An integrated framework for project portfolio selection

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The task of selecting project portfolios is an important and recurring activity in many organizations. There are many techniques available to assist in this process, but no integrated framework for carrying it out. This paper simplifies the project portfolio selection process by developing a framework which separates the work into distinct stages. Each stage accomplishes a particular objective and creates inputs to the next stage. At the same time, users are free to choose the techniques they find the most suitable for each stage, or in some cases to omit or modify a stage if this will simplify and expedite the process. The framework may be implemented in the form of a decision support system, and a prototype system is described which supports many of the related decision making activities.

Keywords: Project portfolio selection, project management, integrated framework, decision support

Introduction

Project portfolio selection and the associated activity of managing selected projects throughout their life cycles are important activities in many organizations, since project management approaches are so commonly used in many industries for activities such as research and development of new products, implementing new systems and processes in manufacturing and information systems, and contracting engineering and construction projects. But there are usually more projects available for selection than can be undertaken within the physical and financial constraints of a firm, so choices must be made in making up a suitable project portfolio.

There are many relatively divergent techniques that can be used to estimate, evaluate, and choose project portfolios. Many of these techniques are not widely used because they are too complex and require too much input data, they provide an inadequate treatment of risk and uncertainty, they fail to recognize interrelationships and interrelated criteria, they may just be too difficult to understand and use, or they may not be used in the form of an organized process. But because of growing competitive pressures in the global economy, it has been suggested that project portfolio analysis and planning will grow in the 1990s to become as important as business portfolio planning became in the 1970s and 1980s. Firms that wish to be competitive by selecting the most appropriate projects must therefore use techniques and procedures for portfolio selection that are based on the most critical project measures, but these techniques will not be used if they cannot be understood readily by managerial decision makers. Although there is no lack of techniques for project evaluation and portfolio selection, there is a total lack of a framework for organizing these techniques logically in a flexible process which supports the project portfolio selection process.

The objectives of this paper are to: (a) evaluate briefly the current state of the art in project portfolio selection methods and to develop a number of related propositions for effective portfolio selection, based on the literature, (b) suggest an integrated framework to provide decision support for portfolio selection, allowing decision makers to utilize a desired subset of available methodologies in a flexible and logical manner, and (c) describe a decision support system which can embody this framework in the support of portfolio selection activities.

Tools for decision support, not decision making tools, are emphasized in this discussion, since the thought processes in decision making should be supported and not supplanted by the tools used. This support is provided through techniques or models, data, and management of large amounts of information, so decision makers can make informed decisions based on the most important facts. To bring these points forward, we examine the literature and develop a series of propositions that must be met if a framework is to be developed that will succeed in practice. Then an integrated framework is proposed which allows decision makers to choose from a variety of techniques or
models, based on these propositions. This integrated approach can help decision maker(s) to select a project portfolio that maximizes the criteria of interest, suitably balanced on both quantitative and qualitative measures they choose. The approach also has provision for built-in assistance to account for different types of resource limitations and project interdependencies. Finally, a prototype decision support system is described for modeling, managing, and displaying project and portfolio information during portfolio selection.

**Propositions for project portfolio selection**

A *project* can be defined as “a complex effort, usually less than three years in duration, made up of interrelated tasks, performed by various organizations, with a well-defined objective, schedule, and budget”. A *project portfolio* is a group of projects that are carried out under the sponsorship and/or management of a particular organization. These projects must compete for scarce resources (people, finances, time, etc.) available from the sponsor, since there are usually not enough resources to carry out every proposed project which meets the organization’s minimum requirements on certain criteria such as potential profitability, etc. *Project portfolio selection* is the periodic activity involved in selecting a portfolio, from available project proposals and projects currently underway, that meets the organization’s stated objectives in a desirable manner without exceeding available resources or violating other constraints.

