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Title: Literature Review: Technology Selection

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Abstract: Literature on technology and project selection methodologies and associated factors and issues in these methodologies are reviewed in this paper. Paper also includes annotation of most of the papers cited.

Literature Review: Technology Selection

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Introduction [1], [2] [3], [4]

The recent increase in the important of technology management has been driven by globalization trend and the concern about the organization competitiveness. Believing that implementing new and appropriate technology will help organization push back its business barriers [5]. As mentioned in Schmidt paper [6], technology should be treated as a part of technology-management system rather than as an isolated decision event.

Technology selection is considered as an important component in technology management. The success of a project is contingent on being able to select appropriate technologies to fulfill organization objectives. Allocating resources to a poor technology effect not only the budget on the project budget, but also loss of time and opportunity to invest in a project that is more beneficial to the organization. [7].

Selection process is described as the process of making a choice between a number of distinctive alternatives. Project and technology selection usually describes in term of constrained optimization problem. Given a set of project proposals, the goal is to select a subset of projects to maximize some objectives without violating the constraints. The selected subset is called a portfolio. Finally the portfolio will be chose by the addition models that help selecting technology or project from the portfolio. [8].

Why is it difficult to select technology? From Tavares [9] and Scarso [10], technology selection process has been viewed as a very complicated process due to the underlying reasons. First, the rapidly increasing of technology (more options to select). Moreover, the technologies themselves also possess the high difference in major attributes among options and the intrinsic uncertainty that often surrounds the technology such as the current and future availability of technology, economic information about technology,

3. Work place and product safety,

4. Disposability /recyclability of the material and waste

5. Environmental impact (noise, pollutants, emergency discharge, ease of material disposal)

7. Regulation: the last major concern is the government regulations which covers some broad areas: the regulation on product, process, safety, environment, and recyclability. The two questions that manager should try to answer before selecting the projects are: Whether or not the specific technology will be able to meet those regulation criteria, and how to reduce the project cost and be able to meet the standard.

Project Selection Methodologies

There are hundreds of existing selection methodologies that can be used for specific purpose. The followings are the group of the variety tools that were used in the literature. They could be summarized as followings:

1. Ranking

Ranking method is a methodology that helps rank a set of proposed projects. In general, once the projects have been ranked, the manager then select to invest from the top of the list toward bottom, funding the budget from the best project until the budget is exhausted or the less of the projects are not attractive. There are many applications that rely their methodologies on the ranking procedure.

In Navarrete paper [35], [36], the authors proposed a new method for ranking alternatives which are evaluated with respect to multiple objectives under inexact and imprecise information.

Pairwise Comparison [37]: The process begins with each project needs to be compared with every other project. Once the comparison matrices are available, the projects will be ranked by either dominance count method (each project compare with the less of the options) or anchored scale method (select best and worst project and assigned scores of 100 and 1, the less will have to compare with the "anchor point" project).

Scoring Models: The process involves a mathematical formula or an algebra expression that produce a score for each project under consideration. The formula incorporates those factors believed to be important. Then, each factor is weighted to reflect its importance relative to the other factors. Then computed overall score for each of the projects. Projects are then ranked in order of their scores.

The sample applications of scoring model can be seen in many papers such as Cooper [38], Moore [39], In Iyigun paper [40], he used a weighted scoring model involve the upper management criteria, while Davies [41] corporate people and group problem solving in his scoring model.

Analytic Hierarchy Procedure (AHP) [37], [12]: AHP was developed by saaty (1980) as a tool to assist in making sound decision base on model of the organizational goals and strategies, pairwise comparison is made until all alternative are record. AHP helps decision maker to cope with the intuitive, the rational, and the irrational, all at the same time. It provides the framework to view the problems in an organized but complex framework that allows for interaction and interdependence among factors and still enable the decision maker to think about them in a simple way. AHP framework can be used to help organizes feelings and intuition and logic in a structure approach to decision making process. AHP incorporates both qualitative and the quantitative aspects of human thought. It employs data from the various variables that comprise the decision and judgements of these variables from decision makers. The qualitative approach is used for defining the problem and its hierarchy, and the quantitative approached is used to express judgements and preference concisely.

2. Economic Models

Economic models for project selection compare the project candidate on their contributions to the firm profits. Economic model is one of the most common use techniques in technology selection process. There are many models that had been developed in this area. The following are some of the well-known methodologies:

Cash Flow Payback: focus on the time from start until net cash flow equals zero. This technique does not take into account the time value of money. It looked at when the investment will be recouped. Payback is a simple method that can be used as a screening tool in technology selection process.

Net Present Value: Net present value is often used on capital budgeting. The basic notion rely on the idea that a unit money now is worth more than a unit money in the future, because the current money can generate more revenue during the time between. NPV computation makes comparison possible between now and later cash flow stream, which can be used to make comparison between the projects that have different cash flow stream. The example can be seen in Bordley [34] and Moore paper [39], in the paper he combined the NPV concept with the scoring model.

Internal Rate of Return: IRR is the discount rate that would reduce NPV of a cash flow profile to zero. IRR must be computed iteratively and adjusted until the computed NPV equal zero. For the technology selection criteria, the higher the IRR the better the project will generate benefit to the organization.

From Asquith [42]: IRR heuristics is better than NPV in 3 cases 1. Usually project manager has incentive to overstate cash flow that occurs in late project life. 2. IRR provide a channel to accept project that does not have positive cash flow. 3. In the case that IRR > WACC

Also most of the economic models required the estimation of future income which might be difficult to obtain, especially in the case that project is in the basic stage. There are many examples that used economic models for selecting the projects. The following are some of them:

1. Kangari [43] used portfolio approach (AD, EV of NPV) to select project.
2. White [44] used the IRR to construct a capital budgeting priority list
3. Winston [45] created simplified method to help choosing the project
4. Chiu [46] combined fuzzy cash flow concept with economic model project for help selecting the project. In his paper, fuzzy cash flow analysis has been used to determine the uncertain cash flow and discount rate by specified them as triangular fuzzy number to calculate fuzzy present worth with deviation.
5. Hajdasinski [47] used overall rate of return (ORR) project evaluation criterion based on the concept of the so-called transition point (TP).
A generalization of the ORR criterion is fully NPV compatible and applicable to both investment and financing projects.
6. Kenedy [48] used marginal return on investment capital (MRIC) (IRR modified) to help select the project.
7. Ezawa [49] used Influence-diagram-based decision analysis software, the methodology assess the potential commercial value of project.
8. Salahor [50] presented Modern Asset Pricing (MAP) for helping value upstream petrochemical project.
9. Nelson [51] used capital budgeting analysis that include utility maximization, non-economic criteria, project interdependence, uncertainty. The model also used technology assessment, equipment evaluation, capacity elasticity, cost budgeting analysis, and adjusted NPV for analysis.

3. Decision Theory

Decision theory is used in situation which the decision maker faces a sequence of decisions (choices) and uncertainty of the results. The decision theory techniques provide a mean to plot the highest value branch through the decision tree which help guide the decision maker at every decision node. The following are some of its applications:

1. Siha [21] provided a decision model framework in the paper.
2. Schmidt [8] presented Branch and bound algorithm model that account those three interactions which are benefit interactions, resource interactions, and outcome interactions.
3. Giritli [16] provided a multi-objective decision making approach
4. Lockett [52] presented the used of decision tree for selecting projects
5. Heidenberger [53] used a mixed integer linear programming (*Dynamic project selection*) that use stochastic decision tree concept which provides both costs and benefits for selecting project.

4. Portfolio Optimization

Portfolio optimization is the model that taking the interaction among the projects into account. It provides the channel to include resource dependencies, budget constraints, technical constraints and technical interactions, market interactions, and program consideration. Common tools are mathematical programming model, sensitivity analysis, simulation, and cluster analysis.

1. Mathematical programming is a technique for selecting a set of entities out of the large collection such that selected set maximizes or minimize some objects function subject to the set of constraints. Some of the applications are discussed in the following papers:

Multicriteria Optimization Applications

Tavares [9], Ranta [54], Khouja [55], Santhanam [15] proposed the multi-criteria optimization models in their papers for help selecting the project.
Dias [56] presented the multicriteria project selection problem subject to linear constraints using fuzzy sets.

Czajkowski [29] proposed DSS model for space technology using integer programming to reduce an unmanageably number of projects.

De Sabtiago [57] proposed a mathematical method to select optimal technology that minimize cost and maximize annual profit for chemical industry.

Haddock [58] proposed decision support system for specific machine selection.

Baker [59] presented the uses of DEA technique for technology selection and its applicability.

Khouja [55] used DEA to identify technology that provide the best combinations.

Liberatore [60] used cost benefit analysis and integer programming for allocating resources.

