PROJECT PORTFOLIO SELECTION MANAGEMENT THROUGH DECISION SUPPORT: A SYSTEM PROTOTYPE

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ABSTRACT

Many organizations have been making serious efforts to analyze project proposals in order to generate estimates and evaluations for choosing project portfolios. Thus far, no integrated framework has been proposed to help decision makers perform the function of selecting the most suitable or optimal project portfolio. In this paper we propose a decision support system concept based on a framework described in a previous working paper (Archer & Ghasemzadeh 1996). This framework is flexible enough to allow users to choose the methodologies that suit their organization in assisting decision makers to make the best choice. We discuss issues relevant to decision support in this field, and describe an initial prototype interface which was developed for decision makers to interact with the decision support system in the final stage of portfolio selection (portfolio balancing and adjustment). Finally, we discuss research and development issues yet to be addressed in developing and testing a full scale prototype that would support decision makers throughout the project portfolio selection process.

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1. Introduction

Many organizations are making serious efforts to analyze project proposals in order to generate estimates and evaluations for choosing an optimal project portfolio (Dos Santos, 1989). Some of the criteria that must be addressed during this process include the organization's objectives and priorities, and the financial benefits, intangible benefits, availability of resources, project interdependence, and allowable risk levels in the project portfolio (Schniederjans and Santhanam, 1993). Thus far, no integrated framework has been proposed to help decision makers perform the function of selecting the most suitable project portfolio.

In an endeavor to address this important problem, in a previous study (Archer & Ghasemzadeh 1996) we reviewed the literature and evaluated some of the most popular models that are used for project portfolio selection; then we introduced an integrated model that incorporates a framework in which the selection of the techniques to be used is left to the decision maker. The suggested framework helps to organize the portfolio selection process, and supports the decision maker in selecting a suitably balanced project portfolio based on the organization's objectives, subject to resource limitations.

In the current report, the objective is to continue and extend the previous work, with the intent of exploring issues relating to the support of decision making during project portfolio selection. We will propose a decision support system concept which addresses the issues we have identified, and present our experience with an interface prototype which could be used during the last stage of this decision making process, to demonstrate some of our ideas. The content of this paper is as follows. First, we review the proposed framework and discuss its findings. Then we put these findings into the perspective of a decision support system (DSS) that could support decision makers in project portfolio selection, including a brief discussion of data management and model management requirements associated with such a system. In order to demonstrate the potential for such an approach, we describe a prototype interface we developed for use in the final phase of the selection process, where portfolio balancing and adjustment can be carried out interactively by decision makers. Finally, we outline some of the additional work needed to address some related and fundamental unresolved issues in developing a system prototype to support the entire process of project selection.

2. The Proposed Project Portfolio Selection Framework

The proposed framework (Archer & Ghasemzadeh 1996) consists of three major stages. As depicted in Figure 1, these are the pre-process, process, and post-process stages. During the pre-process stage, the first step is to select those techniques to be used in portfolio selection which are suitable to the organization's culture, problem solving style, and project environment. Once completed, this particular step would not normally be repeated for a particular organization, except for minor adjustments for future portfolio selection activities. Figure 2 gives more detail on the framework than Figure 1, by including some of the potential techniques that could be adopted by an organization, for use during each stage of the portfolio selection process. The portfolio selection process shown in Figure 2 would normally be repeated at regular intervals, to employ resources freed up by current projects completed or abandoned, to judge other projects proposed as additions to the portfolio, and to address changes in the internal and external environment (e.g. drastic changes in resource availability).

An important first step in the selection process is Pre-screening by means of guidelines developed in advance, to eliminate projects which are not yet ready for active consideration or which clearly do not fit the organization's strategy. For example, a project for which no feasibility analysis has been performed cannot be judged as being either acceptable or unacceptable until more information is made available through additional analysis. Elimination of such projects at this stage helps to reduce the total workload required to analyze remaining project proposals.

In the Process stage, Individual Project Evaluation can involve such techniques as scoring, benefit contribution, risk analysis, market research, or checklist. These techniques treat each project in isolation or as a member of a group of two or more interdependent

