December 2003

An Object-Oriented Model of the Portfolio Selection Problem

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Abstract

Most 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, including some with high likelihood of 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 attempts to develop a comprehensive model of the portfolio problem using an object oriented approach. The object-oriented approach will allow future research to focus on and further develop individual pieces of the model, without loss of overview and integration.

Keywords: Portfolio selection, object-oriented, multi-criteria, decision support system

Introduction

Most decisions involve satisfying multiple objectives. An alternative is chosen based on a multitude of often conflicting decision criteria. A solution is sought that provides the best compromise with respect to optimizing these various desired objectives. Multi-criteria decision making, in the last twenty years, 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 alternatives to be selected, rather than a single alternative. Examples include deciding on an investment portfolio, choosing colleges to apply to for graduating high school seniors, selecting members on a team, etc. Rather than selecting a best single investment option, a portfolio is desired that balances security with expected payoff. College applications should include schools that are most desirable and schools that are most likely to accept. Selecting members on a team requires a balance of players with various skills, as well as ensuring teamwork among the members. Thus in each of these situations, one cannot simply find the top x choices to constitute the portfolio or team, but rather the dependencies between the various selected individual alternatives must be taken into account. The utility attached to the 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.

Literature on financial investment portfolio selection (e.g. Markowitz 1952, Elton and Gruber 1995, Ballestero and Romero 1996), as well as on R&D project selection (e.g. Golabi 1984, Stewart 1991, Henig and Katz 1996) is abundant. However, most of these publications do not address generalized mappings of solution methodologies to general portfolio problem types. Most published papers discuss very specific problem types or decision situations and very specific solutions, usually based on heuristics, and cannot easily be generalized. In addition, many specific techniques that have been proposed in the literature are not widely used because they tend to be too complex, do not address all relevant issues associated with portfolio selection, require too much input data, or may be too difficult to understand for decision makers to use (Ghasemzadeh and Archer 2000). According to Hess (1993) "management science has failed altogether to implement project selection models". Weistroffer and Smith (2002) looked at theoretical concepts and formal models that could be used in identifying portfolio problem types in real world decision environments, and on mapping possible solution techniques to these models. The current study builds on their work, in constructing a comprehensive, object-oriented model of the portfolio problem.

Problem Description

The general multi-criteria decision making (MCDM) problem (see for example Steuer 1986) involves a set of feasible decisions or possible actions, and a set of corresponding solutions or outcomes. The complexity arises from the reality that the outcomes are measured with respect to multiple criteria or objectives, and usually none of the outcomes will be optimum with respect to all of the criteria. Thus compromise solutions that are acceptable to the decision makers are sought. An example of a MCDM problem might be designing a new auto engine. The decision domain would include all possible combinations of, say, quality of material used, engine capacity, etc. The solution domain would include corresponding decision outcomes with respect to fuel efficiency, engine power, construction cost, durability, etc. Ideally, we would like an engine to be fuel efficient (i.e. minimize fuel consumption), be powerful (i.e. maximize horse power), be reliable (i.e. maximize durability), and cheap to build (i.e. minimize cost). However, maximizing horse power and durability would likely result in less than optimum fuel consumption and cost.

An important special case of the MCDM problem is the multi-attribute decision making (MADM) problem, where the decision domain is a discrete set of solution alternatives. An example of a MADM problem would be selecting a candidate from a pool of new faculty applicants. The alternatives would be the set of applicants, each of whom would be evaluated based on multiple attributes, such as which courses the person would be able to teach, potential scholarship output, etc. The likelihood that one candidate would be optimum with respect to all attributes is slim.

The portfolio selection problem adds another dimension of complexity. Instead of seeking a single alternative that maximizes the overall utility, a set of alternatives, i.e. a portfolio is required. An example of such a portfolio selection problem may arise when a university department is hiring not one new faculty member, but rather needs to fill a fixed number (n) of positions. The intuitive approach is to rank all candidates and pick the n top ranked ones. However, this may not be a good strategy. For example, in order to cover all the various courses taught in the department, picking candidate **X** may very well make some other otherwise highly ranked candidate become less desirable, if that person's course specialties overlap with candidate **X**'s specialties. The value of each candidate is dependent on the other selected candidates. It may not even be best to include the highest ranked candidate out of the candidate pool. It is possible that two medium rated candidates have a higher combined value than picking the top candidate together with his/her best complementary candidate. This eliminates sequentially selecting the top candidates as a general strategy.