The following papers used ***Non-linear programming to help selecting the project:***

Santhanam [33] proposed model that was formulated as a nonlinear 0-1 programming problem and represented a significant addition to existing IS, capital budgeting and R&D project selection models.

Kyparisis [61] used dynamic programming that contains a multi constraint nonlinear problem which used discount rate and multiple constraint.

In Saber paper [62], four major approaches of nonlinear goal programming are reviewed and discussed: simplex based; direct search; gradient search, and interactive approaches for selecting project

Goal Programming [63] [64].

Goal Programming is the oldest in the field of multi-criteria decision making. It was first introduced by Charnes and Cooper in 1952. The applications of Linear, Integer, and Goal programming span a diverse domain. The following is a representative, but not an exhaustive list of application areas: Refinery scheduling,. Chemical plant design, Power systems planning, Planning of national economics, Portfolio selections, Scheduling of carriers and crews (Airline, Bus, Train), Academic resources planning, Health planning, Military and Engineering applications, Diet planning, Cutting stock problems, Timetable Scheduling etc. The technique is widely used by many project managers for selecting project among multi-criteria decision making (MCDM). A systematic approach for constructing GP model as follow:

1. Create Objective
2. Ranked and weight desired level of attainment for each objective
3. Penalty weights for over attainment of each goal.

The followings are some of the GP applications in the papers:

Madey [65] and Mukherjee [66], used a multi-attributes model using goal programming and compromise programming.

Khorramshahgol [67] suggested that the manager to use Delphi method to collect expert opinion and goal programming to select the project. Some of the drawback of goal programming are also discussed.

2. Sensitivity Analysis is a study to observe the change of optimal set if there is a change in one or more of the values, and rerun the procedure to select the optimum portfolio. The analysis helps decision maker to understand the robustness of the selected portfolio and to quantify the difference in the payoff.

3. Simulation

Simulation is used for predicting the future outcomes. Generally, the technique is used when the project has alternate path and the end goal depend on the chance of the outcome. Simulation usually requires the probability distribution of the events. It also needs to be done large enough to assure statistically valid results. The following paper provide some of the simulation application for selecting the project:

Zeng [68] proposed DSS which used simulation, network, and optimization for selecting the project. By using DEA to evaluate and improve the operational efficiency.

Dowsland [69] used historical information for creating Simulation mode

In Bard paper [70], a particular technology has been chosen, and the decision maker must allocate a fixed amount of resources to different projects to maximize a given measure of performance. The problem is formulated as a probabilistic network and solved heuristically using Monte Carlo simulation.

4. Cluster Analysis

Cluster analysis [71] also known by the name of segmentation analysis and taxonomy analysis. It is a technique for accomplishing the task of grouping and selecting project that support some specific objectives. The methodology did not directly rank project. The technique identifies group or cluster of projects that are related or similar in some sense.

In principle, cluster will be ranked and the entire important cluster would be fund. The following are some of the samples of using cluster analysis.

1. Holt [72] uses Cluster Analysis (CA) to choose contractors
2. Mathieu [73] proposed DSS for large-scale selection of corporate judgement and experience by using: interaction matrix, hierarchical cluster analysis, Boston consulting group strategic planning matrix

5. Cognitive Modeling

Cognitive modeling is also known as "policy capturing" attempts to understand the actual processes used by manager. As a selection tool, it is intended to lead to the understanding of how decision are made, and mimic the decision that would be made by specific managers. The methodology is intended to reduce the work of manager where the large number of projects would be made. The application can be seen in Schwartz [74].

6. Expert Judgement

The technique includes experts' opinion and experience to help forecasting the results of the projects. The followings are some papers that used expert judgement in project selection process.

1. Kim [14] proposed an empirical based selection which examined expert Judgement using the principle of organization behavior.
2. Khorramshahgol [67] used Delphi method to evoke technical expert opinion for defining project criteria and polled until a consensus is reached.
3. Dalkey [75] described three features of Delphi as anonymity, controlled feed back, statistical group response.
4. Helin [76] presented Q-sort/nominal-interaction (QS/NI) procedure to meet consensus sets of prioritized goals. Once a consensus for the set of goal is established, various project evaluation methods can effectively be used by types of projects (exploratory, applied, development) and decision making (screening, prioritizing, resource allocation) in combination with nominal interaction method.
5. In Mathieu paper [73], his model corporate judgement and experience to the selection analysis by using: interaction matrix, hierarchical cluster analysis, Boston consulting group strategic planning matrix

7. Quality Function Deployment Matrix

Kim [77] and Young [28] used quality function deployment (QFD) matrix for selecting project. The underlying notions rely on the need to satisfy customer, continuous improvement, and employee participation. In the past QFD matrix has been successfully used for improving product quality. In the papers, the technique was applied to help selecting technology that can meet the customers' needs.

The goal of technology selection, development and transition, is to efficaciously provide competitive new product systems that answer broad end-user needs in the world market. Many factors influencing technology selection and funding can be sorted to align both evolutionary and revolutionary technology developments with new products and end-user needs.

Starting with general market's needs, technology concept potential, feasibility and limit research, the tools can be used to guide future product planning, and supply the basis for technology development decisions incorporating broad business essentials.

Strengths of Formal Project Selection Methodology

However as mentioned in Cabral-Cardoso study [78], there are some benefits of using formal technology selection techniques which are:

1. The simple technique can be used for prescreen the project
2. The technique may lead to increasing communication
3. Generally, employing technique helps raising new question
4. The process usually led the researchers to rethink the project and generate focused deliverables and deadlines. [34]
5. By forcing the implementers to think through implementation hurdles in the technology, it creates a large amount of qualitative insight that can be used to improve the project performance. [34]
6. It usually include interesting new parties in the selection processes
7. The technique helps increasing involvement in the organization.

Weaknesses of Formal Project Selection Methodology

In spite of numerous models on project selection, only a small number of the proposed methods had been used by project manager. The following are some of the reasons why proposed models might not be used: [79], [80], [78], [6], [11]:

1. Complexity of model: In many occasions the methods are too sophisticated beyond the routine use of managers.

2. Unavailability of data: most of the proposed methods involve model requiring much quantitative input data which is not readily available in the company. Sometimes due to

the nature of the problem, it can be very difficult to gain quantitative accuracy as most evaluation are subjective, and also relying on quantitative methods alone could mislead the manager judgement.

3. The methodologies tend to reinforce traditional accounting procedure which is not fit with today technology change.

4. Inadequacy of model: Model itself also has some limitations. Most of the techniques were modeled in the management science literature as a constrained optimization problem which usually ignore organizational context. Furthermore, the common deficiencies is to assume fixed criteria and alternative with no mechanism for altering the problem (obtain new criteria, objective, alternative) within the planning cycle.

Finally, most of the methodologies fail to balance commercial view with the issue of capabilities. They did not provide the way to compare project at different life cycle in the process of reviewing, monitoring, and stopping the programs.

Conclusion

Based on the reviewed papers, most of the formal project selection models are not being used much in the real project selection process. Since there is little convincing evidence that "formal selection methods" actually improve decision made about R&D project selection [81], there has been a tendency to ignore the fact that their use may lead to other useful effects such as increasing communication, raising new questions, interesting new parties and increasing involvement. These processes may indirectly improve decision making process.

Moreover, most the work in project selection are focused on evaluating and identifying the best subset of projects among several proposals under some resource constraints.

However, the sequential decision problem of optimally sequencing a set of projects which must be undertaken over time are recommended [82].

The author perceives the need for new methodology that better support these activities. The new methodologies can be a combination of existing that is simple and flexible enough for current situation. The author also noticed some general issues that influence the choice of project selection methodology which are the nature of the problems including size and complexity of the projects and the level of management that is primarily concerned. Further study in these areas are suggested.

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77. Kim, K., K. Park, and S. Seo, *Matrix approach for telecommunications technology selection.* Comput Ind Engineering, 1997. **33**(3-4): p. 833-836.

78. Cabral-Cardoso, C. and R.L. Payne, *Instrumental and Supportive Use of Formal Selection Methods in R&D Project Selection.* IEEE Transaction on Engineering Management, 1996. **43**(4): p. 402-410.

79. Lee, J., S. Lee, and Z.-T. Bae, *R&D Project Selection: Behavior and Practice In a Newly Industrializing Country.* IEEE Transaction on Engineering Management, 1986. **EM**(3): p. 141-147.

80. Watts, K.M. and J.C. Higgins, *The Use of Advance Management Technique in R&D.* International Journal of Management Science, 1987. **15**(1): p. 221-229.

81. Cbral-Cadoso, C. and R.L. Payne, *Instrumental and Supportive Use of Formal Selection Methods in R&D Project Selection.* IEEE Transactions on Engineering Management, 1996. **43**(4): p. 402-410.