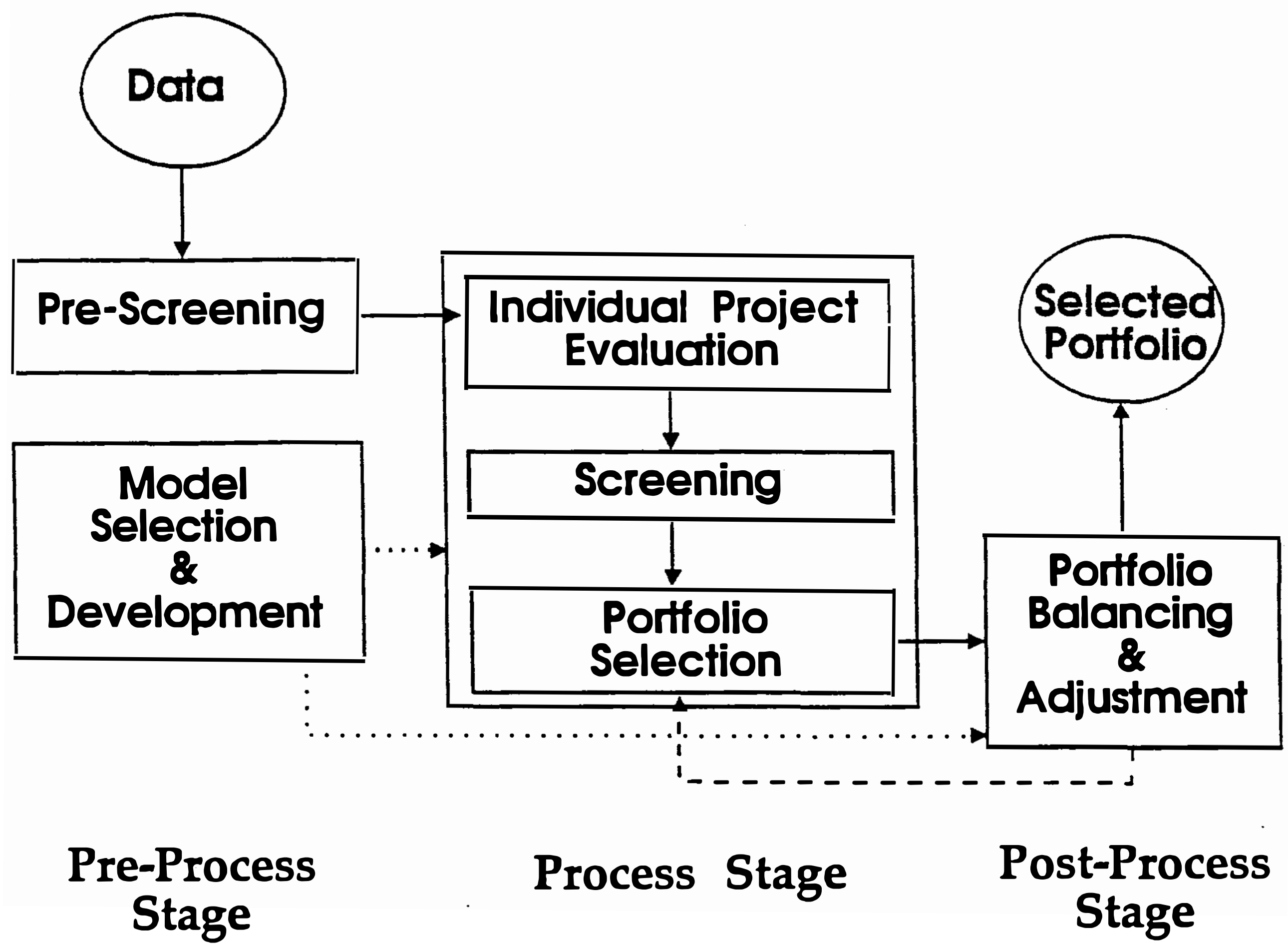

Figure 1

Proposed Project Portfolio Selection Process

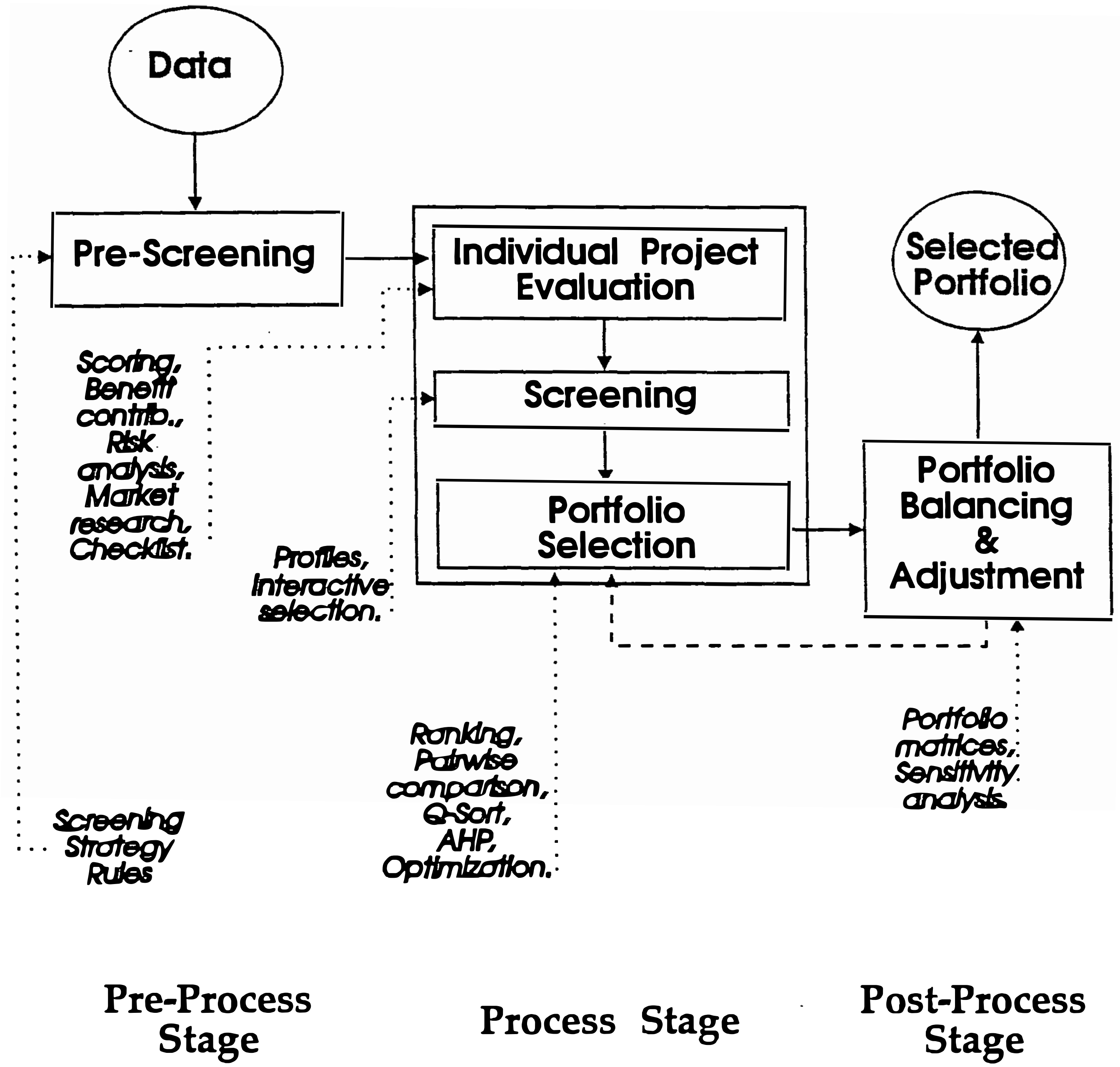

Figure 2

Some Potential Techniques for Portfolio Selection

projects. For further details on these and other techniques, consult our working paper (Archer & Ghasemzadeh 1996) which reviews the project portfolio selection literature, and provides references to more detailed descriptions. Note that projects currently underway are also re-evaluated at this time. The output from this step must be a common set of parameter estimates for each project, such as estimated resource requirements, downside risk, completion time, etc. The Screening step is an opportunity to eliminate projects which do not meet pre-determined criteria. Techniques used at this stage could include profiles or interactive selection. For example, projects with an estimated rate of return below a certain threshold could be eliminated, provided they were neither mandatory nor required to support other projects still being considered.

The Portfolio Selection step uses techniques which simultaneously compare all projects which have survived to this point, through techniques selected from the following: optimization, clustering, analytic hierarchy process, ranking, pairwise comparison, or Q-Sort. The intent is to select the projects which are the best of those considered, subject to resource constraints, and based on a pre-determined objective such as maximizing the net present value. Sensitivity analysis may be useful during this stage to compare the impact on the overall objective of including or dropping a particular project or related group of projects.

In the Post-Process stage, decision makers make final adjustments and to balance the portfolio interactively on the basis of risk or other parameters the organization believes to be important. This stage uses as a beginning point the output of the Portfolio Selection step, but all projects selected and rejected at the Selection step are re-considered during this final process. Tools used in this stage include portfolio matrix displays and sensitivity analysis. It may be necessary, if projects are dropped or added at this stage, to re-visit the portfolio selection process step in order to re-calculate important parameters, and to determine how much adjustment has been made to the overall objective function as a result.

2.1 Analysis of the Proposed Framework

Some of the information in this section is summarized from the conclusions of our previous study, with additional discussions of aspects that are also important to decision support during the portfolio selection process.

2.1.1 Important Factors Affecting Project Portfolio Selection

The factors discussed in the following were gleaned from an analysis of existing techniques used for portfolio selection and discussed in our previous study (Archer & Ghasemzadeh 1996). We hasten to add that the completeness of this set and the relative importance of each factor have not been tested through a field survey, although such a study is under consideration. We expect that the relative importance of these factors would depend upon the size of the organization, expenditures on project development, and the category of projects undertaken by the organization.

a) *Theoretical model basis*

b) *Characteristics of the projects or portfolio*

- multiple objectives
- project interdependence
- mutually exclusive projects
- resource limitations
- qualitative attributes
- number of projects
- project phase considerations
- risk
- parameter uncertainty

c) *Desirable decision support characteristics*

- sensitivity analysis
- portfolio balancing
- user-friendly interface

c) *Desirable decision support characteristics (continued)*

- overall perspective
- group support
- strategic considerations

2.1.2 Desirable Characteristics of a Support System

The following discussion is based in part on conclusions from our previous work (Archer & Ghasemzadeh 1996), which gave rise to our suggestion for an integrated and flexible framework for portfolio selection.

Choice of Techniques Used in the Selection Process

An important assumption in our considerations is that there is unlikely to be a single best way of portfolio selection, and that each organization must choose, within the project class(es) being considered, the methodologies that suit its culture and that allow it to consider the project attributes it believes are the most important in making selection decisions.

Categories of Projects

We need to assume that the overall planning in allocating budgets to each particular category of projects, based on the firm's overall strategy, has already been carried out and that the process we are discussing relates to the selection of the project portfolio in one particular category. This allows the choice of techniques specific to and suitable for the organization's environment and culture in the category being considered, and avoids "apple and orange" comparisons. For example, software development projects for internal company use should not be considered in the same portfolio selection process as consumer product development projects, unless there is a direct relationship or dependency between projects from these different categories. Project categories previously identified in the literature (Archibald 1992) include: commercial and government projects under contract, R&D for new products or services, capital facilities design and construction, information systems development and installation, management projects, and major maintenance projects.

Support Requirements

a) The following have been found to be important characteristics of decision support for project portfolio selection:

- flexibility in selecting models that suit organizational culture and strategy,
- a sound theoretical basis for the portfolio development process,
- flexibility in considering project/portfolio characteristics deemed important by users,
- attention to the decision support characteristics mentioned in Section 2.1.1.

b) Information overload needs to be controlled, and minimized so decision makers can concentrate on the critical aspects of their decisions,

c) Group decision support is critical, since most portfolio selection decisions are made by a group or committee of decision makers,

d) A decision support system must link to the organization's project management database since:

- data collected while projects are underway are used to make judgments on that project when it is reviewed at portfolio decision times,
- historical project data can provide a basis for estimating parameters for new projects being considered,
- estimates developed at portfolio selection time should be evaluated against actual project experience in order to judge progress in meeting objectives.

e) The system must allow decision makers to decide upon techniques to be used at each stage, or even to develop their own techniques that would fit within the framework,

f) Users should be given enough guidance so they can follow through the suggested framework approach, with a level of user interaction at each step to suit the techniques chosen.