To complicate matters further, n, the number of alternatives in the portfolio may be variable, and n equal constant constitutes an important special case.

Revisiting the engine design problem, suppose the company decides to build several new engines, to meet the different demands of its customer base. The problem now becomes one of finding a portfolio of different engines that are not only measured on the criteria mentioned earlier, but also on the extent to which customer needs or desires are fulfilled. This may be a case where n is variable. On the one hand, a large number of different engines will likely satisfy a greater contingent of customers. But on the other hand, having fewer products reduces production costs.

Figure 1 illustrates a general portfolio using unified modeling language (UML) notation. The rectangular boxes represent object classes, and the connecting line represents an *association*. The hollow diamond indicates that the association is an *aggregation* or "part of" relationship. Numbers or asterisks next to the association are *multiplicities*; they indicate how many objects in one class are related to how many objects in the other class. Thus a portfolio has one or more alternatives, and each alternative can be part of zero, one, or more portfolios. Object classes have attributes that can be shown in the middle compartment of the rectangle. The bottom compartment is to show object behaviors, if desired.

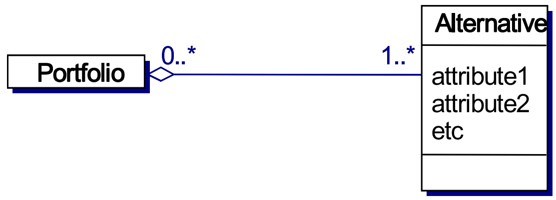

Figure 1. General Portfolio

Figure 2 shows an example portfolio for the faculty selection problem. Each portfolio has n candidates, who are evaluated on teaching quality, scholarship quality, department fit. Also, each candidate has zero or more publications, and each candidate has one or more teaching areas (publication and teaching area are a "part of" each candidate).

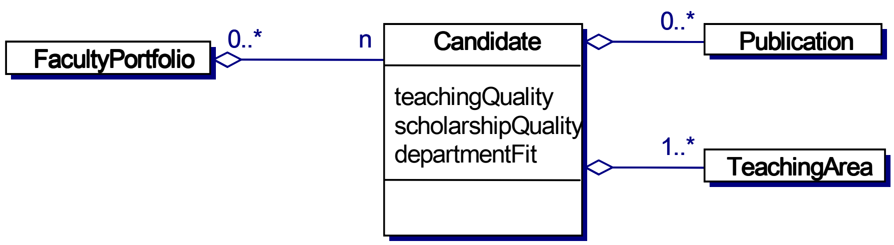

Figure 2. Faculty Selection Problem

Figure 3 shows the auto engine portfolio example mentioned above. Unlike in the faculty selection problem, where the number of members of the portfolio is fixed (the university authorized hiring n new faculty members), in the engine portfolio problem the number of members in the portfolio is open, and influences the values of the portfolio attributes "demand coverage" and "production cost".

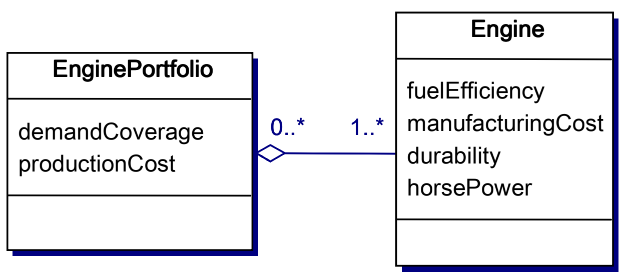

Figure 3. Auto Engine Portfolio

Decision Model Approaches

The above two examples of portfolio selection problems show one possible classification of such problems: fixed number of members in the portfolio versus variable number. Other factors that distinguish different types of portfolio problems include continuous decision variables (as in MCDM) resulting in possibly infinitely large decision alternative sets, versus a finite set of decision alternatives (as in MADM), resulting in a finite (though possibly very large) set of potential portfolios. Further, the dependencies between alternatives may have different consequences. For example, when building a team (whether a sports team or perhaps an IS development team), it is not only the individual capabilities of team members that should be taken into account, but also the synergistic effects derived from people being able to work together, i.e. the total being greater than the sum of the parts. On the other hand, when constructing a portfolio of investments, there is no synergistic or team effect, but rather the goal is reduction of risk.