82. Chun, Y.H., *Sequential Decisions under Uncertainty in the R&D Project Selection Problem.* IEEE Transactions on Engineering Management, 1994. **41**(4): p. 404-413.

Annotated Bibliography

Al-Araimi, S. A. (1997). Industrial Project Selection Criteria in the Sultanate of Oman. PICMET '97: Innovation in Technology Management: The Key to Global Leadership, Portland, Picmet.

This paper examines the criteria of industrial project selection decision-making in the Sultanate of Oman. Twenty-five basic criteria are used to evaluate each project with respect to its impact on them. These criteria are grouped into five categories, namely financial, marketing, technical, economic and strategic criteria. Each criterion has been defined by experts from the Ministry of Commerce and Industry in the Sultanate of Oman.

Albala, A. (1975). "Stage Approach for Evaluation and Selection of R&D Projects." IEEE Transaction on Engineering Management **EM-22**(4): 153-164.

In spite of numerous papers on project selection, a small number of the proposed methods have been used by DM, because 1. Most of the proposed methods involve model requiring much quantitative input data, not readily available in the company 2. In many occasion the methods are too sophisticated beyond the routine use of managers.

Factor that can be used to pre-evaluate the project 1. commercial assessment (market characteristics, new product characteristics) 2. Environment assessment 3. Technical assessment (Status, operating status) 4. Economic and financial assessment

Alidi, A. S. (1997). Use of the AHP for the Assessment of Petrochemical Industry Technologies. PICMET '97: Innovation in Technology Management: The Key to Global Leadership, Portland, Picmet.

The relevant question facing petrochemical manufacturing corporations in oil and gas rich developing countries is probably not whether ranking of foreign process technologies should be done, but rather how it should be accomplished and what criteria

should be applied. In this paper a methodology based on the Analytic Hierarchy Process (AHP) is proposed to assist in this selection process.

Asquith, D. and J. E. Bethel (1995). "Using heuristics to evaluate projects: The case of ranking projects by IRR." Engineering Economist **40**(3): 287-294.

The use of a simple heuristic for evaluating projects is examined. It is posited that ranking projects by an internal rate of return (IRR) and rejecting marginal projects can be superior to a net present value (NPV) rule if 3 situations occur. The 3 situations are: 1. Project managers have incentives to overstate cash flow forecasts that occur late in a project's life. 2. Project rankings determine project acceptance because not all positive NPV projects are accepted. 3. A project's IRR is greater than the weighted average costs of capital. In these instances, the IRR heuristic undervalues distant cash flows and thus, reduces project managers' incentives to positively bias forecasts.

Babcock, C. (1995). "The art of technology assessment." Computerworld **29**(20): 118.

According to a commentary, IS managers are slowly being confronted with a tempting array of low-cost technologies that offer both pitfalls and opportunities. The savy IS manager will need to understand not only how new technology can push back business barriers, but also how easily the firm's culture will be able to absorb it.

Baker, R. C. and S. Talluri (1997). "Closer Look at The Use of Data Envelopment Analysis for Technology Selection." Comput Ind Engineering **32**(1): 101-108.

This paper proposes an alternate methodology for technology selection using data envelopment analysis (DEA). It addresses some of the shortcomings in the methodology suggested by M. Khouja, and presents a more robust analysis based on cross efficiencies in DEA. Although, this paper concentrates on a specific methodology with no apriori weights, extensions in DEA that account for a decision maker's input in technology selection are also addressed. Finally, the applicability of the methodology from both buyer and manufacturer view points is discussed.

Bard, J. F., R. Balachandra, et al. (1988). "An Interactive Approach to R&D Project Selection and Termination." IEEE Transactions on Engineering Management **35**(3): 139-146.

How well a firm manages its research and development (R&D) portfolio can be an important determinant of competitive advantage. The major drawback to previously devised quantitative techniques is due to failure to address adequately the qualitative aspects of R&D decisions. A methodology is proposed for evaluating both active and prospective projects that considers a full range of environmental, organizational, and technical concerns. The approach is interactive, building on 2 sets of critical factors. First, projects are screened to see if they are at an acceptable level, and if they are making reasonable progress toward completion. Those that fail the test are terminated, and the rest are weighed with candidate projects to see which should be included in the portfolio. The job is executed with a mathematical programming routine that maximizes expected returns. A case study focusing on a peripheral equipment maker demonstrates the methodology.

Bard, J. F. and A. Feinberg (1989). "A Two-Phase Methodology for Technology Selection and System Design." IEEE Transactions on Engineering Management **36**(1): 28-36.

A 2-phase methodology that can be used to guide research and development managers in the evaluation and selection of competing technologies is presented. In the first phase, a deterministic multiattribute utility theory is used to rank the technological alternatives and to eliminate inferior candidates. An application taken from a study centering on the evaluation of electric and hybrid passenger vehicles is used as an illustration. In all, 39 persons representing 8 different automotive interests were interviewed to assess their risk preference and attitudes toward the vehicle design. In the 2nd phase, a particular technology has been chosen, and the decision maker must allocate a fixed amount of resources to different projects to maximize a given measure of performance. The problem is formulated as a probabilistic network and solved heuristically using Monte Carlo simulation. Findings suggest that for each attribute at least one project is available for improving its value, and in some cases, an option exists for undertaking 2 or more.

Bhatia, S. (1992). Appropriate technology transfer: A must for improving global competitiveness. Portland International Conference on Management of Engineering and Technology - PICMET '91, Portland, Picmet.

The author describes the existing technology transfer methodology used in the major high technology industries and proposes a model of technology transfer that involves research groups' focus on different aspects of the product development cycle. A case study of a large development environment is discussed. Various levels of technology transfer methods employed for achieving a highly reliable product in a short development cycle--so that the opportunity window is not missed--are discussed. Some issues in selection of appropriate technology are discussed, and suggestions for improvements are provided.

Bordley, R. F. (1998). "R&D Project Selection Versus R&D Project Generation." IEEE Transactions on Engineering Management **45**(4): 407-413.

Much of the technical literature emphasizes R&D project selection. This paper reviews the author's experience with R&D project selection. In our view, this experience suggests that the emphasis should be on the genreation of high quality R&D projects through effective communication of corporate priorities, implementation issues, and related technical efforts.

Boylan, R., S. Walsh, et al. (1997). Key Success Factors Affecting Choice in an Emergent Technology Base, Portland, Picmet.

Micro-electro mechanical systems are projected to comprise a $15 billion market in the year 2000. Pacific Rim companies will produce 30% of these new products. Preliminary findings of a major field study report on issues including core competencies and a choice of technology bases from a field of up to seven competing technologies.

Cabral-Cardoso, C. and R. L. Payne (1996). "Instrumental and Supportive Use of Formal Selection Methods in R&D Project Selection." IEEE Transaction on Engineering Management **43**(4): 402-410.

Although a large body of literature exists about the use of formal selection techniques (FST) in the selection of research and development (R&D) projects most of it has focused on the instrumental use of the techniques and much scepticism exists about their value. Very little attention has been paid to the political or supportive use of the techniques, though project selection is often a political process. This study uses a two by two analytical framework combining these two forms of use. An empirical analysis of 149 individuals in 149 different companies describing 258 R&D selection decisions uses discriminant analysis to identify the determinants of the four different kinds of use at three levels of analysis: the individual, the project, and the organization. Considerable consistency is shown across levels and the importance of the supportive/political use of FST is emphasized.

Cbral-Cadoso, C. and R. L. Payne (1996). "Instrumental and Supportive Use of Formal Selection Methods in R&D Project Selection." IEEE Transactions on Engineering Management **43**(4): 402-410.

Although a large body of literature exists about the use of formal selection techniques (FST) in the selection of research and development (R&D) projects most of it has focused on the instrumental use of the techniques and much scepticism exists about their value. Very little attention has been paid to the political or supportive use of the techniques, though project selection is often a political process. This study used a two by two analytical framework combining these two forms of use. An empirical analysis of 149 individuals in 149 different companies describing 258 R&D selection decision uses discriminant analysis to identify the determinants of the four different kinds of use at three levels analysis: the individual, the project, and the organization. Considerable consistency is shown across levels and the importance of the supportive/ politcal use of FST is emphasized.

Charnes, A., W. W. Cooper, et al. (1955). "Optimal Estimation of Executive Compensation by Linear Programming." Management Science **1**(2): 138-151.

Chiu, C.-Y. and C. S. Park (1994). "Fuzzy cash flow analysis using present worth criterion." Engineering Economist **39**(2): 113-138.