Relationship to Project Management Activities

The portfolio selection process involves considerations at three managerial levels: strategic, managerial or tactical control, and operational control (Anthony 1965). The strategic level relates to the fit of projects with the business focus and strategic directions of the firm, and as we suggested above, strategic decision making concerning the overall portfolio should be completed in advance of considering any particular projects. Managerial control relates very much to the portfolio selection process itself, and information needed for this process may originate internally from operational control activities relating to existing projects, or from external sources. Portfolio selection is related to ongoing project management activities at both the managerial and operational control levels because:

a) data collected while projects are underway are used to make judgements on that project when it is reviewed at portfolio decision times,

b) historical project data can provide a basis for estimating parameters for new projects being considered,

c) project gating decisions are not necessarily made at the same times that portfolio selection is done, and terminations or other changes to a project will affect resources available to other projects,

d) project selection decisions are made on the basis of estimates on the entire project, but data from the component phases of the project life cycle are used to make these estimates. The latter are important to project management activities,

e) estimates developed at portfolio selection time should be evaluated against actual project experience in order to judge progress.

f) when the portfolio includes a few large projects, resource scheduling is an important determining factor in timing the estimated project completion dates.

Risk and Uncertainty Measures

We will define project "risk" as the probability that a project will fail. This can be estimated conditionally in advance for each phase of the project and then combined into an overall project risk. For example, suppose that a project is proposed for new product development, in which the technical risk (probability that the product will not be developed successfully) is 0.5. Suppose that the estimated probability that the product will fail in the marketplace, given that it has been successfully developed, is 0.7. The overall project risk is then 1 - 0.5*(1 - 0.7) or 0.85, indicating a relatively high risk project. A related measure is the "downside risk", which is the product of the amount at stake and the probability of failure. Risk measures which are suitable to a particular portfolio may depend upon the project category. For example, risk for information systems projects has been identified on dimensions of project size (risk tends to increase in proportion to project size), organizational experience with the technology (risk increases for lower levels of experience), and project structure (less structured projects have higher risk) (McFarlan 1981). Hottenstein and Dean (1992) identified four risk dimensions (market, strategy, technology, and organization) in the evaluation of advanced manufacturing technology. They also propose an organized technique to judge these risks. There have been other discussions of project risk evaluation in the literature (Dean & Nishry 1965; Souder 1972; Lucas & Moore 1976). However, more research is needed in the estimation of risk parameters for use in project portfolio analysis.

A topic with some similarity to risk estimation is the estimation of parameter uncertainty, which has a direct impact on the values used in making comparisons among projects being considered for a portfolio. We will define uncertainty as the innaccuracy in the estimates of resource requirements, risk, and any other parameters associated with a project. Uncertainty will depend upon the amount of past organizational experience with similar projects, technologies, and markets. There has been very little consideration of this topic in the literature, but there is a great deal of potential in using possibility theory or fuzzy theory to estimate uncertainty in a qualitative language which may have a more natural meaning to decision makers. Estimates might then tend to be more realistic than those based on numerical scales. These techniques have been applied successfully in a number of other fields (Zimmerman 1991), and further investigation of their use in portfolio selection is warranted.

It is hoped to investigate the estimation of both risk and uncertainty in more detail as they apply to project portfolio selection, since these will have a great deal of impact on the confidence of decision makers with the outcome of a project portfolio selection process.

Model Integration

If users are to be given the flexibility of choosing their own techniques or models, they will need the support of a carefully designed model management system. To be successful in project portfolio selection such a system will need to support models of different types (e.g. net present value models, 0-1 integer programming models, etc.), but these models should have a common interface through which data may be interchanged with models of possibly different types. This involves considerations of model representation and integration, for which there has been a certain amount of investigation in the literature (Dolk & Kottemann 1993; Kottemann & Dolk 1992; Muhanna & Pick 1994; Geoffrion 1987). Given definitions of a) a model schema as a formal specification of a class of real problems or systems, b) a model instance as a specification of a particular problem or system by combining the model schema's variables or coefficients with data values from a given set, and c) a solver as an executable program or routine capable of solving an instantiated model (Muhanna & Pick 1994), effective model management provides the ability to develop and reuse models in new unplanned circumstances, and to provide incremental improvements to these models. Model management should provide for a) model-solver independence (separation of model specification/model schema from implementation/solver), b) model-data independence (separation of model schema from sets of data values that instantiate schema variables and coefficients) and c) division of model schema specification into external/ interface specifications and internal/structural or behavioural specifications (Muhanna & Pick 1994).

Integrated modeling approaches which have been suggested in the literature include *schema integration* and *process integration* (Dolk & Kotteman 1993). Schema integration, which is supported by structured modeling, logic modeling, or graph grammars (Geoffrion 1987; Chari & Krishnan 1993; Jones 1993), is useful only when homogeneous models are to be integrated and the same solver can be applied to the individual components and to the integrated model. A simple example is the integration of departmental financial planning models into a corporate financial plan.

Since the models suggested in our portfolio selection framework are not homogeneous, schema integration would be extremely difficult to apply in this case. Process integration is useful when heterogeneous models (models from different paradigms) are to be integrated. This is the case with our portfolio selection framework, making process integration a suitable approach. The major issues that arise during process integration are *synchronization* and *variable correspondence*. Synchronization deals with the order in which models must be executed, and the timing of dynamic interactions among the models. Variable correspondence deals with the input/output relationships among the component variables in the various models being used, and assuring dimensional consistency among these variables. In our proposed approach, models are not executed in parallel. They typically terminate after transferring their outputs for use by subsequent models. Synchronization in this case is not a critical issue. To handle variable correspondence, a central database can be used. This can act first as a data repository, and secondly as a transfer site to provide matched data for the input and output variables of the various models being used.

3. Decision Support System Approach to Project Portfolio Selection

As we can see from the foregoing and from Figures 1 and 2, in all process stages the decision makers would interact with the proposed system, which would provide supporting models and data. Data would either be input data directly, generated by models as they are used, or extracted from existing project management databases containing information useful to the analysis of the candidate projects. Provision for continuous interaction between system and decision makers is important because: a) it is extremely difficult to formulate explicitly in advance all of the preferences of the decision makers, b) involvement of decision makers in the solution process indirectly motivates successful implementation of the selected projects, and c) interactive decision making has been accepted as the most appropriate way to obtaining the correct preferences of decision makers (Mukherjee, 1994). If this interaction is to be supported by a computer-based system, then there is a need for a sub-system to manage the related techniques/models, and another sub-system to support the data needs of the process. This is illustrated in Figure 3, and is a system which is equivalent conceptually to a DSS, or Decision Support System (Turban 1995). More details are given below on the decision support system approach as it applies to project portfolio selection.

Turban (1995) defines decision support systems: "A Decision Support System (DSS) is an interactive, flexible, and adaptable computer-based information system system, specially developed for supporting the solution of a non-structured management problem for improved decision making. It utilizes data, it provides an easy-to-use interface, and it allows for the decision maker's own insights. A DSS also utilizes models, it is built through an interactive process (frequently by end-users), and it supports all the phases of decision making. It may also include a knowledge base." Clearly then, a DSS must have the capability to manage models, data, and dialog. It may also have an intelligent component to assist decision makers in making decisions in a particular problem situation, or to assist in decisions about which models to use in solving certain problems. If such a DSS is built, it will not be accepted until it is shown to perform satisfactorily in real application environments. Adelman (1991) discusses several techniques which can be used for validating DSS designs (factorial experiments, case studies, and quasi-experimental designs).

Group Decision Support Systems (GDSS) expand the definition of DSS in that they are DSS which facilitate the solution of unstructured problems by groups of decision makers. This is accomplished by providing support for the exchange of ideas, opinions, and preferences within groups (Finholt & Sproull 1990), and is clearly a requirement of a portfolio selection DSS. A GDSS may be implemented at one location where it provides computer support for a group of decision makers, or it may involve simultaneous communication among decision makers at different sites. The factors which are critical to the success of GDSS (Buckley & Yen 1990) include considerations of: a) Design (enhancing structuredness of the decision problem, participant anonymity, organizational involvement, ergonomics), b) Implementation (extensive user training, top management support, qualified facilitator, trial runs), and c) Management (reliability, continuing enhancements, qualified technical support).

Published work on group attempts to reach consensus on portfolios include work by Souder (1975), who explores combinations of paired comparisons, group discussions, and member interactions in decision making of this type. In the portfolio selection process, when aided by a computer-based decision support system, group support can be as simple as a computer-projected display on a large screen visible to the committee. Or it may be more complex, as in systems where each committee member sees a separate display with which he or she interacts, using computer-based models and data independently of others to come to conclusions. The results are then shared with other group members through a common system and display (Turban 1995) so a consensus can be developed and decisions made.