There have been many published articles and books on the subject of project evaluation and selection, discussing well over 100 different techniques. Certain taxonomies of these techniques have appeared in the literature, but for the purposes of our discussion the process of portfolio selection uses project evaluation and selection techniques in a progression of three phases: *strategic considerations, individual project evaluation, and portfolio selection*. Techniques used in the first phase can assist in the determination of a strategic focus and overall budget allocation for the portfolio, while those in the second can be used to evaluate a project independently of other projects. The third phase deals with the selection of portfolios based on candidate project parameters, including their interactions with other projects through resource constraints or other interdependencies. In the following, each phase is considered separately. The techniques applicable to each phase are described first, followed by a series of propositions that specify requirements dealing with that phase’s impact in a suitable portfolio selection framework, which will be described in a following section.

**Strategic considerations phase**

The strategic implications of portfolio selection are complex and varied and involve considerations of factors both external and internal to the firm, including the marketplace and the company’s strengths and weaknesses. These considerations can be used to build a broad perspective of strategic direction and focus, and specific initiatives for competitive advantage. This strategy can be used to develop a focused objective for a project portfolio and the level of resources needed for its support. Project portfolio matrices have been used to evaluate the strategic positioning of the firm, where various criteria for a firm’s position are shown on one or more displays on two descriptive dimensions. These displays can be used by decision makers to evaluate their current position and where they would like the firm to be in the future. Wheelwright and Clark discuss a project mapping approach which develops a strategic direction for the firm, but Khurana and Rosenthal discovered that the front end planning process is often done poorly. It is clear that the strategic direction of the firm must be determined before individual projects can be considered for a project portfolio; many firms do extensive preparation and planning of strategy before considering individual projects.

**Proposition 1.**

*Strategic decisions concerning portfolio focus and overall budget considerations should be made in a broader context that takes into account both external and internal business factors, before the project portfolio is selected.*

An important operational consideration is that, while there are many possible methodologies that can be used in selecting a portfolio, there is no consensus on which are the most effective. As a consequence each organization tends to choose, for 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. Also, the methodologies most useful in developing a portfolio for one class of projects may not be the best for another (e.g. good estimates of quantitative values such as costs and time may be readily available for certain construction projects, but qualitative judgment is more likely to be used for development of advanced new products).

**Proposition 2.**

*A project selection framework should be flexible enough so that stakeholders can choose in advance the particular techniques or methodologies with which they are comfortable, in analyzing relevant data and making choices of the type of projects at hand.*

A major concern with most of the models for choosing project portfolios is that they are complex and difficult to use, and they require large amounts of input data. To alleviate these problems, the portfolio selection process should be organized in a logical manner so each step moves from a top-down (strategic considerations) or bottom-up (individual project considerations) perspective towards an integrated consideration of the projects most likely to be selected. However, each step should have a sound theoretical basis in modeling, and should generate suitable data to feed the following step. Users need access to data underlying the models, with ‘drill-down’ capability to develop confidence in the data being used and the decisions being made. At the same time, users should not be overloaded with unneeded data; it should be available only when needed and requested. Users also need training in the use of techniques that specify project
parameters to be used in making decisions. An overall balance must be achieved between the need to simplify and the need to generate well-founded and logical solutions.

Proposition 3.

To simplify the portfolio selection process, it should be organized into a number of stages, allowing decision makers to move logically towards an integrated consideration of projects most likely to be selected, based on sound theoretical models.

Proposition 4.

Users should not be overloaded with unneeded data, but should be able to access relevant data when it is needed.

Project evaluation phase

The benefit derived through project evaluation methods is measured in terms of each project’s individual contribution to one or more portfolio objectives (e.g. return on investment). Evaluation on an individual project basis includes such methods as:

- **Economic return.** This includes Net Present Value (NPV), Internal Rate of Return (IRR), Return on Original Investment (ROI), Return on Average Investment (RAI), Payback Period (PBP), and Expected Value (EV). The latter allows a consideration of risk at various project stages, usually based on either IRR or NPV. These techniques include time dependency consideration of investment and income flows. The Capital asset pricing model (CAPM) can also be used. A 1991 industry survey of the use of the above techniques (not including CAPM) indicated a movement towards the use of NPV, a moderate reduction in use of IRR, and a significant reduction in the use of PBP when compared to a 1978 survey.

- **Benefit/cost techniques** involve the calculation of a ratio of benefits to costs, where inputs may be derived from present value calculations of both benefits and costs, to transform them to the same time basis.