In practice, engineering economic analysis involves uncertainty about future cash flows. To deal quantitatively with imprecision or uncertainty, fuzzy set theory is primarily concerned with vagueness in human thoughts and perceptions. As an alternative to conventional cash flow models where cash flows are defined as either crisp numbers or risky probability distributions, we propose an engineering economic decision model in which the uncertain cash flows and discount rates are specified as triangular fuzzy numbers. The present worth formulation of this fuzzy cash flow model is derived. The result of the present worth is also a fuzzy number with nonlinear membership function. The present worth can be approximated by a triangular fuzzy number. Deviation between exact present worth and its approximate form is examined. Finally, the fuzzy project selection is performed by applying different dominance rules. To demonstrate the application of the fuzzy present worth function, a comprehensive numerical example is presented.

Chu, P.-Y. V., Y.-L. Hsu, et al. (1996). "Decision support system for project portfolio selection." Comput Industry **32**(2): 141-149.

A decision support system (DSS) is developed to help managers select the most appropriate sequences of plans for product research and development (R & D) projects that have strict constraints on budget, time, and resources. The primary objective of the DSS is to provide an optimal combination of R & D projects. The DSS consists of several subsystems, each of which has a specific function. At the core of the DSS are a cost model, which covers time-cost tradeoff analysis, and a strategic selection algorithm, which, based on dynamic programming, provides an optimal development plan for managing R & D projects. A working board supports an interactive environment between managers and the DSS. A data checking system eliminates inconsistent data and plans in advance. This paper identifies key issues in the arrangement of R & D projects and describes various systems that have been interlinked to make the DSS a success. It also reveals that the DSS can be expanded to a decision support system shell to support similar types of problems.

Chun, Y. H. (1994). "Sequential Decisions under Uncertainty in the R&D Project Selection Problem." IEEE Transactions on Engineering Management **41**(4): 404-413.

In most cases, the research and development (R&D) project selection problem is concerned with how to evaluate and identify the best subset of projects under some resource constraints. An examination is made of the sequential decision problem of optimally sequencing a set of projects that must be undertaken sequentially over time. The optimal ordering strategy is derived for 2 special cases: 1. a series system of tasks in which the selection process is terminated as soon as one of the tasks is failed, and 2. a parallel system of alternatives in which the selection process continues until any of the alternatives is completed successfully. Further consideration is given to the precedence restriction in a series system of tasks that specifies that, for some technological or budgetary constraints, a certain task must be undertaken before another. In a parallel system of alternatives, an investigation is made of the availability condition under which a certain alternative will not be available if not selected within a certain period of time.

Cooper, M. J. (1978). "An Evaluation System for Project Selection." Research Management **21**: 29-33.

The author present scoring model for project selectin. The primary contribution of the paper is a systematic taxonomy of criteria that should be included in the model. Three main types of criteria are proposed: impct, feasibility, and research merit. Impact involves the extent to which the project is relavent to organizstion goals, is supported by higher authority or customers, and extent to which customer is involved in the project. Feasibility involves technological risk, the technical competence of the organization, and the effectiveness of management. Research merits involoves the extent to which the project presents an opportunity for good research, and the extent to which it enhances the researcher talents.

Cooper, R. G. (1981). "An Empirically Derived New Product Project Selection Model." IEEE Transactions on Engineering Management **28**(3): 54-61.

An empirically based screening model for new industrial product research and development (R & D) projects has been developed. The model differs from previous approaches in that the validity and weighting of the variables are based on field data. Development of the model was based on a survey of 103 industrial product firms, in which managers at each firm characterized an unsuccessful and a successful project according to 48 variables. Thirteen key factors were identified. The relationship between success and failure for each of the 13 factors was established through a multiple regression analysis. The analysis showed 7 of the factors to be especially strong indicators. These were: 1. product superiority and uniqueness, 2. project/company resource compatibility, 3. market need, growth and size, 4. economic disadvantages of the product, 5. newness of the firm, 6. technological resource compatibility, and 7. market competitiveness. The model was tested and showed an overall accuracy level of 84.1% and a mean error of 2.47. The model stresses that a new project must have a product or economic advantage to be successful. A unique product that is first to market does not always mean success.

Czajkowski, A. F. and S. Jones (1986). "Selecting Interrelated R&D Projects In Space Technology Planning." IEEE Transaction on Engineering Management **EM**(1): 17-24.

A decision support model and solution procedure are presented for selecting interrelated R&D projects in space technology planning. Technical and benefit interactions among projects are explicitly considered. The problem addressed is that of selecting among technologically enabling and value enhancing projects. A 0-1 integer programming model is formulated and a solution technique is presented that places technology project sets into two categories: 1) those the decision-maker should consider, and 2) those that are dominated by sets in the first category. Use of the model and

solution techniques is demonstrated in the context of a NASA case example pertaining to earth resources space programs. The efficiency of the model (with the solution technique) in reducing an unmanageably large number of feasible and efficient sets is demonstrated in the example problem.

Daim, T. (1997). A Review of Evaluation Attributes for Selecting Advanced Manufacturing Technologies. PICMET '97: Innovation in Technology Management: The Key to Global Leadership, Portland, Picmet.

This paper reviews the attributes used for selecting Advanced Manufacturing Technologies (AMT). The early studies consisted of either case studies or field surveys. Later, several researchers started to identify different impact areas. The attributes used were found to be grouped under three major impact areas: Technology, Organization and Market.

Dalkey, N. C. (1969). "The Delphi Method: An Experiment Study of Group Opinion." Rand Corp.: Res. Pap. RM-5888-PR.

Davies, G. B. and A. W. Pearson (1980). "Application of Some Group Problem-Solving Approaches to Project Selection In Research and Development." IEEE Transaction on Engineering Management **EM**(3): 66-73.

There are very few situations in practice where the selection problem is simply one of choosing one or more projects from a larger set of proposals which have been previously well defined. More often than not proposals are developed in the context of a need, and their characteristics modified as they are tested against the objectives which they have to meet. For such a process to be successful it must involve many people, and it has been found in practice that a number of the group problem-solving approaches described in the literature can be of considerable value for bringing out ideas, generating alternatives, identifying important parameters, and encouraging implementation. This paper describes how these different methods can be put together to form a flexible, but

systematic, method for project selection and illustrates the approach through the use of a simple example.

De Santiago, M., O. A. Iglesias, et al. (1986). "Optimal Technology Paths For Chemical Industry Production." Comput Chem Engineering **10**(5): 421-431.

A mathematical method is developed for selecting optimal technology paths for the production of a given amount of chemicals, using a set of feedstocks which are available in a limited quantity or not, and assuming that several alternative process technologies are accessible for transforming feedstocks into final products. From the superstructure of technology alternatives the optimal set is selected, with the objective function of minimizing annual cost or maximizing annual profit with a view to public or private interest.

Dias, O. P. (1988). "R & D Project Selection Problem With Fuzzy Coefficients." Fuzzy Sets System **26**(3): 299-316.

This paper deals with the multicriteria project selection problem subject to linear constraints, with zero-one decision variables. Linguistic rather than numerical values are used in the project appraisals for each criterion, with their meanings represented by normal fuzzy sets. The grade of membership of a given alternative, in the fuzzy set of all nondominated alternatives, is computed by an algorithm that converges rapidly on the final solution. Continuity and normality are the only restrictions imposed on the membership functions. An example of the overall procedure and topics for future research are presented.

Dowsland, W. B., D. Das, et al. (1981). "Project Selection Using a Learning Process." Chart Mechanicl Engineering **28**(2): 59-63.

The problem of selection between competing 'in-house projects' has received a great deal of attention recently, resulting in many project selection models and techniques. Often these do not take into account historical information, so on the basis of data supplied by a number of companies, a simulation model was developed for varying

the resources available at different project stages of the normal Discounted Cash Flow selection approach. Applying the model to data supplied by several companies shows that a significant improvement in profitability is possible if the selection procedure takes into account the type and complexity of the job involved as well as its financial status. This improvement results from the increased application of effort in the early stages of 'higher risk' projects to identify any factors which may lead to their failure.

Ezawa, K. J. and J. B. Scherer (1992). Technology management using computer-aided decision engineering tool. Portland International Conference on Management of Engineering and Technology - PICMET '91, Portland, Picmet.

A methodology is presented for the analysis and selection of research projects using a state-of-the-art, influence-diagram-based decision analysis software program, the Computer-Aided Decision Engineering Tool (CADET). The application of this methodology to the development of research project funding recommendation is reviewed and discussed. Decision analysis techniques and CADET are used to comparatively assess the potential commercial value of research projects that transform technological advances into development-ready technical capabilities for use in new products and services. CADET, which was developed for this task, provides a flexible, user-friendly environment for this analysis, and also incorporates an expert system-based front-end to assist new users. This methodology further facilitates the management of emerging technologies by increasing interaction and communication between research and marketing organizations.

Gaynor, G. H. (1988). Managing Technology - a Driving Force for the Future. The International Conference on Technology Management, Miami, Inderscience Enterprises Ltd.