3.1 Portfolio Database

The project portfolio database is the primary means of communication among the various modules associated with the decision support system, and also serves as a repository for relevant data collected from other sources for use in the portfolio selection process. For example, certain data from the organization's project management database(s) would be essential to making decisions about ongoing projects and for estimating parameters (and their uncertainties) and risks to be associated with new projects. For this reason, great care must be taken in choosing the type of database used so that information can be transferred to and from it easily. This is enhanced if the database package conforms to the ODBC (Open Database Connectivity)[1] standard, and it must also provide the necessary support for the variety of modules which may be used with the system. Suggested information includes, for each project, a description and objectives, precursor and follow-up projects, the time, cost and other critical resources that are necessary to accomplish the project, project parameters such as risk, and so on. The portfolio database is updated during the portfolio selection process through direct user input, interactions with associated project databases, and from the outputs of models and their components.

In the portfolio database, individual candidate projects could be categorized according to a hierarchy, organized according to the needs of the organization. For example, in a product development organization, projects could be classified according to whether they involved basic science investigations, engineering research, market need investigations, or modifications to existing products. The reason for this suggested classification is that different research and development teams would likely be involved in these classifications. This classification would allow clustering of projects according to the sub-organization involved, where the data needs would also be similar within each sub-organization.

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[1]The ODBC standard originated at Microsoft, to provide software drivers in application packages and programming languages for access to data from databases which support this standard. There are hundreds of applications and languages which currently support the ODBC standard (Sarna & Febish 1995).

4. Prototype Interface Development

As shown in Figure 3, a decision support system for project portfolio selection would include the following components:

1. A project portfolio database (prototyped to support the interface prototype).
2. A user interface, including portfolio matrix displays (prototype discussed below).
3. A model management system which supports the techniques or models selected by the organization from the set of possibilities illustrated in Figure 2. This was not implemented in this prototype.

4.1 Project Portfolio Database

The project portfolio database contains relevant information about all the projects being considered. This information includes, for each project, a description and objectives, precursor and follow-up projects, the time, cost and other critical resources that are necessary to accomplish the project, and other relevant information. The database is updated during interactions with the user and also when calculations are performed by any model components. These updates include relevant data extracted from other databases that relate to ongoing management of existing projects. The portfolio database serves as an interface between the other components of the integrated portfolio selection system. Each model that is used receives its input from this database and stores its output in it. This allows communication of variable values among different models, as discussed previously. Data for information displays are also stored in and retrieved from the database

4.2 User Interface

As shown in Figure 3, the user interface provides a bridge between users and the components of the decision support system (model management system, portfolio database, and processing subsystems). It is used by decision makers to input data and decisions, to retrieve data from related project management databases, and to provide direction and control of the system. It also presents the results of computations to users. The following section describes the prototype developed as a demonstration of the user interface. The prototype was limited to the typical type of user interactions and displays which might be experienced

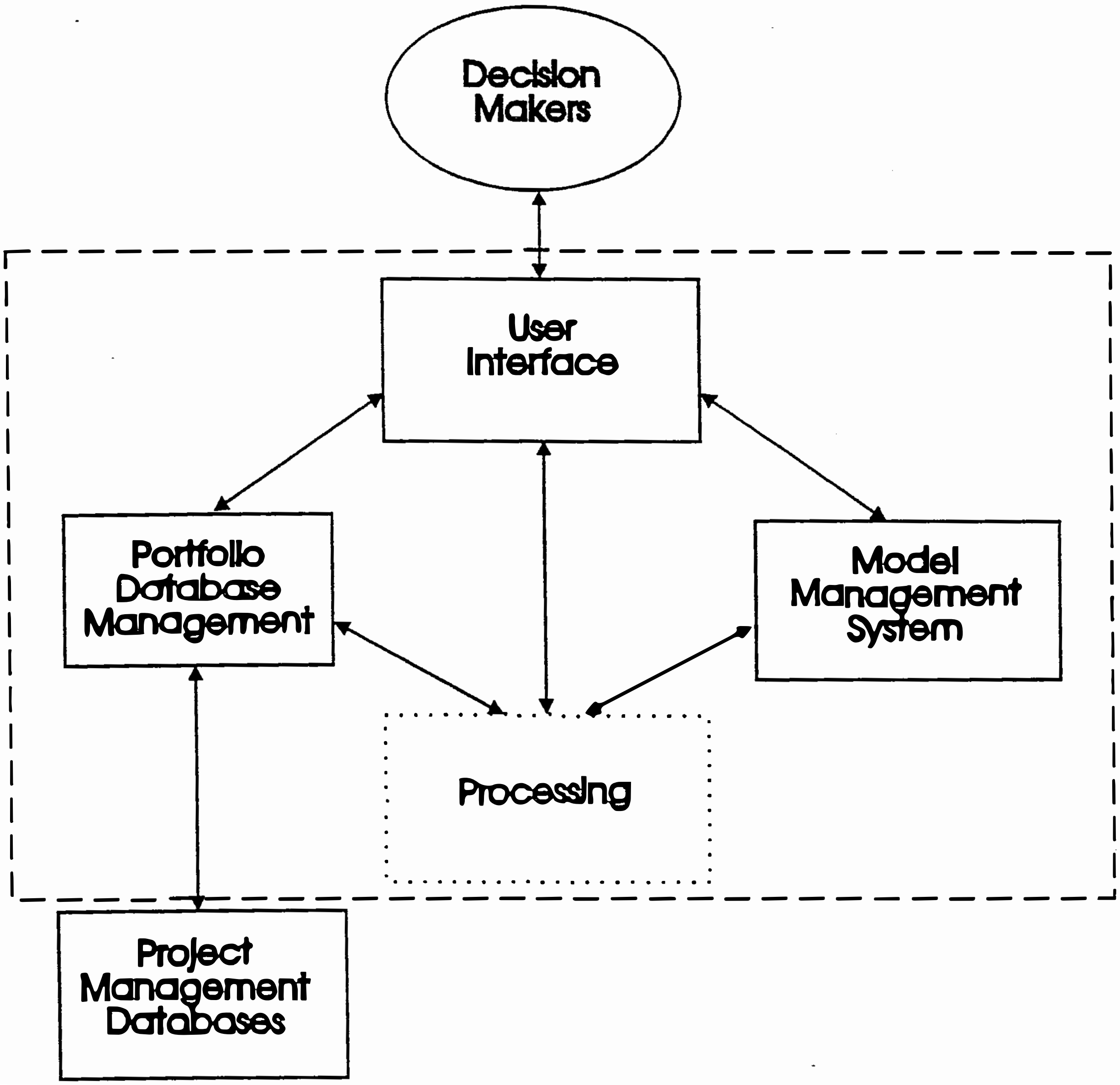

Figure 3

Project Portfolio Decision Support System

during the third stage of the portfolio selection process. In this stage, the user is balancing and making final adjustments to the portfolio, by considering projects which have been selected during the second stage. Other projects which were not selected during the portfolio selection step of the second stage are also available to add to the portfolio during the third stage, and projects already selected may be dropped. Because this is a balancing process, data must be provided to the decision maker that indicates how sensitive the objective function and resource requirements are to changes being made. This helps to avoid adjustments which might seriously degrade the objective achieved during the portfolio selection step.

4.3 Prototype Interface

As mentioned above we incorporated in the prototype only the project portfolio matrix display and the parts of the user interface and project database components that are related to it. The portfolio matrix display style was selected for the interface prototype since this displays the end product of the selection process, and must be easily understood by all the users. The prototype therefore gives a good opportunity to examine the chances for success if the remainder of the DSS were also to be developed.

The ToolBook© interface development environment was selected for the prototype since it supports all of the required features of the user-interface and project portfolio components, and also supports Dynamic Data Exchange (DDE), which allows it to exchange data with other software packages supporting this (Microsoft) standard. The Excel© spreadsheet package was chosen to support the portfolio database. It supports DDE, and it can be used for calculations (e.g. it embeds financial models such as NPV, ROR, etc.) and certain logical functions, in addition to supporting a limited database functionality. Both packages operate under Microsoft Windows©.