Many special cases of the portfolio problem exist, often represented through constraints. For example, when hiring multiple new faculty members, constraints might be that one new hire must be at the assistant professor level and one at a senior level. Such constraints may limit the solution space of feasible portfolios considerably and thus make the selection easier. As mentioned earlier in this paper, many proposed solution techniques were designed for such special cases. Looking at all possible theoretical situations based on constraints is not really feasible; however, a classification with respect to such constraints might be useful if one can determine the most common types of real world decision situations. In other words, develop a number of representative model situations that cover many of the real world problems, such as the financial investment portfolio problem, the college selection problem, the team selection problem, the meal composition problem, the R&D project selection problem, etc. Many of these, though, will have multiple versions, complicating matters further.

Figure 4 illustrates these decision model classifications using UML notation. It shows three attributes that characterize the general portfolio problem, **cardinality** (fixed size or variable size portfolio), **alternatives type** (continuous variables or discrete alternatives), and **dependency type** (e.g. synergistic dependency or risk aversion). The connecting lines with the triangular arrow head indicate *subclass*, or "is a kind of" relationships. Product design, financial investment, college selection, team selection, research and development project selection, and meal composition all are types of portfolio problems. Other kinds of portfolio problems (subclasses) may be added to this model. Going back to our earlier examples of a faculty hiring portfolio and an auto engine portfolio, these can be viewed as examples of team selection and product design, respectively.

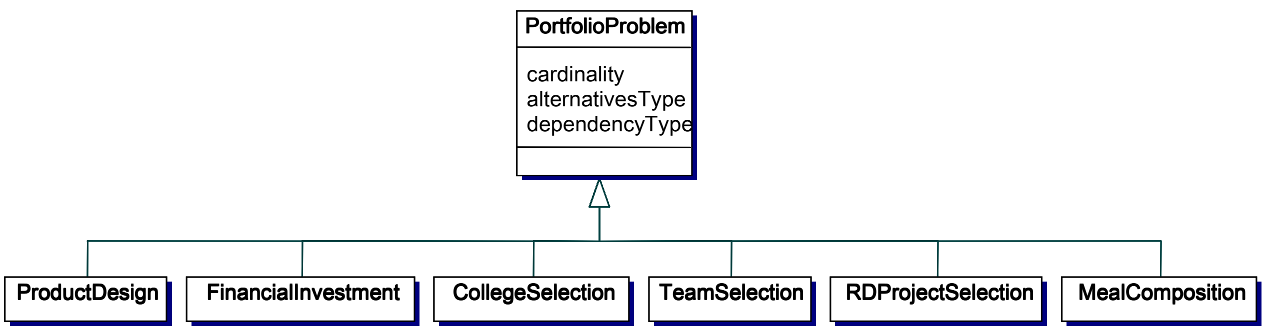

Figure 4. Classification of Portfolio Problems

Process Framework

In the above we focused on modeling the static aspects of the decision problems. Other researchers have maintained that a framework for portfolio selection should be considered a process that includes specific steps. The following framework is loosely based on that proposed by Ghasemzadeh and Archer (2000):