The author proposes a definition of managing technology, suggests some specific requirements for implementation and focuses on the need for integrating the technical functions from research through manufacturing under a single management responsibility. Emphasis is placed on the strategic issues of managing technology, managing the use of technology, justifying investments in technology, selecting and evaluating projects, technology plans, reducing total project time and improving the performance of technical managers and professionals. The role of education in the process is discussed.

Gaynor, G. H. (1988). Selecting, Monitoring and Terminating Projects. the First International Conference on Technology Management., Miami, Inderscience Enterprises Ltd.

Recognizing and understanding the strategic critical issues related to managing technology is an essential ingredient for successful project management. Selecting appropriate projects that support the corporate strategis is the first and foremost decision. Industry has developed sophisticated techniques regarding the mechanics of project management. However, the data, the resultant soft information, the non-quantifiable aspects, and the judgments that provide the financial figures are far more important than the resulting answers. The author focuses on project selection, project monitoring, and project termination.

Giritli, H. (1984). Multiple-Objectives Decision Making Approach to the Choice Of Technology In the Construction Industry. The 4th International Symposium on Organization and Management of Construction, Waterloo, Ont.

The efficient use of resources should be regarded as the main determinant of the choice of technology for construction. It is also clear that each decision on the utilization of resources will have a consequential impact on technological decisions. This paper provides an objective tool which will be helpful to the problem of the choice of technology in the construction industry from the standpoint of resource utilization. The characteristics of the technology choice are examined, and then it is noted that a multi-objective methodology should be preferred for the proper selection of technology. A multi-objective decision-making approach is proposed, illustrating its application to the technology selection problem with two objectives.

Haddock, J. and T. A. Hartshorn (1989). "Decision support system for specific machine selection." Comput Ind Engineering **16**(2): 277-286.

This paper presents a decision support system (DSS) that assists in the specific selection of a machine that is required to process specific dimensions of a part. The selection will depend on part characteristics, which are labeled in a part code and correlated with machine specifications and qualifications. The choice of the optimal machine, vs possible alternates, can be made by a planner comparing a criterion measure (or measures). Examples of possible criteria are: the relative location of machines, machining cost, processing time, and availability of a machine (or machines).

Hajdasinski, M. M. (1995). "Remarks in the context of 'the case for a generalized net present value formula'." Engineering Economist **40**(2): 201-210.

In his 3 recent papers, R. G. Beaves (1988, 1989, 1993) develops an overall rate of return (ORR) project evaluation criterion based on the concept of the so-called transition point (TP) which he has defined in 2 different versions. In the present contribution, it is shown that some projects may produce undefined ORRs for either TP version, and that other ORR-like criteria may also generate undefined results for projects for which the net present value (NPV) criterion is defined. To eliminate the cases of the ORR undefinability, a generalization of the ORR criterion is proposed that makes this criterion fully NPV compatible and applicable to both investment and financing projects. This criterion embraces all the existing ORR approaches that are based on the notions of the initial and terminal wealths, including both of Beaves's approaches.

Hauser, C. A. (1993). "If I could do it all over again!" Annual International Conference Process American Product Inventory Control Society: 111-112.

Implementing a new information and planning system or making major changes to an existing one is a big job with many risks. However, when completed successfully it also can return enormous rewards. The risks can be greatly reduced with a good project plan executed by dedicated, well informed, educated personnel.

Heidenberger, K. (1996). "Dynamic project selection and funding under risk: a decision tree based MILP approach." European Journal of Operation Research **95**(2): 284-298.

This paper presents a mixed integer linear programming (MILP) model for a new class of dynamic project selection and funding problems under risk given multiple scarce resources of different qualifications. The underlying stochastic decision tree concept extends classical approaches mainly in that it adds a novel node type that allows for the continuous control of discrete branching probability distributions. The control functions are piecewise linear and are convex for the costs and concave for the benefits. The MILP-model has been embedded in a prototype Decision Support System (DSS). With respect to the proposed solution the DSS provides complete probability distributions for both costs and benefits.

Helin, A. F. and W. E. Souder (1974). "Experiments Test of a Q-sort Procedure for Prioritizing R&D Projects." IEEE Transaction on Engineering Management **EM-21**(4): 159-164.

Hetke, A. (1994). "Let the product drive the process. Part 1." Foundry Manage Technology **122**(9).

Product requirements drive both process technology and process selection. Probably the first challenge to any product engineer is to select the right process for a product. The goal is to pick a product or a process that meets technological and products requirements. That should be the dictate of the process selection. In order to intelligently pick the right process, an in-depth analysis of what the collective impacts of the casting process are on customer needs must be done.

Holt, G. D. (1996). "Applying cluster analysis to construction contractor classification." Build Environment **31**(6): 557-568.

The essential task of prequalifying contractors most often involves a large number of firms, each being represented by many disparate dimensions. Therefore, to effectively perform prequalification normally requires an inordinate amount of resource commitment by the construction owner. The statistical technique of cluster analysis (CA) could aid this decision process by classifying contractors into groups of like nature or common characteristics/ability. Further, the technique can identify the most discriminating criteria involved in achieving such classification and, thereby, help avoid subjective rejection of 'good' firms, when large numbers of contractors are being considered. Example applications of the CA method are presented, in a construction contractor prequalification scenario.

Iyigun, I. and Y. Tanes (1994). "Interactive project prioritization model implementation." IEEE International Engineering Management Conference: 212-217.

Arcelik A.S. is a leading home appliance manufacturer in Turkey. Changing position of Turkey and the market have led the organization to establish an R&D department at 1991. For effective utilization of R&D resources, a project prioritization and selection methodology has been developed. A weighted scoring model is selected as a base of methodology. The method is extended to provide the involvement of upper management by defining new criteria and an interactive decision process. During the development of model department managers contributed for the identification of criteria. Implementation of the methodology as well as difficulties, the solutions to them and organizational constraints are summarized.

Kachigan, S. K. (1991). Multivariate Statistical Analysis. New York, Radius Press.

Kangari, R. and L. T. Boyer (1981). "Project Selection under Risk." ASCE Journal of Construction Division **107**(4): 597-608.

Three methods for the selection of construction projects are presented including, weighted average cost of capital, portfolio approach, and market model approach. The weighted average cost of capital fails to consider the individual risk of projects, therefore modification is required. A new portfolio analysis and its implication in construction projects is presented. Standard deviation and expected value of net present value are considered to be an appropriate approach in portfolio analysis. Difficulty arises in evaluating the coefficient of correlation when the number of projects increases, and utility function of the decision maker that can be derived only under restricted conditions. The market model approach considers company, industry, and market related factors and in conjunction with experienced managerial judgment allows the most appropriate selection of projects. This model eliminated some of the difficulties of the portfolio approach.

Karger, D. W. (1985). "Non-Technical Considerations In Applied Research, Development, and Engineering Project Selection." American Society of Mechanical Engineer Paper.

Research directors, project managers, researchers, engineers, and other scientific personnel very often forget and/or ignore the overall objectives of their employer. In an industrial organization the ultimate objective is to 'make money' (profits) through the exploitation of results obtained in virtually all engineering and scientific projects. It means that the results must lead directly to producible, saleable and profitable products and/or services. In a governmental department or laboratory, the desired result usually is a superior and a usable (in a practical manner) weapon system or the improvement or enhancement of an existing system. Rather than 'making money', the desire of congress and most citizens is to get the 'largest bang for our dollars' as possible. Industrial considerations are emphasize and such discussion is based upon much personal experience in combination with research results obtained by analyzing computer data. Most of the observations have analogue observations in governmental situations.

Kennedy, W. F. and D. A. Plath (1994). "A return-based alternative to IRR evaluations." Healthcare Financial Management 48(3): 38-49.

A dilemma often faced by healthcare financial managers is whether to describe a potential investment project to organizational decisionmakers in terms of the projects' internal rates of return (IRR) or to use the net present value (NPV) method. The IRR represents an intuitively appealing method of measuring investment value, but a number of conceptual and methodological problems associated with IRR measurement would seem to argue the use of the NPV method. While the NPV measure is theoretically valid,

it lacks the intuitive appeal of the IRR in communicating the value of investment alternatives. The marginal return on invested capital (MRIC) method is a modified IRR measurement which alters the traditional calculation methodology used to produce the IRR. Using the MRIC measure avoids the multiple rates of return problem and eliminates the conflict in ranking mutually exclusive projects that are associated with return-based measures of project evaluation.

Khorramshahgol, R., H. Azani, et al. (1988). "An Integrated Approach to Project Evaluation and Selection." IEEE Transactions on Engineering Management **35**(4): 265-270.