The prototype is saved as an executable file. Once the user clicks on the relevant icon, the ToolBook© and Excel© software begin executing and the relevant files are opened. The first screen that appears is presented in Figure 4. Clicking the "Execute" button on this screen

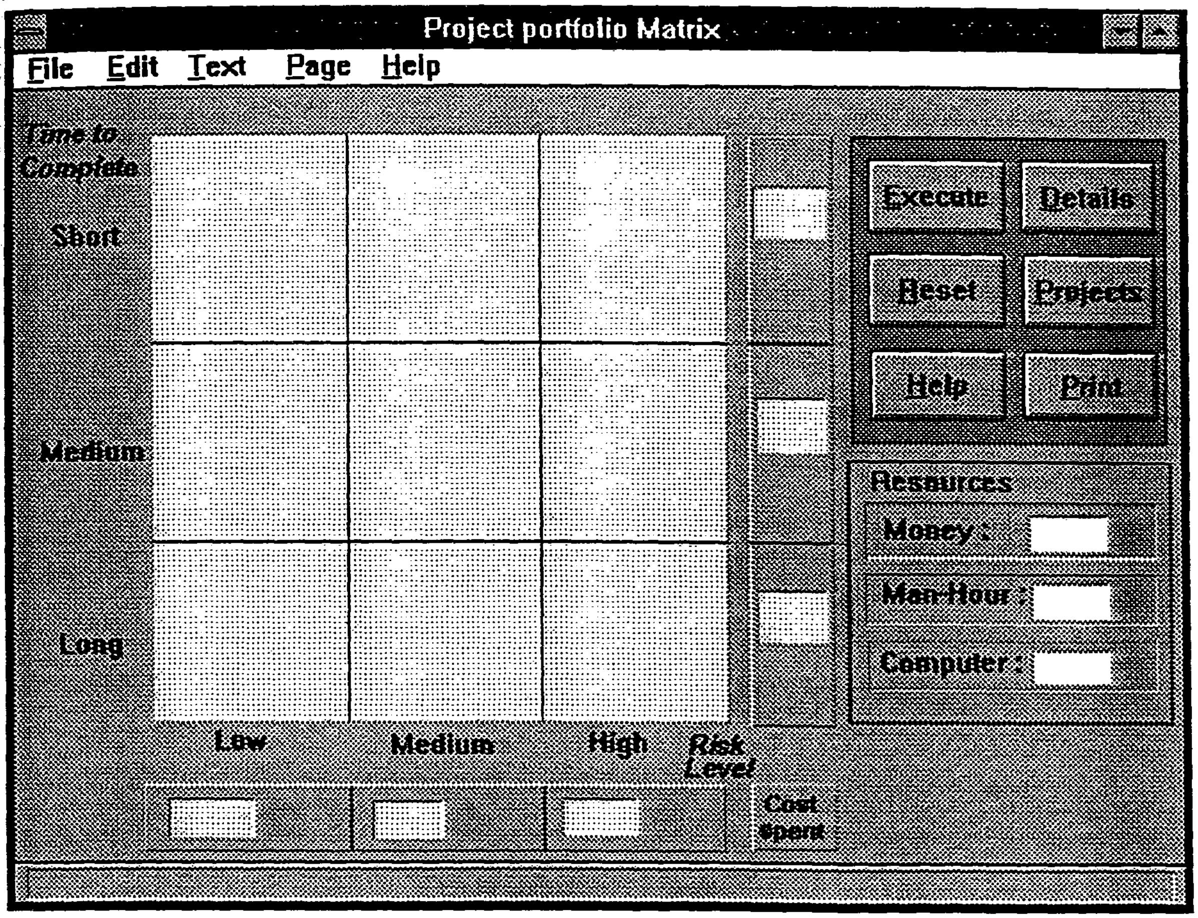

Figure 4

Opening Screen Display For The Prototype

will cause the system to tap into the project database, which is managed by Excel©, to get relevant information about the optimized set of projects. It should be noted that in the full-scale DSS some of the project information is either input by the user, created and stored by other models, or extracted from project management databases. However, since other components were not yet developed and incorporated in the prototype, we used an artificial data set in the prototype's database.

Based on the retrieved information, the system will display the project portfolio matrix and calculate the relevant variables, as depicted in Figure 5. Each project is represented by a circle. The radius of the circle is proportional to the financing necessary to complete the project, and the color of the circle shows the inclusion or exclusion of that project in the portfolio. A green circle (black in this figure) means that the project has been selected, and a red circle (light shading in this figure) means that it has not been selected.

If the cursor is positioned in a particular circle, the name of the related project is presented in the status line at the bottom of the screen. For example, in Figure 7 the name of the project located at the upper-left corner of the matrix is "project planning and control system". A list of all of the selected projects is also available and can be presented by clicking on the "Projects" button. A sample list of projects is presented in Figure 6. Clicking on the "print" button on the menu that appears will generate a printed list of selected projects.

The percentage of surplus or deficit in each critical resource, based on the proposed portfolio, is presented in the lower right corner of the screen. Since resource limitations would be applied by the portfolio selection model, the resource values for the optimal portfolio selected by the system would be greater than or equal to zero. As we can see in Figure 5, a surplus of 6%, 27% and 13% in Money, Man-hours, and Computer Resources respectively would exist if the suggested portfolio is accepted.

Another important piece of information which is presented on this screen is the distribution of investment among different categories of projects. In Figure 5, the vertical axis