- **Risk** is a combination of the probability of an event (usually an undesirable occurrence) and the consequences associated with that event. Every project has some risk associated with not meeting the objectives specified for the project. To analyze project risk, a project is first decomposed into component activities, forming the project’s work breakdown structure (WBS). Depending on the depth of analysis appropriate at the point in the project’s life cycle, the WBS can range from relatively simple (e.g. development and market activities during early feasibility analysis of a new product) to complex (e.g. detailed breakdown of activities for the business plan prior to commitment for full scale development). Risk events relating to each activity are then identified, and their probabilities and consequences estimated. Information used in estimating risk can be derived from expert opinion, technical data, or previous experience with similar projects. A model which combines the risks from each activity, including interdependent events, can then be used to estimate overall project risk. Models used in analyzing risk include Monte Carlo simulation, decision theory and Bayesian statistical theory, and decision theory combined with influence diagram approaches. Risk is important when considering the inclusion of a project in a portfolio, and a portfolio should be ‘balanced’ by avoiding an over-commitment to high risk projects that may jeopardize the future of the organization.

- **Market research** approaches can be used to collect data for forecasting the demand for new products or services, based on concepts or prototypes presented to potential customers, to gauge the potential market. Techniques used include consumer panels, focus groups, perceptual maps, and preference mapping, among many others.

The use of specific project evaluation techniques is situation dependent. For example, a product development organization may use market research, economic return, and risk analysis to develop project characteristics that can be useful in selection exercises. Or a government agency may use economic and cost benefit measures. Measures used may be qualitative or quantitative, but regardless of which techniques are used to derive them, a set of common measures should be used so projects can be compared equitably during portfolio selection.

Proposition 5.

Common measures should be chosen which can be calculated separately for each project under consideration. These will allow an equitable comparison of projects during the portfolio selection process.

Selection of, or adjustments to, a project portfolio is a process which recurs. Existing projects require resources from the available pool, and therefore their schedules and resource requirements interact with potential new projects. It is common practice to re-evaluate at major ‘milestones’ or ‘gates’ to determine whether they merit continuing development.

Proposition 6.

Current projects that have reached major milestones or gates should be re-evaluated at the same time as new projects being considered for selection. This allows a combined portfolio to be generated within available resource constraints at regular intervals due to (a) project completion or abandonment, (b) new project proposals, (c) changes in strategic focus, (d) revisions to available resources, and (e) changes in the environment.

The number of projects which may be proposed for the portfolio may be quite large, and the complexity of the decision process and the amount of time required to choose the portfolio increases geometrically with the number of projects to be considered. In addition, the likelihood of making sound business choices may be compromised if large numbers of projects must be considered unnecessarily. For this reason, screening processes should be used to eliminate projects in advance that are clearly deficient, before the portfolio selection stage of the process begins.
screening may be used to eliminate projects which do not match the strategic focus of the firm, do not yet have sufficient information upon which to base a logical decision, do not meet a marginal requirement such as minimum internal rate of return, etc.

**Proposition 7.**

*Screening should be used, based on carefully specified criteria, to eliminate projects from consideration before the portfolio selection process is undertaken.*

**Portfolio selection phase**

Portfolio selection involves the simultaneous comparison of a number of projects on particular dimensions, in order to arrive at a desirability ranking of the projects. The most highly ranked projects under the evaluation criteria are then selected for the portfolio, subject to resource availability. Classes of available portfolio selection techniques include:

- **Ad hoc approaches** such as (a) Profiles,² a crude form of scoring model, where limits are set for the various attribute levels of a project, and any projects which fail to meet these limits are eliminated (study of the human-computer interface aspects of such approaches have shown²⁴ that users prefer these minimum effort approaches, whether or not they give an optimal solution), and (b) Interactive selection,² involving an interactive and iterative process between project champions and responsible decision maker(s) until a choice of the best projects is made.