Since effective project evaluation and selection require the incorporation of conflicting objectives of decision makers into decision models, many multicriteria decision-making (MCDM) methods have been developed. Goal programming (GP) is perhaps the oldest and most widely used; however, despite its advantages, one major drawback is that decision makers must specify their goals and priorities a priori. A goal programming model is thus formulated using information obtained from both the Delphi method, which evokes expert opinion, and analytic hierarchy process, which helps the decision makers prioritize and rank their objectives of alternatives in a complex and unstructured environment. After being outlined, the proposed model is applied to a fictitious bank. This example shows that the proposed method can help decision makers identify organizational objectives and priorities systematically, develop alternative projects to achieve those objectives, and allocate resources among projects.

Khouja, M. (1995). "The use of data envelopment analysis for technology selection." Computers & Industrial Engineering **28**(1): 123-132.

The range of manufacturing technologies available to firms has significantly increased in the past 20 years. A potential buyer of a technology such as machine tools, industrial robots, or flexible manufacturing systems is faced with many options in both performance and cost. A decision model for technology selection problems using a 2-phase procedure is proposed. In phase 1, data envelopment analysis is used to identify technologies that provide the best combinations of vendor specifications on the performance parameters of the technology. In phase 2, a multi-attribute decision making model is used to select a technology from those identified in phase 1. Unlike most other models for technology selection, this model takes into consideration the fact that the performance of a technology, as specified by its vendor, is often unobtainable in reality. The proposed model is illustrated using robot selection and is tested on an actual robot data set.

Kim, I. and C. Kim (1992). Comparison of Korean to western R&D: Project selection factors for new product development. Portland International Conference on Management of Engineering and Technology - PICMET '91, Portland, Picmet.

The factors that affected the success or failure of R&D projects for new industrial products in the past have been explored. The success and failure factors in Korea are shown to be different from those of western countries. An empirically based selection model of R&D projects is demonstrated. Factors and weights pertaining to the model are examined, and implications and guidelines on accomplishing R&D projects successfully in Korea are provided. The results indicate that the magnitude of the potential market is important for the success of R&D projects. However, the ease of market entry is not important to the success of the R&D projects. It is also observed that project/company resource compatibility is the most important factor.

Kim, K., K. Park, et al. (1997). "Matrix approach for telecommunications technology selection." Comput Ind Engineering **33**(3-4): 833-836.

Global competitive environment in telecommunications requires that the current R&D project selection process should be changed. This paper argues that quality function deployment(QFD) matrix that has been successfully used for drawing technologies from customer needs can be applied to the selection of telecommunications technologies. It describes the selection process by successive matrix handling. The steps to draw technology priority are detailed. Nominal measures, such as current company rating, competitor's ratings, planned level, improvement ratio, that are used for prioritizing customer needs in QFD matrix, cannot be directly applied to telecommunications. Instead, several new measures are devised to prioritize telecommunications services and to develop competitive benchmarks.

Kim, S. H. and K. Kang (1988). R&D Project Selection In Hong Kong, Korea and Japan. The International Conference on Technology Management, Miami, Inderscience Enterprises Ltd.

Growth of technology in small industries of a developing country is essential to the economy of the country. Due to the lack of resources in small industries, the selection of R&D projects must be carefully evaluated. This paper illustrates the important factors for the selection of Research and Development (R&D) projects, and their relationships to technology innovation in the Asian countries.

Kyparisis, G. J., S. K. Gupta, et al. (1996). "Project selection with discounted returns and multiple constraints." European Journal of Operation Research **94**(1): 87-96.

This paper considers the problem of selecting a subset of N projects subject to multiple resource constraints. The objective is to maximize the net present value of the total return, where the return from each project depends on its completion time and the previously implemented projects. It is observed that the optimal order (sequence) of projects does not depend on the particular subset of selected projects and hence the overall problem reduces to a multiconstraint nonlinear integer (0-1) problem. This problem can be solved optimally in pseudo-polynomial time using a dynamic programming method but the method is impractical except when the number of constraints, K, is very small. We therefore propose two heuristic methods which require O(N$+3$/K) and O(N$+4$/K) computations, respectively, and evaluate them computationally on 640 problems with up to 100 projects and up to 8 constraints. The results show that the best heuristic is on the average within 0.08% of the optimum for the single-constraint case and within 2.61% of the optimum for the multiconstraint case.

Lamb, M. C. and M. J. Gregory (1997). Industrial Concerns in Technology Selection. PICMET '97: Innovation in Technology Management: The Key to Global Leadership, Portland, Picmet.

Technology selection is very important in all technology-based companies. Most methodologies that have been developed to assist and improve this process have not been widely used. This paper uses the findings of a recent study to identify a set of design criteria for a practical and useful methodology.

Lee, J., S. Lee, et al. (1986). "R&D Project Selection: Behavior and Practice In a Newly Industrializing Country." IEEE Transaction on Engineering Management **EM**(3): 141-147.

An empirical study is presented on the practices of research and development (R&D) management with special emphasis on the project selection behavior in Korea. Based on a review of literature pertaining to the R&D project selection, a survey framework was first generated. The data were collected from 73 laboratories of Korean private companies through a structured questionnaire, via a mail survey supplemented by some telephone interviews. As expected, the usage of formal models in R&D project selection are considerably limited in Korea. The findings, however, suggest that the formal models utilized by the research laboratories are varied distinctively according to research types. Exploratory and supportive R&D projects are selected by using screening models, while high-risk, new business development projects are selected by using evaluation models. For the selection of exploratory and supportive R&D projects, the major decision makers are laboratory directors, and the important decision criteria are technical factors. On the other hand, the major decision makers for the high-risk new business development projects come from the top management of firms, and they consider the market factors important as well as strategic factors. Several aspects of idea generation and collection for the R&D project selection are also presented.

Liberatore, M. J. (1987). "An Extension of the Analytic Hierarchy Process for Industrial R&D Project Selection and Resource Allocation." IEEE Transactions on Engineering Management **34**(1): 12-18.

The research and development (R&D) project selection decision must address the allocation of resources to a set of proposals for scientific and engineering activities. The project selection and resource allocation process can be seen as a multiple-criteria decision-making problem within the context of the long-range and strategic planning process of an organization. The applicability of an extension of the Analytic Hierarchy Process (AHP) is explored for priority setting and resource allocation in the industrial R&D environment. An AHP modeling framework for the R&D project selection decision is developed and then linked to a spreadsheet model to assist in the ranking of a large number of project alternatives. Cost-benefit analysis and integer programming are performed to help in the resource allocation decision. The AHP is simple to use, and it can accommodate inconsistencies in human judgment. Using microcomputer-based software, such as Lotus 1-2-3 or Expert Choice, can form the basis of an expert support system for R&D project selection and resource allocation.

Lockett, A. G. and A. E. Gear (1973). "Representation and Analysis of Multi-Stage Problems in R&D." Management Science **19**(8): 947-960.

This article addressed the issue of multi-stage decision makine in R&D projects, a "project tree" is prepared. The author use NPV as the optimization criterion, but note that they chose it for expository purposes only. They do not recommend it as a superior to alternative.

Madey, G. R. and B. V. Dean (1985). "Strategic Planning for Investment in R&D Using Decision Analysis and Mathematical Programming." IEEE Transactions on Engineering Management **32**(2): 84-90.

Examination is made of the strategic planning and investments associated with research and development (R&D) project selection and budgeting within a division of an aerospace company. A multi-attribute model is presented that is employed in an R&D

planning environment characterized by considerable risks resulting from technological, economic, governmental, and market factors. Several forms of a multi-attribute utility objective function are maximized utilizing mathematical programming methods. Approximate techniques, including goal programming and compromise programming, are assessed and shown to produce results that are reasonably close to and require less computation than more exact methods. Solutions are employed to recommend to management an R&D portfolio that maximizes expected utility for the division.

Mathieu, R. G. and J. E. Gibson (1993). "Methodology for large-scale R & D planning based on cluster analysis." IEEE Transaction on Engineering Management **40**(3): 283-291.

This research is a description of a decision support approach to large-scale R & D planning. A quantitative model is used based on three analytical tools: 1) the interaction matrix, 2) hierarchical cluster analysis, and 3) the Boston Consulting Group (BCG) strategic planning matrix. Results of the model are used to determine the number of R & D program areas, the technological focus of each R & D program area, and the relative allocation of resources to the R & D program areas. Traditional optimization techniques for R & D planning often generate solutions without allowing for the judgment, experience, and insight of the decision maker(s). The decision support approach presented here supports, rather than replaces, the judgment of the R & D planner by using a graphic display of the relative position of technology clusters, and by using an interactive and iterative approach to problem solving. An application to R & D program planning for Virginia's Center for Innovative Technology's Commercial Space Program is presented.

Moore, J. R. and N. R. Baker (1969). "Computational Analysis of Scoring Models for R&D Project Selection." Management Science **16**: B212-B232.

Mukherjee, K. and A. Bera (1995). "Application of goal programming in project selection decision - A case study from the Indian coal mining industry." European Journal of Operation Research **82**(1): 18-25.