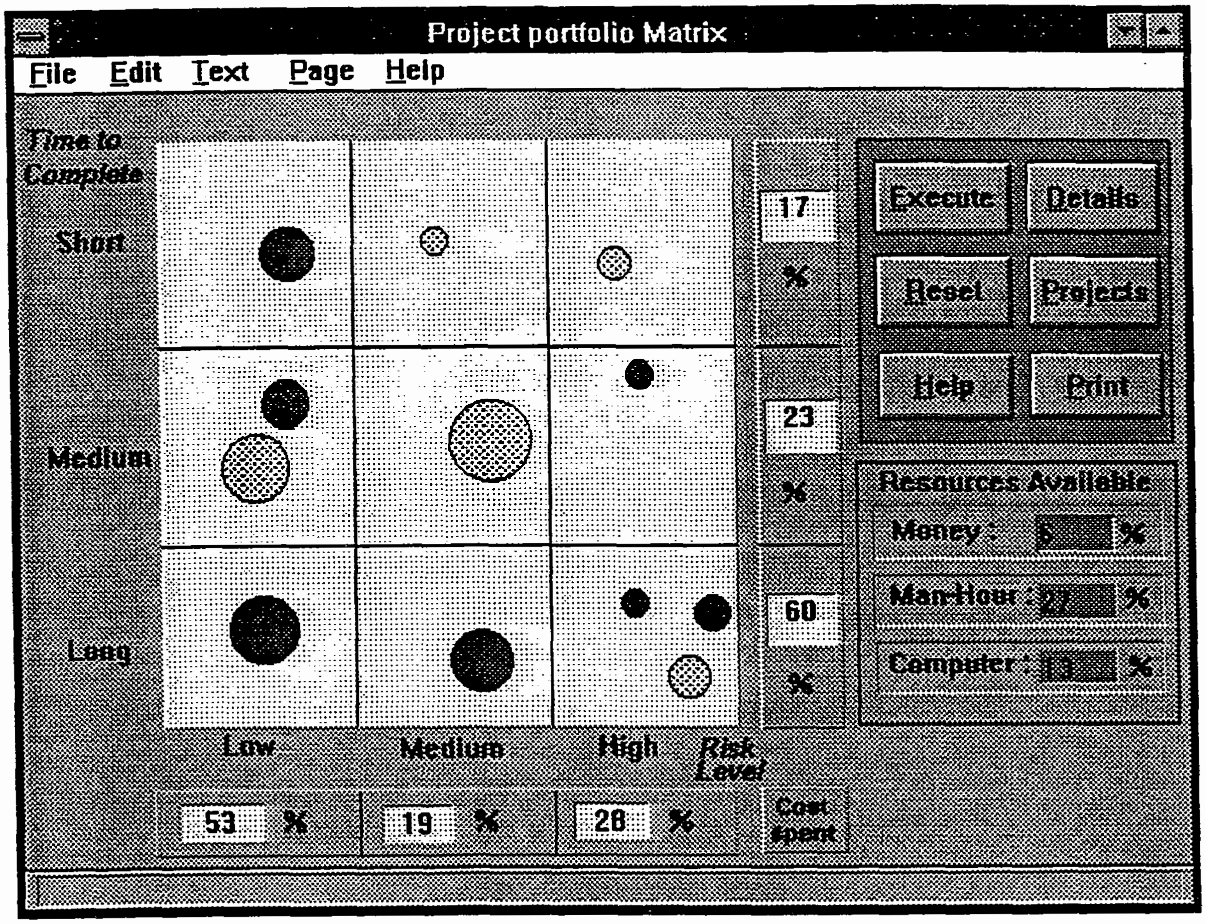

Figure 5

Projects Displayed As Circles On The Portfolio Matrix

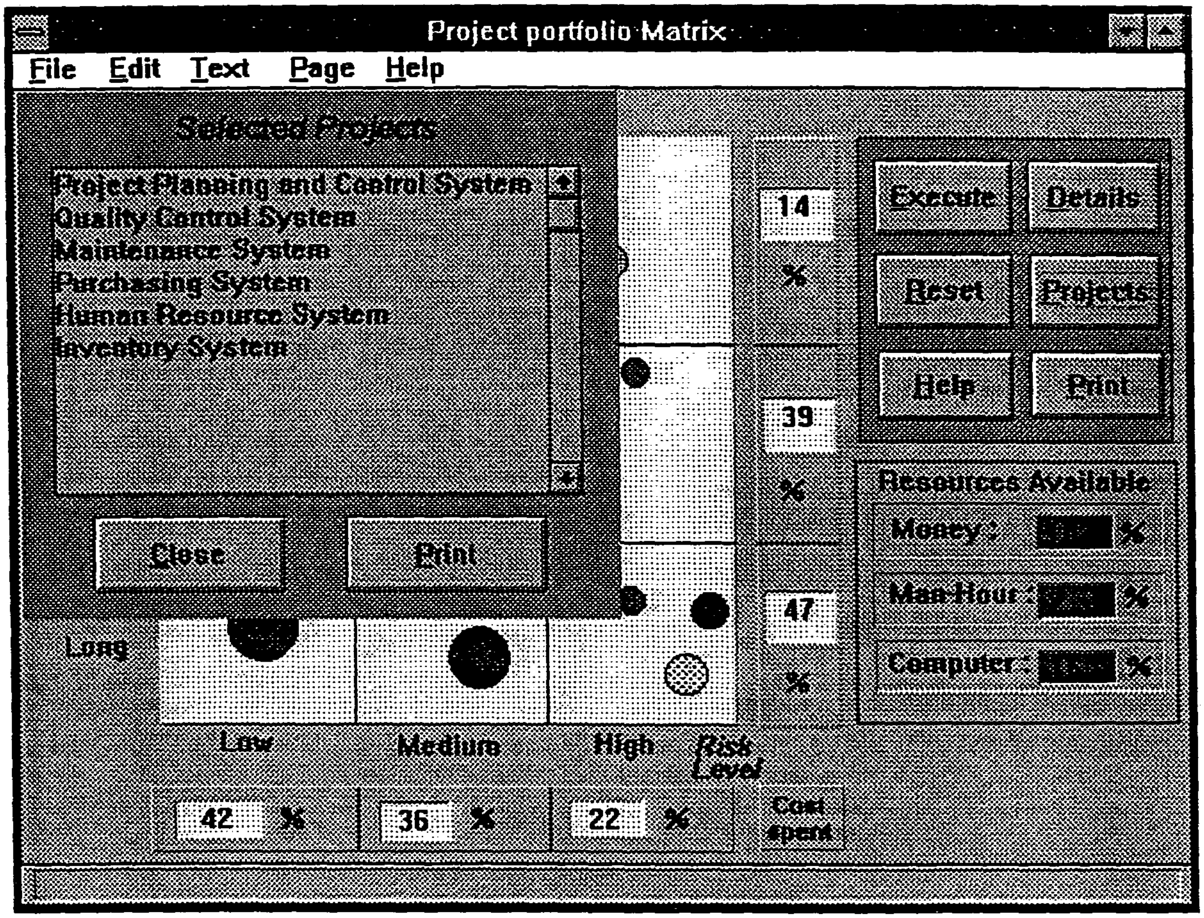

Figure 6

Display Of Selected Project List

represents the "time to complete" dimension of projects divided into three categories: Short, Medium, and Long. As we can see in this figure, 17%, 23%, and 60% of the total investment would be spent on projects that should be completed in Short, Medium, and Long time frames, respectively.

The horizontal axis represents another important dimension, the amount of risk involved in performing a project. This dimension has also been divided into three categories: Low, Medium, and High risk projects. As Figure 5 indicates, 53%, 19%, and 28% of the investment is to be spent on Low, Medium and High risk projects respectively. Decision makers usually choose a portfolio of projects that is balanced in terms of the overall risk. Typically, a high risk project will have the greatest expected benefit if completed successfully. For instance, a balanced portfolio might include one or two high risk as well as several low risk projects. A mixture of projects with different risks will allow an organization to achieve acceptable results while taking some risks to implement projects with potentially high benefits. (Davis and Olson, 1985).

If the portfolio does not seem balanced and the distribution of the budget among different categories of projects is not appealing to decision makers, it can be adjusted interactively, with the results of the change appearing immediately. For example, spending 60% on long-term projects might not be appealing; the system allows decision makers to adjust the portfolio by deleting and/or adding certain projects, meanwhile observing the impact of the change on the distribution of investment among different project categories.

To change the portfolio, a user moves the cursor to a certain project and clicks on it; if the project was already selected it will be de-selected and its colour changed to red; if it was not already selected the colour will change to green due to being selected. The results of such changes are immediately reflected in the project database; the distribution of investment among different categories and the availability of resources is also changed accordingly and the results presented on the screen. Resource surplus is indicated by a green colour for that resource. A deficit is indicated by red, and white indicates there is zero resource remaining.

There are two major limitations on changes to the combinations of projects incorporated in the portfolio. The first arises from interdependence among projects. The system helps the user to observe project interdependencies when the cursor is moved into the circle which represents a project (see Figure 7). Since presenting the interdependencies of all of the projects simultaneously will clutter the screen, especially when the number of interdependencies is high, the system only shows the interdependencies for the project that the cursor is on, and hides the others. Once the cursor is moved away from the project's circle, the relevant arrows would disappear. By seeing interdependencies on the screen, the decision maker understands which projects would be affected by de-selecting the project under consideration. For example, if project B depends on project A, and both projects are in the selected portfolio, the user cannot de-select project A, a prerequisite for project B, unless both are de-selected. The final DSS will automatically prevent the user from selecting or de-selecting projects when such constraints are binding. The system will also provide the user with information feedback when these constraints might be violated by such actions.

Another limitation on portfolio changes is due to the fact that resources are limited, so adding a certain project to the portfolio might cause one or more of the critical resources to go negative. As Figure 8 shows, the selection of the "budgeting system" project on the lower right of the matrix will cause a deficit of 6% in financial resources. Selection of the "maintenance system" project would cause all critical resources to go negative (Figure 9). The decision maker can either avoid making such changes in such a situation, or increase the amount of the relevant resource available if a project is to be included in the portfolio.

The user can get more information in a different form by clicking on "Details". Figure 10 shows the screen that would be presented in this case. Here, projects are represented by ellipses instead of circles. The major axis of the ellipse represents the total cost of the project at completion, and the minor axis represents the amount of money that remains to be spent to complete the project. The closer a project is to completion, the flatter its ellipse becomes; obviously, new projects appear as circles and projects near completion appear as lines. This display helps to bring the amount of sunk investment to the decision maker's attention.