- **Comparative approaches** include Q-Sort,²⁵ pairwise comparison,² the Analytic Hierarchy Procedure (AHP),²⁶ dollar metric, standard gamble, and successive comparison.²⁷, ²⁸ Q-Sort is the most adaptable of these in achieving group consensus. In these methods, first the weights of different objectives are determined, then alternatives are compared on the basis of their contributions to these objectives, and finally a set of project benefit measures is computed. Once the projects have been arranged on a comparative scale, the decision maker(s) can proceed from the top of the list, selecting projects until available resources are exhausted. With these techniques, both quantitative and qualitative and/or judgment criteria can be considered. A major disadvantage of Q-sort, pairwise comparison and AHP is the large number of comparisons involved, making them difficult to use for comparing large numbers of projects. Also, any time a project is added or deleted from the list, the process must be repeated.

- **Scoring models**²⁸ use a relatively small number of decision criteria, such as cost, work force availability, probability of technical success, etc., to specify project desirability. The merit of each project is determined with respect to each criterion. Scores are then combined (when different weights are used for each criterion, the technique is called ‘Weighted Factor Scoring’²) to yield an overall benefit measure for each project. A major advantage is that projects can be added or deleted without re-calculating the merit of other projects.

- **Portfolio matrices**²⁹ can be used as strategic decision making tools. They can also be used to prioritize and allocate resources among competing projects.²⁹ This technique relies on graphical representations of the projects under consideration, on two dimensions such as the likelihood of success and expected economic value. This allows a representative mix of projects on the dimensions represented to be selected.

- **Optimization models** select from the list of candidate projects a set that provides maximum benefit (e.g. maximum net present value). These models are generally based on some form of mathematical programming, to support the optimization process and to include project interactions such as resource dependencies and constraints, technical and market interactions, or program considerations.², ³⁰ Some of these models also support sensitivity analysis,¹⁹ but most do not seem to be used extensively in practice.³¹ Probable reasons for disuse include the need to collect large amounts of input data, the inability of most such models to include risk considerations, and model complexity. Optimization models may also be used with other approaches which calculate project benefit values. For example, 0-1 integer linear programming can be used in conjunction with AHP to handle qualitative measures and multiple objectives, while applying resource utilization, project interaction, and other constraints.²³

Multiple and often conflicting objectives (or criteria) may be associated with portfolio selection, and projects may be highly interdependent. This could be due to value contribution, resource utilization, or mutual exclusion. For example, before project C can be undertaken, projects A and B must be completed, since their outputs feed project C. In addition, resource constraints such as available capital and technical workforce over the planning horizon should be considered, including resource time dependencies.

**Proposition 8.**

*Project interactions through direct dependencies or resource competition must be considered in portfolio selection.*

Many portfolio selection techniques do not consider the time-dependent resource requirements of projects,² and most implicitly assume that all projects selected will start immediately. This does not fit the reality of project management, where projects compete for limited resources, should be scheduled to use resources as smoothly as possible in time, and should be completed within some planned interval.

**Proposition 9.**

*Portfolio selection should take into account the time-dependent nature of project resource consumption.*

One of the drawbacks of model-based optimal portfolio selection methods,², ³⁰ is that they may proceed to portfolio selection without intervention by decision maker(s) who may wish to make desirable adjustments to the selected portfolio.²⁹ If the emphasis of a system is to be on decision support rather than decision making, decision makers must be able to make adjust-
Proposition 10.

Decision makers should be provided with interactive mechanisms for controlling and overriding portfolio selections generated by any algorithms or models, and they should also receive feedback on the consequences of such changes.

Portfolio selection is usually a committee process, where objective criteria such as predicted rate of return and expected project cost are mingled with subjective criteria relating to the needs of the different organizations represented on the project selection committee. All committee members should have access to information with which project inter-comparisons are made, as well as information on the project portfolio as a whole. Decision making environments for group decision support are available, which allow interactions among the decision makers as well as between decision makers and the support system.33 This allows portfolio selection decisions to be made that more closely meet the overall objectives of the organization.

Proposition 11.

Project portfolio selection must be adaptable to group decision support environments.