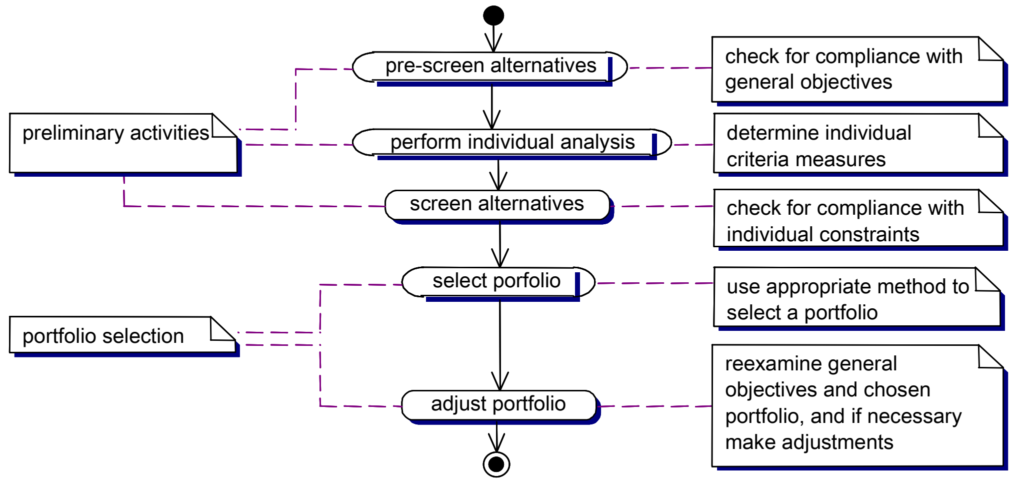

Figure 5. Portfolio Selection Process Framework

These activities can be incorporated into our UML model as behaviors of the portfolio problem, i.e. things that are done in a portfolio problem. This is shown in Figure 6.

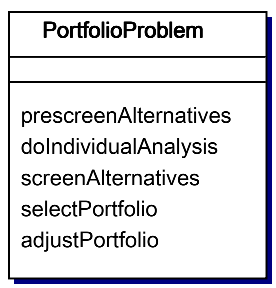

Figure 6. Portfolio Problem Behaviors

The Object-Oriented Approach

As indicated earlier, the advantage of the object-oriented approach in modeling the portfolio selection problem is that it allows us to develop each component (object class) separately in more detail, as well as add more components to the model, without disturbing the overall framework. Figure 7 shows what we have done above as a single diagram, with some possible additional aggregation classes, and with possible attributes and behaviors added to some of the classes.