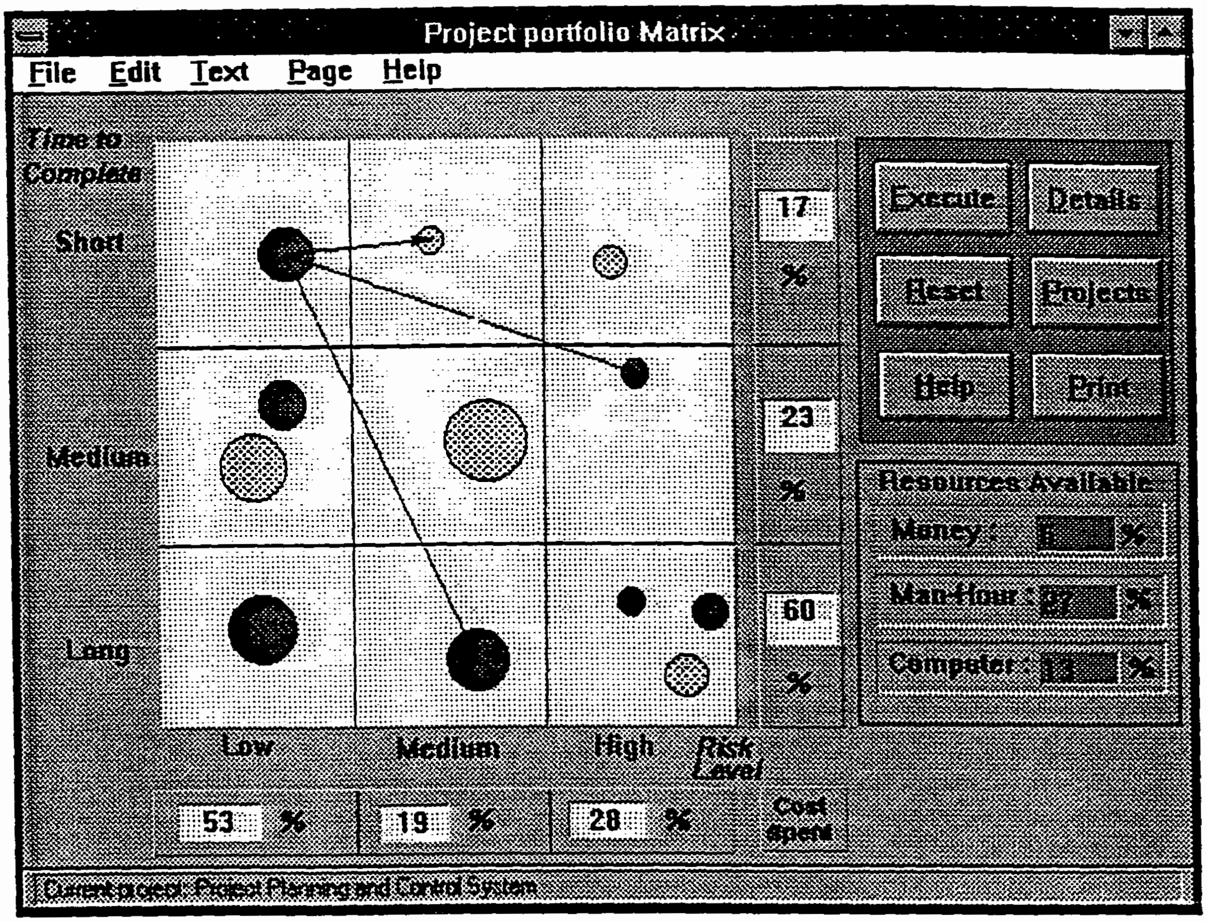

Figure 7

Project Interdependency Display

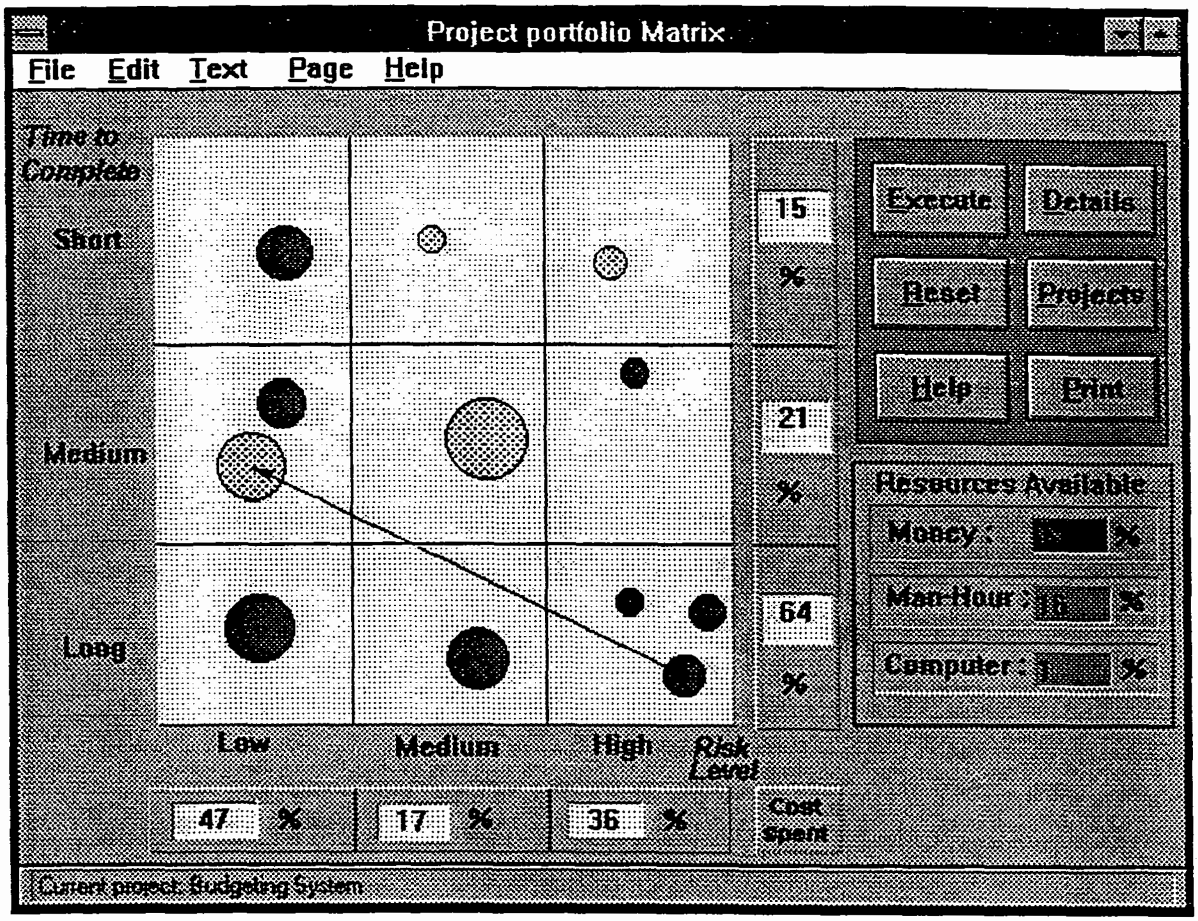

Figure 8

Impact On Resources Of Selecting "Budgeting System" Project

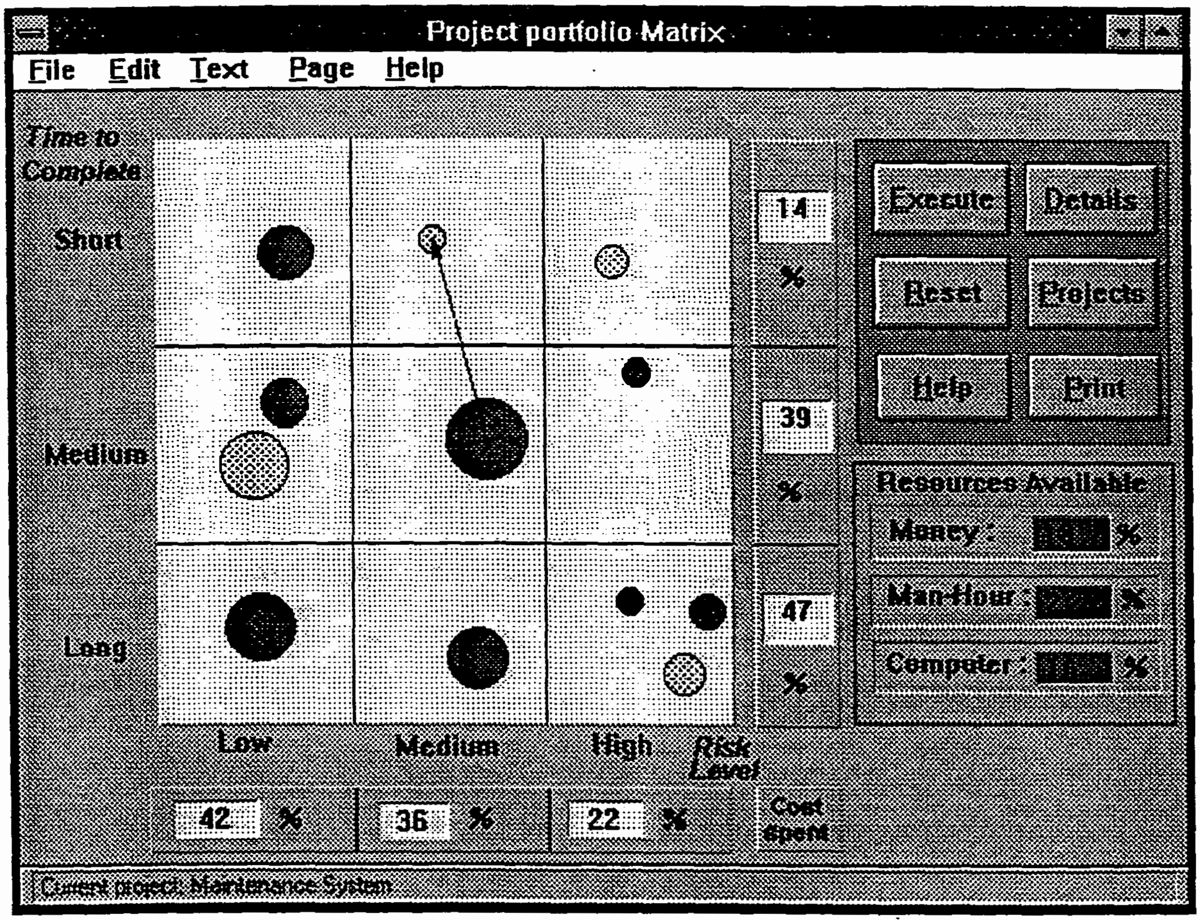

Figure 9

Impact On Resources Of Selecting "Maintenance System" Project

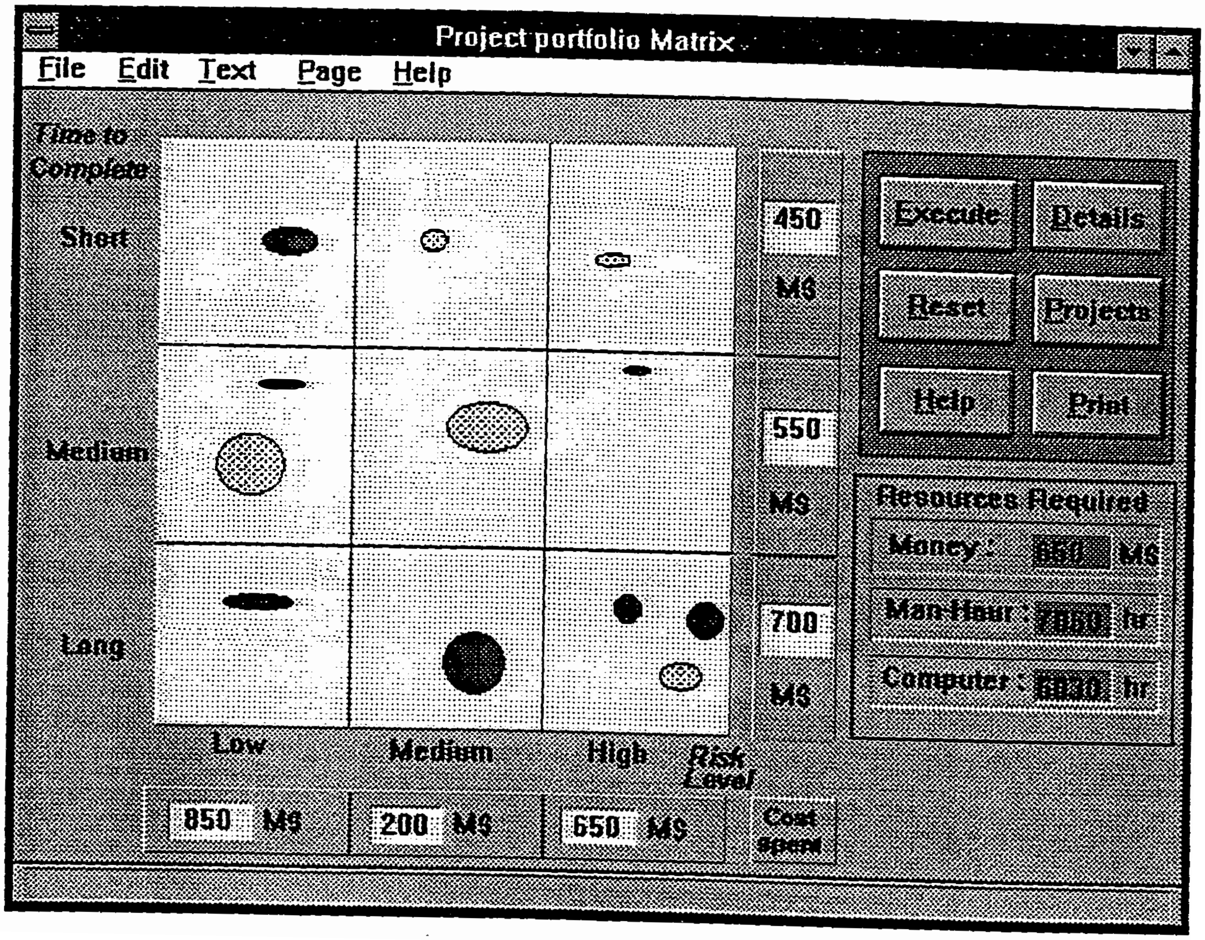

Figure 10

Projects Presented As Ellipses On The Project Matrix

Another difference between the screens in Figures 10 and 8 is that in Figure 10 the numbers are absolute whereas in the Figure 8 they were presented as percentages. For example, in Figure 10 the total amount of money that should be spent to complete Short, Medium, and Long term projects is \$450k, \$550k, and \$700k respectively, and for Low, Medium, and High risk projects it is \$850k, \$200k, and \$650k respectively.

The amount of required resources are presented in absolute numbers in this screen as well. For example, to perform the suggested projects in this portfolio, \$650k, 7060 man-hours, and 6030 hours of computer work is required. As before, if the amount of required resource does not exceed the amount available, that resource is shown in green; if it exceeds the amount the color is red. If the amount required is exactly the same as the amount available, the color is white. Other characteristics of this screen, such as project name displays and project interdependencies, are the same as for the screen shown in Figure 8.

If users make changes to the optimal portfolio, it can be re-displayed by clicking on the "Reset" button. Portfolio results can also be printed by clicking on the "Print" button.

4.4 Potential Improvements to the Prototype

It is clear that a great deal of development remains if the prototype interface is to be expanded into a full prototype DSS. Before pressing ahead with this development, there are some fundamental questions to be addressed, based on lessons learned during prototype development. These include:

1. The choice of a suitable development platform. This must be flexible enough to handle interactions with the types of modeling software that may be chosen for use with the system, to allow data retrieval from a variety of project management databases, and to provide the flexible and efficient support needed for the user interface. Potential choices for this platform include Toolbook©, Visual Basic©, and SAS©. Each has its advantages and disadvantages, but these must be evaluated with the long term potential of the DSS in mind.

2. The form and content of the display. This is a design issue which must be approached carefully (see next section), since the final decisions of users may be adversely

affected by data which are not displayed in the most effective and accurate manner.

3. The types of models to be used as "guests" of the host DSS. The intent is to avoid "re-inventing the wheel", by using existing software if it does the appropriate calculations and returns results efficiently. However, this may not always be possible, in which case additional development may need to be undertaken to provide the modeling capability needed.

5. Research and Development Issues Relating to the Proposed DSS