Project portfolio selection framework

Among published methodologies for project portfolio selection, there has been little progress towards achieving an integrated framework that decomposes the process into a flexible and logical series of activities that involve full participation by the selection committee. Such an approach could take advantage of the best characteristics of a combination of existing methods well grounded in theory. Other attempts to build integrated support for portfolio selection have been reported.5,34,35 However, these have been limited and specific to the methods used, rather than providing flexible choices of techniques and interactive system support for users. Based on the propositions outlined in the foregoing discussion, an integrated framework for project portfolio selection suited to decision support system (DSS) application is described in the following (relevant propositions are abbreviated as Px, where x is the number of the proposition indicated in the previous section).

Stages in the project portfolio selection framework

In line with considerations of simplification (P3), we decomposed the selection process into a series of discrete stages which progress from initial broad strategy considerations towards the final solution. This is depicted in Figure 1, where the major stages are represented by the heavy outlined boxes. The ovals in the diagram represent pre-process activities, which we also discuss. Post-process stages (that follow the portfolio selection process) are also shown in the lightly outlined boxes for completeness, since these may result in data generation and project evaluation during development, that may also affect portfolio selection at some future time. We now consider the sequential activities that go into developing the portfolio. Since we know the desired end result, which is an optimal or near-optimal portfolio that satisfies the constraints placed on it by the selection committee, it is best to analyze the process from end to beginning, to show how information needed for models/techniques used at each stage is made available from previous stages.

Portfolio adjustment. The end result is to be a portfolio which meets the objectives of the organization optimally or near-optimally, but with provisions (P10) for final judgmental adjustments which are difficult to anticipate and include in a model. Selecting a project portfolio is a strategic decision, and the relevant information must be presented so it allows decision makers to evaluate the portfolio without being overloaded with unnecessary information (P4). The final stage is a portfolio adjustment stage which provides an overall view, where the characteristics of projects of critical importance in an optimized portfolio (e.g. risk, net present value, time-to-complete, etc.) can be represented, using matrix-type displays, along with the impact of any suggested changes on resources or selected projects. It is important to use only a limited number of such displays, to avoid confusion (cognitive overload) while the final decisions are being made. User should be able to make changes at this stage and, if these changes are substantially different from the optimal portfolio developed in the previous stage, it may be necessary to re-cycle back to re-calculate portfolio parameters such as project schedules and time-dependent resource requirements. In addition, sensitivity analysis should be available to predict and display the impact of change (addition or deletion of projects) on resources and portfolio optimality (P10).

An important aspect of portfolio adjustment is achieving some form of balance among the projects selected, again through user interaction (P10). This will require interactive displays on certain portfolio dimensions, such as risk, size of project, and short term vs long term projects while adjustments are being made.
For example, the proportion of high risk projects should not be too high due to the fact that failures of several of these projects could be dangerous to the future of the company. On the other hand, low risk projects may not carry the high return that is often typical of risky projects, so the expected return from the portfolio may be too low if project selection is too conservative on the risk dimension. Balance on project size is also important, because the commitment of a high proportion of resources to a few large projects can be catastrophic if more than one fails. And too many long term projects, no matter how promising they are, may cause financing or cash flow problems.

**Optimal portfolio selection.** Performed in the second-last stage. Here, interactions among the various projects are considered, including interdependencies, competition for resources, and timing (P8, P9), with the value of each project determined from a common set of parameters that were estimated for each project in the previous stage. AHP, scoring models, and portfolio matrices are popular among decision makers for portfolio selection, because they allow users to consider a broad range of quantitative and qualitative characteristics as well as multiple objectives. However, none of these techniques consider multiple resource constraints and project interdependence. AHP, pairwise comparison, and Q-sort also become cumbersome and unwieldy for larger numbers of projects. A serious drawback of portfolio matrices is that they do not appear to meet stated objectives such as profit maximization, so this approach should not be considered for the portfolio selection stage.

We suggest a two-step process for the portfolio selection stage. In the first step, the relative total benefit is determined for each project. A comparative approach such as Q-Sort, pairwise comparison, or AHP, may be used in this step for smaller sets of projects, allowing qualitative as well as quantitative measures to be considered. This may involve extensive work by committee members in comparing potential project pairs. For large sets of projects, scoring models are more suitable as these do not involve comparison of large numbers of project pairs. The result of either of these approaches would be to establish the relative worth of the projects.