A methodological foundation for using the goal programming technique for solving the investment decision problem in coal mines is presented. A case study is developed of the Indian coal mining industry. The case study includes 4 goals for project selection: 1. capital investment required, 2. average cost of production, 3. annual profit, and 4. manpower requirement. The set of feasible project proposals includes both reconstruction and new mine projects. As the priorities of goals are not truly preemptive, a weighted goal programming model is developed applying a simple scaling method for normalization. An approach is demonstrated that integrates ratings from different executives and experts for computation of composite weights. In addition, various alternative case situations are identified that provide sufficient information for selecting the most appropriate capital investment plan.

Navarrete, N., Jr., M. Fukushima, et al. (1980). Qualitative Multicriteria Ranking Method For Project Selection. Bangkok, Asian Institute of Technology.

A new method is proposed for ranking alternatives which are evaluated with respect to multiple objectives under inexact and imprecise information. This method use linguistic valued variables for characterizing imprecise, fuzzy, and hardly quantifiable input information, particularly the subjective description of the consequences of the alternatives, the statements of relative importance of the criteria, and the expressions of preference over the consequences. Moreover, multilevel relations are utilized to reflect varying subjective degrees of risk both in assessing criterionwise preference relations. Due to the quantitative nature of the method and its minimal information requirements, this approach seem to be appropriate vehicle for problems where the decision maker can express his attitudes, values, and preference with ease and confidence only when his subjective perceptions are evaluated in some suitanle quantitative scales which he can effectively communicate, particularly during the exploratory and preliminary investigation stage of the project feasibility studies.

Navarrete, N. J., M. Fukushima, et al. (1979). "A New Ranking Method Based on Relative Position Estimate on Relative Position Estimate and Its Extension." IEEE Transaction on Systems **SMC-9**(11): 681-689.

Nelson, C. A. (1986). "Scoring Model For Flexible Manufacturing Systems Project Selection." European Journal of Operation Research **24**(3): 346-359.

This paper presents a method for identifying, evaluating, and prioritizing manufacturing modernization projects. The paper distinguishes between modernization, which contains significant uncertainty, and capital replacement which contains minimal risk. Extending classical capital budgeting analysis, which prioritizes capital replacement projects by the criterion of utility maximization, the model described herein addresses the complexities of non-economic criteria, project interdependence, and uncertainty. Exploiting results from risk-oriented R&D project selection literature, the model incorporates the scores of five additive terms: technology assessment, equipment evaluation, capacity elasticity, cost-budget analysis, and adjusted net present value.

Ranta, R. (1997). The Evaluation of the Performance, Economy, Ecology and Safety of Passenger Cars Using the Multi-Criteria Optimization Concept. PICMET '97: Innovation in Technology Management: The Key to Global Leadership, Portland, Picmet.

This paper deals with the utilization of the modern multi-criteria optimization method. The basic principles of theory are shortly presented. The evaluation is based on the historical development of the specified car utilities. The aim of evaluation is to show which kinds of cars contain a good combination of important utilities.

Romero, C. (1986). "A Survey of Generalized Goal Programming." European Journal of Operational Research **25**: 183-191.

Rushinek, A. and S. Rushinek (1991). "Product Evaluation and Selection System for Project Management Software." Comput Industry **16**(3): 289-301.

The selection of computer systems can be a frustrating process. The overall satisfaction derived from a system depends on matching system specifications to user needs. This case study describes a Product Evaluation and Selection System that correlates user needs to system specifications. This case illustrates the selection of project management software. A recommendation report ranks the software in descending order of their correlations to user needs. Implications for users, consultants and vendors are discussed and illustrated.

Saaty, R. W. (1987). "The Analytic Hierarchy Process-What It Is and How It Is Used." Mathematical Modeling **9**(3-5): 161-176.

The analytic hierarchy process (AHP) is a method to quantify physical and psychological events. There are three major principles in AHP: " decomposition of the problem, comparative judgements, and synthesis of priorities." The model is hierarchial in nature and contains many criteria for decision making. Once the hierarchal structure is established, pairwise comparisons are made between similar components. Th results of the pairwise comparisons generate a criteria matrix. By solving for the principal eigen vector of the matrix, the relative weights for each criteria are established. The process is repeated for the alternatives. In the end, a final normalized score is generated for each alternative. The final decision is based on this score. AHP has been applied to planning, resource allocation and conflict resolution. The author presents two examples using AHP.

Saaty describes the steps to follow in AHP:

1. Define the problem and specify the objectives
2. Structure a hierarchy of objectives from the top to the lowest
3. Construct a set of pairwise comparison matrices for each of the lower levels
4. Determine the consistency using the eigenvalue
5. Perform step 3 and 4 to all levels in the hierarchy
6. Use hierarchical composition to weigh the eigenvectors by the weights of criteria, and take sum over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.

7. Obtain the sum of the products of each consistency index with the composit priotity of its criterion and devide it by the sum of the products of the random consistency index for that size matrix with the composite priority of the corresponding. This ratio is the consistency of the entire hierarchy.

The beneifts of AHP is enable us to cope with the intuitive, the rational, and the irrational, all at the same time. It could be used to integrate our perceptions and purposes in to overall synthesis. And it does not require judgement to be consistent or transitive. Saaty states that consistency ration of 10 percent or less for hierarchy is acceptable.

Saber, H. M. and A. Ravindran (1993). "Nonlinear Goal Programming Theory and Practice: A Survey." Computer & Operations Research **20**(3): 275-291.

Four major approaches of Nonlinear Goal Programming are reviewed and discussed; (1) simplex based; (2) direct search; (3) gradient search and (4) interactive approaches. The applications of Nonlinear Goal Programming are also discussed and classified into the following nine areas: (1) engineering design; (2) energy; (3) manufacturing/metal cutting; (4) marketing; (5) finance and accounting; (6) agriculture/farm planning; (7) routing and scheduling; (8) quality control and (9) R&D project selection.

Salahor, G. (1998). "Implications of output price risk and operating leverage for the evaluation of petroleum development projects." Energy Journal **19**(1): 13-46.

This paper is the first in a series that describes how Modern Asset Pricing (MAP) may be used for project evaluation in the upstream petroleum industry. It shows how MAP methods can be used to value a project, if it is possible to split its cash-flows into two components: one for revenue and one for cost. Two design choices for a 'now or never' natural gas field development are used as examples of what can be gained by this type of approach to project evaluation. The first choice involves a tradeoff between capital and operating costs, while the second involves a tradeoff between costs and potential production rate. The results show that the use of standard DCF methods can

induce systematic, and possibly misleading, biases into the analyses that lie behind project design and selection.

Santhanam, R. and G. J. Kyparisis (1996). "Decision model for interdependent information system project selection." European Journal of Operation Research **89**(2): 380-399.

Existing methods for information system (IS) project selection neglect an important aspect of information technology, namely the interdependencies that exist among various IS applications (projects). Recognizing and modeling these project interdependencies provides valuable cost savings and greater benefits to organizations. In this paper, an IS project selection model is developed that identifies and models benefit, resource and technical interdependencies among candidate projects. The proposed model is formulated as a nonlinear 0-1 programming problem and represents a significant addition to existing IS, capital budgeting and R & D project selection models. The model is converted, using linearization techniques, and tested (validated) by applying it to real-world IS project selection data. By comparing the performance of this model with existing project selection models, the contribution of this model is highlighted.

Santhanam, R. and J. Kyparisis (1995). "A multiple criteria decision model for information system project selection." Computers & Operations Research **22**(8): 807-818.

It has been widely recognized that the selection of information system (IS) is a critical part of IS planning. Multiple factors that impact the decision to select an appropriate set of IS projects include project risk, corporate goals, benefits, the availability of scarce IS resources and the interdependencies that exist among candidate IS projects. Existing methods for IS project selection do not include all these criteria in one decision model. Project selection models in other disciplines, such as R&D and capital budgeting, are synthesized to develop an IS project selection model that explicitly incorporates all of these factors. The proposed model provides a method to take advantage of hardware and software sharing among IS applications. The decision model is formulated as a nonlinear 0-1 goal programming model and represents an improvement over currently available project selection models.

Scarso, E. (1997). Quantitative Methods for the Economic Appraisal of a New Technology: A Critical Review. PICMET '97: Innovation in Technology Management: The Key to Global Leadership, Portland, Picmet.

The decision to invest in new technologies is a crucial question of strategy which requires a careful economic analysis. This paper presents a critical review of the most prominent project evaluation techniques, with the aim of assessing their strengths and weaknesses when applied to the appraisal of technology opportunities.

Schmidt, R. L. (1993). "A Model for R & D project selection with combined benefit, outcome and resource interactions." IEEE Transaction on Engineering Management **40**(4): 403-410.

