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Decision Support for Portfolio Problems

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Abstract

Many decisions must consider multiple, generally conflicting, decision objectives. And many decisions require not a single solution alternative, but a set or portfolio of alternatives. A business will generally produce a portfolio of products. Government will raise revenue through a portfolio of taxes. A prospective college student is wise to apply to a mix of schools, increasing the likelihood of at least one acceptance. A project team leader needs to select several team members, creating a balance of skills and taking into account the synergy of the team. While the single solution alternative decision problem has been widely studied and many solution approaches and decision support systems have been developed, the portfolio problem has been largely neglected. Specific problem environments have been discussed using heuristic, ad hoc methods, but no general methodology has been developed. This research focuses on identifying the characteristics of portfolio problem, on developing theoretical concepts and formal models to be used in identifying problem types in real world decision environments, and on mapping possible solution techniques to these models.

Keywords: Portfolio selection, decision making, decision support system

Introduction

Typically, decisions are based on a multitude of often conflicting decision criteria. A solution is sought that provides the best compromise with respect to these criteria. *Multi-criteria decision making* has become an established field of research, with extensive theory, a wide choice of solution methods, and many available computer-based decision support packages (see, for example, Weistroffer and Narula, 1997). However, there are many decision settings that require a set of solutions, i.e. a portfolio, rather than a single best compromise. Examples include the selection of an investment portfolio, choosing colleges to apply to for graduating high school seniors, deciding on whom to include on a team, etc. Rather than picking a best single investment option, a portfolio is desired that balances security with expected payoff. College applications should include schools that are most desirable as well as schools that are likely to accept. Building a team requires a balance of players with various skills.

There is an abundance of literature on financial investment portfolio selection (e.g. Markowitz, 1952; Elton and Gruber, 1995; Ballestero and Romero, 1996), as well as on research and development (R&D) project selection (e.g., Golabi, 1984; Stewart, 1991; Henig and Katz, 1996). However, most of these publications discuss very specific decision situations and suggest very specific solution methods, usually based on heuristics, and cannot easily be generalized. No well developed theory on solving portfolio decision problems exists, and there are few decision support software packages that specifically address these type of problems.

The Portfolio Decision Problem

The portfolio selection problem adds an extra dimension of complexity to the ordinary multi-criteria decision problem. Instead of seeking a single solution that maximizes the overall utility, a portfolio of solutions is required. Intuitively, one might want to approach this by solving the multi-criteria problem repeatedly, seeking the top *n* choices to constitute the portfolio. Unfortunately, this approach does not usually result in the most desired portfolio. For example, when a university department is hiring not one new faculty member, but rather needs to fill a number (n) of positions, picking the n top candidates may result in an imbalance of teaching or research specialties covered. The value of each candidate is dependent on the other selected candidates. The overall

best candidate may not even be included in the overall best portfolio, if two medium rated candidates have a higher combined value than picking the top candidate together with his/her best complimentary candidate.

The utility attached to the solution alternatives is not additive, that is, the utility of the portfolio cannot, in general, be expressed as a sum of individual alternative utilities. The synergistic effects of the portfolio must be considered.

To further complicate matters, the number of alternatives in the portfolio may be variable, and picking a portfolio with a fixed number of members constitutes an important special case. For example, suppose an automotive manufacturer decides to develop several new auto engines, to meet the different demands of its customer base. The number of engines in the portfolio is itself an important attribute of the portfolio that needs to be evaluated. A large number of different engines will likely satisfy a greater contingent of customers, but having fewer products reduces production costs.

Characteristics of Portfolio Problems

What we have illustrated above is that when solving portfolio problems, in addition to the existing decision problem attributes, such as perhaps research potential and teaching ability for a new faculty member, or engine power and fuel consumption for designing an auto engine, there are additional portfolio attributes that need to be considered. To exemplify portfolio decision problems, it may be necessary to identify these attributes. These portfolio attributes characterize the type of dependencies that exist between the members of the portfolio.

Generally, the dependencies among alternatives may be classified into three types:

Additive – All dependencies can be modeled as constraints, such as "mutually exclusive". The portfolio objective functions are additive with respect to the corresponding alternative attributes. Such problems could be solved using existing multi-criteria decision support systems.

Multiplicative – One or more dependencies can be modeled by multiplicative interaction terms in the portfolio objective functions. This is one way of representing synergistic effects existing among alternatives. The multiplicative dependency can also handle portfolio objectives such as probability of success.

Complex – If a dependency exists that cannot be modeled by either of the options specified above, one has a complex dependency. Such dependencies can involve portfolio attributes that are not properties of individual alternatives. These include ideas such as balance or variety in the portfolio. The portfolio objective functions may have mathematical expressions or exist on a subjective scale.