In the second step of this stage, all project interactions, resource limitations, and other constraints should be included in an optimization of the overall portfolio, based on the relative worth of each proposed project. If all the project measures could be expressed quantitatively, the foregoing step could be omitted since optimization could be performed directly in a mathematical program in the second step. In the unusual case where interdependence and timing constraints were not important, and there is only one resource that is binding, it might be tempting in the second step to simply select the highest valued projects until available resources were used up. However, this does not necessarily select an optimal portfolio. (combinations of certain projects may produce a higher total benefit than individual projects with higher individual benefits). The relative worth of each project should therefore be input to a computerized process, which can be a 0-1 integer linear programming model that applies resource, timing, interdependence, and other constraints to maximize total benefit (P8, P9). Goal programming may be used for multiple objectives in this step, if more than one objective is explicitly identified.

**Screening.** Shown in Figure 1 following the individual project analysis stage. Screening may use such techniques as profiles. Here, project attributes from the previous stage are examined in advance of the regular selection process (P6, P7), to eliminate any projects or inter-related families of projects which do not meet pre-set criteria such as estimated rate of return, except for those projects which are mandatory or required to support other projects still being considered. The intent is to eliminate any non-starters and reduce the number of projects to be considered simultaneously in the Portfolio Selection stage (P7). Care should be taken to avoid setting thresholds which are too arbitrary, to prevent the elimination of projects which may otherwise be very promising.

**Individual project analysis.** The fourth from last stage, where a common set of parameters required for the next stage is calculated separately for each project, based on estimates available from feasibility studies and/or from a database of previously completed projects. Such techniques were discussed in Section 2.2. For example, project risk, net present worth, return on investment, etc. can be calculated at this point, including estimated uncertainty in each of the parameter estimates (P5). Scoring, benefit contribution, risk analysis, market research, or checklists may also be used. Note that current projects which have reached certain milestones may also be re-evaluated at this time, but estimates related to such projects will tend to have less uncertainty than those projects which are proposed but not yet underway. The output from this stage is a common set of parameter estimates for each project. For example, if the method to be used were a combination of net present value combined with risk analysis, data required would include estimates of costs and returns at each development stage of a product or service, including the risks. Uncertainty could be in the form of likely ranges for the uncertain parameters. Other data needed could include qualitative variables such as policy or political measures. Quantitative output could be each project’s expected net value, risk, and resource requirements over the project’s time frame, including calculated uncertainties in these parameters (P5).

**Pre-screening.** Precedes portfolio calculations. It uses manually applied guidelines developed in the strategy development stage, and ensures that any project being considered for the portfolio fits the strategic focus of the portfolio (P1, P7). Essential requirements before the project passes this stage should also include a feasibility analysis and estimates of parameters needed to evaluate each project, as well as a project champion who will be a source of further information. Mandatory projects are also identified at this point, since they will be included in the remainder of the portfolio selection process. Mandatory projects are projects agreed upon for inclusion, including improvements to existing products no longer competitive, projects without which the organization could not function adequately, etc.
A pre-process stage provides high level guidance to the portfolio selection process. Activities in this stage appear in ovals in Figure 1. These include ‘Strategy Development’ (P1) (determination of strategic focus and setting resource constraints), and ‘Methodology Selection’ (P2,P5) (choosing the techniques the organization wishes to use for portfolio selection). Determination of strategic focus may be carried out at higher managerial levels than the portfolio selection committee, because it very much involves the firm’s strategic direction. Strategy development is an unstructured process which can consume a great deal of managerial time, but is critical if the portfolio selected is to promote the business objectives of the firm. Only occasional adjustments will be needed for strategic guidelines developed at this point in the process, although the portfolio selection process itself recurs at regular planning intervals.

Resource allocation to different project categories also involves high level decisions which must be made before the portfolio selection process (P1). Choosing and implementing techniques suitable to the project class at hand, the organization’s culture, problem solving style, and project environment may also depend upon previous experience. Methodology selection (P2,P5) should be based on committee understanding of, and experience with, the candidate methodologies, or their willingness to learn new approaches. The methodology selection stage would not normally be repeated, unless the committee found other methodologies which were better matches to their preferences.