As explained earlier, the prototype only demonstrates the post process stage of the integrated system, incorporating the portfolio matrix and the relevant parts of the project database and user interface components. In order to create the final DSS, a more comprehensive interface should be developed and tested. Then the modeling and support components of the other stages can be added to the system, and the database component can completed. Before the full system is tested and validated, there is no need to develop an interface through which users would be able to gather data from external project management databases, but this consideration must be kept in mind for future development when the system is to be implemented at an operational site.

This project is a rich source of interesting research issues, ranging from fundamental concerns with the interface, appropriate ways to implement various models, the effectiveness of various modeling approaches, and validation and implementation problems. Where it is possible to do so, these issues should be explored in more depth in order to improve the quality and usability of the final DSS product. More issues will surface as the project proceeds, but issues already identified include:

1) More investigation is needed to determine how project risk should be estimated in a variety of situations and for a number of project categories. It is important to determine whether or not there is a common approach for estimating risk that would be acceptable across all project categories, since this would simplify its application in the proposed DSS.

2) Concurrent with estimating project risk, parameter uncertainty estimation and its impact on decisions should also be investigated, including the potential of using techniques such as fuzzy or possibility theory.

3) Although it is common with project portfolio matrix approaches to display project characteristics through the use of circles of various sizes, colours, and placements, there is some doubt about how this affects decisions made by users who view these screens. This is a fundamental user interface problem which should be investigated in detail.

4) A general rule when implementing modeling support is to apply the principle of parsimony. That is, the model should be no more complex than is absolutely essential to accomplish the job. This will affect the choice of models for different components of the DSS, and it will also affect the likelihood that decision makers will actually understand how the model(s) work, and hence whether they will want to use the DSS. The higher the likelihood that a prospective user understands a model and how it works, the more likely it is that the user would be willing to use the model. In designing the system, the parsimony principle should be followed as closely as possible and when it cannot, any resulting negative impacts on system acceptability should be evaluated.

5) Validation of the system is an important issue, since users will only be attracted to it if it assists them in getting "better" results. But how does one define "better" in this case? Is there some objective criteria by which results can be judged? For example, does one compare results obtained by DSS users in particular portfolio situations to those obtained by experts unaided by decision support? Or is there an objective measure which can be calculated through an optimization model, for example? These are questions which need to be addressed if we are to be able to predict the success of this work.

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