Different portfolio decision problem application areas exhibit different typical attributes and thus different kinds of dependencies. Therefore, different solution approaches may be necessary for these different types of problems. On the other hand, portfolio decision problems with similar dependencies and similar portfolio attributes may be approached by the same solution methods (even if the application area is different). Therefore classification of portfolio decision problems becomes important. A preliminary list of portfolio problems that we have identified and possible attributes are shown in Table 1.

Table 1. Characteristic Portfolio Problem Attributes

Problem Type	Attributes
Financial investment	expected return risk spread
College selection	expected return (best college that will accept) risk spread (likelihood of not being accepted to satisfactory college)
Team selection	skill coverage backup coverage team play ability (ability to work together)
Meal composition	nutrition balance cost taste appeal
Project selection	expected return (return on investment) risk avoidance (likelihood of any project failing) resource utilization political acceptability

Product design	consumer demand fulfillment (similar to skill coverage)
	cost
	expected return (expected market share)

Solution Approaches to Portfolio Problems

A general framework for solving portfolio decision problems, loosely based on one proposed by Ghasemzadeh and Archer (2000) is shown in table 2.

Table 2. Solution Framework

Phases	Steps	Activities
preliminary activities	1. pre-screen alternatives	check for compliance with general objectives
	2. perform individual analysis	determine individual criteria measures
	3. screen alternatives	check for compliance with individual constraints
portfolio selection	4. select optimal portfolio	use appropriate method to select a portfolio
	5. adjust portfolio	reexamine general objectives and chosen portfolio, and if necessary make adjustments

Besides requiring appropriate decision models to put the five steps of this framework in a proper context, we also need specific selection methods (preferably implemented in DSS packages) to execute the fourth and fifth steps. As we stated earlier, most published papers lack a clear theoretical foundation, and concentrate on solving a very specific problem using heuristic methods.

A preliminary review and classification of publications proposing the solution of portfolio type problems is shown in table 3.

Table 3. Portfolio Selection Publications

Paper	Area	Objectives	Technique	Other
Santhanam & Kyparisis, 1995	IS project selection	benefits, risk, costs	non-linear 0-1 goal programming	$\sum_{i=1}^{N} b_i x_i + \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} b_{ij} x_i x_j + \sum_{i=1}^{N-2} \sum_{j=i+1}^{N-1} \sum_{k=j+1}^{N} b_{ijk} x_i x_j x_k$
Chien & Sainfort, 1998	evaluating desirability of meals	meal color variety, texture variety, presentation appeal, diversity of preparation methods, flavor	multi-attribute decision analysis	construction of desirability scales and multi-attribute value function; used Bayesian approach for flavor desirability scale; tested constructed desirability scales vs. experts
Mehrez & Sinuany-Stern, 1983a	project selection		interactive approach terminated by decision maker satisfaction	sequence of 0-1 programs insure only maximal feasible sets are presented; no explicitly defined objective functions; direct utility assessment on sets by decision maker
Ghasemzadeh & Archer, 2000	project selection		collapses to single objective with weighted value function.	solves single objective 0-1 linear program; only deals with the "portfolio" characteristics through constraints; includes the timing of the project's start in the variable definition; empirical study with undergrads using small problems
Fox et al., 1984	R & D project selection		quadratic integer programming	implicitly treats present value interactions arriving at a binary quadratic integer program
Chang et. al., 2000	financial portfolio optimization	mean, variance	mixed-integer nonlinear programming	heuristic algorithms (GA, tabu search, simulated annealing); discontinuous efficient frontier with these constraints; approach independent of type of objective function
Golabi, 1985	R & D projects	overall technical quality	MAUT, integer programming	technical quality composed of many attributes, but reduced to one via MAUT; other factors handled by constraints; proposals address different components of system (i.e., non-homogeneous)
Mehrez & Sinuany-Stern, 1983b	project selection	utility	MAUT, integer programming	linear if additive utility model, nonlinear if multiplicative utility model; each project has probability of success independent of others; more is better, i.e., adding a project can only improve utility

Future Work

Future work includes a more comprehensive review of publications that propose the solution of portfolio type problems, and the classification of these publications according to the following criteria:

1. Application area (e.g. project selection)
2. Size of portfolio (fixed or variable)
3. Type of decision variables (continuous decision variables vs. finite number of alternatives)
4. Type of dependencies (additive, multiplicative, or complex)
5. Portfolio attributes (defining the type of synergy between alternatives in the portfolio)
6. Special constraints
7. Solution approach (summary and known methods or tools used)

Such a classification may allow us to generalize solution approaches to a number of representative types of portfolio problems, and also will show where particular need exists to develop further solution techniques.

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