Stages in the project portfolio selection framework (Figure 1) are organized logically, in a manner which allows decision makers to work through the portfolio selection process logically (P3). Each stage involves methodology choices which are at the discretion of users (P2), in order to gain maximum acceptance and cooperation of decision makers with the portfolio selection process. Table 1 summarizes the stages in the framework, the associated activities, and some of the potential methodologies previously mentioned, for each stage.

### Table 1 Activities and methodologies in the portfolio selection framework

<table>
<thead>
<tr>
<th>Process stage</th>
<th>Selection stage</th>
<th>Activity</th>
<th>Potential methodologies</th>
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<tr>
<td>Pre-process</td>
<td>Strategy dev't, methodology selection, development of strategic focus, resource constraints, choice of model techniques</td>
<td>Strategic mapping, portfolio matrices, cluster analysis, etc.</td>
<td>Manualy applied criteria; strategic focus, champion, feasibility study avail.</td>
</tr>
<tr>
<td>Portfolio selection process</td>
<td>Pre-screening</td>
<td>Rejection of projects which do not meet portfolio criteria</td>
<td>Decision trees, uncertainty est., NPV, ROI, etc., resource req's est., etc.</td>
</tr>
<tr>
<td>Individual project analysis</td>
<td>Calculation of common parameters for each project</td>
<td>Ad hoc techniques (e.g. profiles)</td>
<td></td>
</tr>
<tr>
<td>Screening</td>
<td>Rejecting non-viable projects</td>
<td>AHP, constrained opt’n, scoring models, sensitivity analysis</td>
<td></td>
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<tr>
<td>Portfolio selection</td>
<td>Integrated consideration of project attributes, resource constraints, interactions</td>
<td>Matrix displays, sensitivity analysis</td>
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<td>Portfolio adjustment</td>
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<tr>
<td>Final portfolio</td>
<td>Project development</td>
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However, the set of main stages (heavy outlined boxes) in the framework (Figure 1) can be integrated into a Decision Support System (DSS), including a carefully designed model management module that handles models of the many different types which may be chosen. These models require a common interface through which data may be interchanged. The system involves considerations of model representation and integration.

Integrated modeling approaches which have been suggested include *process integration*. Process integration is useful when heterogeneous models (models from different paradigms) are to be integrated, as in our framework. 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 timing of dynamic interactions among the models. Variable correspondence deals with input/output relationships among the component variables in the various models being used, and assuring dimensional consistency among these variables. In our proposed framework, models are not executed in parallel. They typically terminate after transferring their outputs for use by subsequent models, so 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 which is open to inspection by users during the portfolio selection process, and second as a transfer site to provide matched data for the input and output variables of the various models being used.

### Decision support systems considerations

The framework we have outlined can be used for project portfolio selection in an environment which is only partially supported by computerized modeling and databases, since users are given the flexibility of choosing their own techniques or models at each stage. From the foregoing and from Figure 1, in all process stages the decision makers would interact with the proposed system, which provides supporting models and data. Data could either be input 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 (see Figure 1). Provision for continuous interaction between system and decision makers is required 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 (P10) has been accepted as the most appropriate way to obtain correct preferences. If this interaction is to
be supported by a computer-based system, a module is required to manage the related techniques/models, and another module to support data needs. This is shown in Figure 2 as a Decision Support System.33

Published work on group attempts to reach consensus on portfolios includes work by Souder,41 who explored combinations of paired comparisons, group discussions, and member interactions in decision making of this type. Group Decision Support Systems (GDSS) are DSS which facilitate the solution of unstructured problems by groups of decision makers. A GDSS provides support for the exchange of ideas, opinions, and preferences,42 and is clearly a requirement of a portfolio selection DSS (P11). A GDSS may be implemented at one location, or it may involve simultaneous communication among decision makers at different sites. It can be a simple computer-projected display on a large screen visible to committee members, or a system where each committee member sees a separate display with which he or she interacts, using computer-based models and data independently of others. These results are shared through a common system and display,33 to aid in developing a consensus.