Capital budgeting of R & D projects is complicated by several types of interactions. Three types of interactions are generally recognized to occur within a set of projects: benefit interactions, resource interactions, and outcome interactions. This paper presents a model that accounts for the combined effect of benefit, outcome, and resource interactions within a single set of projects. The model also allows for the allocation of several different resources. A branch and bound algorithm is presented to solve the resulting nonlinear integer program with multiple quadratic constraints.

Schmidt, R. L. and J. R. Freeland (1992). "Recent progress in modeling R&D project-selection processes." IEEE Transaction on Engineering Management **39**(2): 189-201.

The authors review the progress that has been made in the development of quantitative models of R&D project-selection processes. Future research needs in the area are assessed. R&D project-selection has traditionally been modeled in the management science literature as a constrained optimization problem. The deficiencies of this approach have been described, and the need for new approaches has been recognized. In particular, the optimization approach ignores the organizational context in which

decisions are made. A new stream of research in R&D project-selection models emerged in the 1970s in response to this need. The philosophy underlying the new approach differs significantly from traditional optimization models. The new approach seeks insight rather than outcomes and focuses on the decision process.

Schwartz, S. L. and I. Vertinsky (1977). "Multi-Attribute Investment Decision: A Study of R&D Project Selection." Management Science **24**: 285-301.

This paper report a study in which executives of Canadian firms were given information about six attributes of 60 hypothetical projects, and ask to rate the probability that they would fund each project. A decision model was prepared for each responding executive. The study found that the high probability of funding was associated with shot payback period, high impact to market share, and high likelihood of receiving government funds.

Shamim Khan, M. (1994). "Managing R&D: Some Key Issues." IEEE International Engineering Management Conference: 135-141.

This paper discusses some of the key issues of R&D management including: importance of R&D, different R&D strategies, selection of R&D projects, interface between R&D and marketing, and methods for evaluating and improving the quality of R&D management. Particular emphasis is given to the management of R&D-marketing interface. Some of the issues that are addressed in the management of R&D-marketing interface are: causes of friction between R&D and marketing functions, and guidelines for achieving an effective integration between the two functions. It is summarized that U.S. industry should place more emphasis on R&D in order to regain its competitive edge. The decisions on R&D strategies and projects should be based upon thorough organizational resource analysis, and technical and marketing considerations. Finally, harmony at R&D-marketing interface is essential for the success of R&D projects.

Siha, S. (1993). "Decision model for selecting mutually exclusive alternative technologies." Comput Ind Engineering **24**(3): 459-475.

This paper describes a decision model framework for selecting appropriate manufacturing technology and attempts to integrate contributing factors that could affect and enhance the selection decision process. The contribution of this model is that it offers a structured approach to the difficult and complex task of technology selection. Further, the model is easy to manipulate and does not require a strong technical background. The proposed model provides a method for integrating tangible and intangible factors into one formulation and differentiates between two types of intangible factors, general and technological. Two software programs are used when implementing the selection

Simonovic, S. P., B. J. Lence, et al. (1995). Sustainability Criteria: An Application to The Hydropower Industry. The 22nd Annual Conference on Integrated Water Resources Planning for the 21st Century, Cambridge, ASCE.

This project determines key sustainability criteria that should be considered in the process of project selection. Sustainability, as used throughout this work, is defined as the ability to meet the needs of the present without compromising the needs of future generations. The key sustainability issues identified are formalized through the establishment of operational definitions for these issues. These definitions are in the form of sustainability measures, or metrics, that can be used to evaluate a given project. These measures are formally evaluated through their application to project selection for alternatives associated with the North Central Project, an electricity supply problem, in Manitoba, Canada. Results obtained from this evaluation may be used to subsequently refine and revise the sustainability measures that are derived.

Stahl, M. J. and A. M. Harrell (1983). "Identifying Operative Goals by Modeling Project Selection Decisions in Research and Development." IEEE Transactions on Engineering Management **30**(4): 223-228.

In an Air Force research and development laboratory structured around 4 divisions, Behavioral Decision Theory was used to identify operative goals as a method of organizational analysis. Six goals were used as criteria in a decision-making exercise in which 69 managers made decisions about hypothetical projects. During the course of the analysis, it became apparent through multiple regression analysis that 2 of the goals (technical merit and Air Force need) were emphasized by the decision makers and deemed operative goals. Together, these 2 goals accounted for 84% of the explainable variance associated with the project selection decisions reached by the participants, contrary to the general perceptions of the senior managers, who had viewed all 6 goals as operative goals of equal importance. The importance assigned to these 2 goals differed in each of the 4 divisions, and the senior managers felt this lack of consensus probably contributed to the conflict that had developed during Project Selection Board meetings.

Tavares, L. V. (1997). On The Assessment of Alternative Technologies for Project Management. PICMET '97: Innovation in Technology Management: The Key to Global Leadership, Portland, Picmet.

Project management is a central issue in the life of most private or public organizations. The selection of the most appropriate technologies is becoming a harder decision to make for several reasons: the spectrum of available technologies is much wider; the major attributes of alternative technologies may present high differences; and the use of out-sourcing solutions is more common. In this paper, a multi-criteria model is proposed to support the process of selecting technologies for project management.

Vepsalainen, A. P. J. and G. L. Lauro (1988). "Analysis of R&D Portfolio Strategies for Contract Competition." IEEE Transactions on Engineering Management **35**(3): 181-186.

In the competition for government and commercial contracts, firms allocate discretionary funds to research and development (R&D) projects to enhance the quality of prototype design. A portfolio model is utilized to characterize R&D projects in the areas of product quality requirements, customer demand, and competing technologies. The model solves priorities for the projects and helps in the estimation of the return on the R&D investment and the potential for sustainable competitive advantage. Using the analytic hierarchy process, subjective estimates of customers' preferences and competitors' technical capabilities are obtained. Earlier technology assessment methods are extended in 2 ways: 1. Multiple attributes of product quality and a firm's innovative

strength in respective technologies are viewed in aggregate. 2. Rational competitor strategies are obtained via simulation based on technological capabilities and R&D budgets. An example drawn from defense contracting illustrates the extensions.

Watts, K. M. and J. C. Higgins (1987). "The Use of Advance Management Technique in R&D." International Journal of Management Science **15**(1): 221-229.

White, B. (1990). "Capital budgeting and project selection on a microcomputer." Comput Ind Engineering **19**(1-4): 529-533.

Capital budgeting is an important function in most firms. Many times the process is loosely defined, and may not be correctly applied. Using a microcomputer to assist in the process can help by not only providing the computational horsepower, but by also insuring that the chosen procedure is correctly used to construct the capital list. This paper has described an approach that uses the internal rate of return criterion to construct a capital budgeting priority list. The program checks for multiple roots and resolves to a single root using an external reinvestment rate that is user specified. The program also allows for mutually exclusive alternatives, and correctly analyzes the incremental projects.

Winston, R. E. (1995). "Rapid method for capital investment decisions." Cost Engineering **37**(4): 41-43.

A simplified method allows ranking proposed capital projects, based on profitability as measured by net present value, before extensive engineering work is done. Engineers with or without financial analysis skills can use equations suitable for use on a calculator or PC to make a rapid, preliminary economic project evaluation. This allows early evaluation of an idea for a new project, before much time is wasted on an unjustified project. Frequently, when making bid comparisons for mechanical equipment such as pumps, compressors, and motors, the equipment being bid on by various vendors will differ in efficiency. These curves and equations are also suitable for determining how much additional capital is justified to obtain some measurable benefit, i.e. higher efficiency. This will save fuel, electric power, additional distillation trays, or packing to reduce reflux. Details are provided.

Young, E. A. (1993). "Guiding technology development and transition into products responsive to end-user needs." IEEE Aerospace Electronic System Manufacturing **8**(8): 10-13.

The goal of technology selection, development and transition is to efficaciously provide competitive new product systems that answer broad end-user needs in the world market. The many factors influencing technology selection and funding must be sorted to align both evolutionary and revolutionary technology developments with new products and end-user needs. Starting with general market needs, technology concept potential, feasibility and limit research there are tools available to guide future product planning, and supply the basis for technology development decisions incorporating broad business essentials. The Military Acquisition Process or the GEAE Engine Development Cycle used with QFD approaches select and guide technology development to fit requirements. The GEAE Process Development Process (PDP) can serve as a guide to the whole technology development process from concept to production.

Zeng, G. (1997). Accurate Evaluation and Improvement for Operational Efficiency of Mineral Transportation Systems. PICMET '97: Innovation in Technology Management: The Key to Global Leadership, Portland, Picmet.

The paper presents a combined simulation, network, and optimization model to develop a decision support system for the mineral transportation decision. It applies Data Envelopment Analysis (DEA) method and models to evaluate and improve the operational efficiency of the transportation system. The paper also states their application in special mineral transportation systems.