, Indiana: Pritsker & Associates, Inc.

4. Pritsker & Associates, Inc. (1980a) $IDEF_2$ Architect's Manual. West Lafayette, Indiana.

5. Pritsker & Associates, Inc. (1980b) $IDEF_2$ Workbook. West Lafayette, Indiana.

6. Whitford, J.P., et al. (1980) Computer Program Development Specification for ICAM Decision Support System (IDSS) Version 2.0. West Lafayette, Indiana: Pritsker & Associates, Inc.