Prototype interface
As shown in Figure 2, a DSS for project portfolio selection includes the following modules:

1. Project portfolio database management.
2. A model management module to support the techniques or models to be used.
3. A user interface to the model management and database management modules.
4. Not shown here are GDSS extensions to allow individual private work spaces in the database during committee portfolio selection activities.

An additional link is included to the project management database, a useful source of information for project attribute estimation and decision making, based on previous project results.

We have developed a PC Windows-based prototype interface, for experimental studies of the portfolio adjustment stage of the proposed framework, which is the stage where user-system interactions are most critical to the successful use of the DSS. This interface includes a link to database management software to support the portfolio database.33

Features included in the interface include a list of currently selected projects, which can be shown as a window overlay of the interface. A graphical display is used to display projects as circles on a two-dimensional presentation, where the dimensions can be chosen to represent project parameters such risk level, project time span, estimated market, etc. Projects currently selected are shown as dark hatched circles, where the area of the circle is proportional to the benefit (e.g. net present value) available from that project. Projects not selected are shown as open circles. Interdependencies of projects with certain other projects are shown by arrows between the corresponding circles on the display. An arrow to a circle representing another project indicates that this project must precede the other project (P8).

More information about each project can be displayed simply by pressing the right mouse button on the relevant circle (P4). The percentage of resources still available and unassigned from the total budget are also shown as sidebars in the display. Also shown are the percentage of committed resources allocated to projects on each dimension of the display. A project’s status may be changed between ‘selected’ and ‘de-selected’ simply by moving the cursor to the corresponding circle and clicking on it (P10). Changes to resource consumption due to such a change are displayed immediately. Users are not allowed to de-select projects upon which another selected project depends. Modifications may be made to this interface according to user requirements (P2), including the choice of project dimensions displayed, the dimension related to circle size, resources displayed, etc.

Discussion
The framework we propose is basically an attempt to simplify and organize the project portfolio selection process. It matches considerations which are important to decision makers who need to make portfolio selection decisions. Since decision makers should be directly involved with the selection process at each of its stages, support tools (either manual or computer-based) will be essential to implement each technique used, and the framework leaves the choice of specific techniques up to the decision makers. This generic approach also allows each technique chosen to be integrated into a decision support system which provides far better and more acceptable project portfolios than those which can be generated by any single technique we have discussed. Because of the staging concept, it is possible to eliminate certain stages if the organization finds it more efficient to do so. After the first application of the framework, strategy development and methodology selection need only be reviewed as required, and not every time the portfolio is reconsidered. Also, for example, screening is discretionary since it is used only to reduce the number of projects (and therefore complexity) in the portfolio selection stage. This may not be needed if the number of projects is small or if there are interdependencies among all the projects being considered. And in the portfolio selection stage, the optimization process may be simplified in various ways, depending on the circumstances.

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An integrated DSS can support these activities, first as a model management system, and second as a repository of data related to all the projects being considered. This is clearly adaptable to a group support system, which is essential if the system is to be used in the real world of business, where most such decisions are made by committees. The prototype described here is a demonstration of the major interactive components of such a system.

Based on the results we have obtained, an extensive development effort is underway to implement the suggested framework as an integrated decision support system, and to test it in real decision making situations. This system will include a powerful linear programming package to generate optimal solutions, a database management system as a data repository, and a highly interactive and user-friendly interface, programmed through a rapid application development environment. An initial testing phase will be to evaluate the usability and usefulness of the system in a laboratory environment, in order to eliminate flaws in the interface design. A second phase will be to demonstrate the system to users in real application environments, to get feedback on further refinements to the system’s modeling capabilities. A third phase will be to implement the system in several corporate environments, and determine which refinements are needed to tailor it to company use. Included in this phase will be an evaluation of the system in a group decision environment.

From the framework we have established, it is also clear that further research is needed into the generic requirements for decision support in project portfolio selection, including: (a) determining which modeling techniques are preferred by decision makers, and how to simplify some of the more useful techniques to make them more acceptable, (b) finding in which situations input information requirements can be supported by data gathered from existing projects, and which inputs can be provided by estimates or values generated from economic models, and (c) examining the scope of strategic decisions which are made outside the purview of the portfolio selection process, to ease the process of portfolio selection.

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