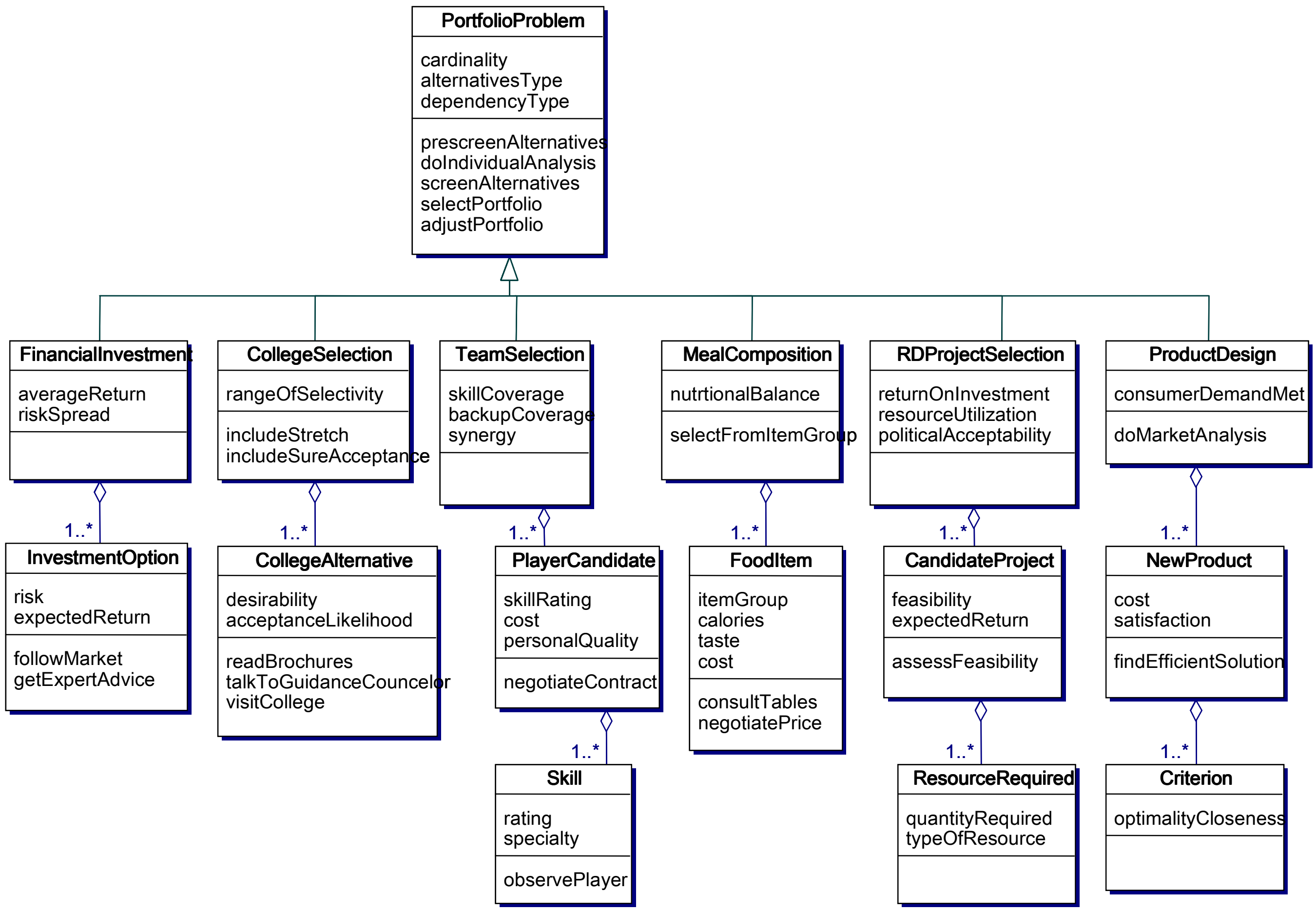

Figure 7. Possible Detailed Portfolio Problem Model

Each of the classes in Figure 7 can be analyzed individually. Specific solution methods for portfolio problem types can be included as behaviors of those subclasses, and their underlying algorithms can be described individually using separate models, such as activity diagrams, which is part of UML notation. If more than one method has been suggested for a specific problem type, this type can be further subdivided, or the various solution techniques can be included in another aggregation class of that subclass, as shown in Figure 8.

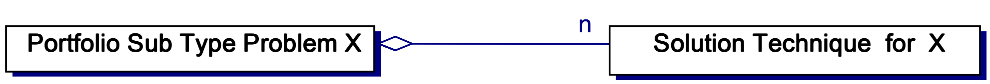

Figure 8. Multiple Solution Techniques

Implications and Conclusion

What we did so far is create a rough framework for the portfolio selection problem, using object-oriented notation. The development of the framework is still in progress. The proposed sub-types of portfolio problems need to be examined as to how well they represent the most important problem types encountered in the real world. Other subtypes may need to be added. Further, each sub-type needs to be examined as to appropriate characteristics (attributes and aggregation classes) and already existing solution methods, as proposed in the literature.

The object-oriented approach has the advantage that it allows adding or modifying individual components (object classes) while keeping within the already developed framework. Once this framework achieves a sufficient level of completeness (the whole idea of the object-oriented approach is that it will allow the framework to continue to grow and evolve, thus it may never be complete), it should help direct the attention of future researchers to those areas in portfolio selection that are most in need of further development with respect to effective solution techniques and user friendly decision support systems. Further, it should allow practitioners that need to solve portfolio problems to identify the specific type of problem they are dealing with, and direct them to already published solution techniques that work for their type of problem.

References

Ballestero, E., and Romero, C. "Portfolio Selection: A Compromise Approach," Journal of the Operational Research Society (47), 1996, pp. 1377-1386.

Elton, E.J., and Gruber, M.J. Modern Portfolio Theory and Investment Analysis, New York: Wiley, 1995.

Ghasemzadeh, F., and Archer, N.P. "Project Portfolio Selection through Decision Support," Decision Support Systems (29), 2000, pp. 73-88.

Golabi, K. "Selecting a Portfolio of Nonhomogenous R&D Proposals," European Journal of Operational Research (21), 1984, pp. 347-357.

Henig, M.I., and Katz, H. "R&D Project Selection: A Decision Process Approach," Journal of Multi-Criteria Decision Analysis (5), 1996, pp. 169-177.

Hess, S.W. "Swinging on the Branch of a Tree: Project Selection Applications," Interfaces (23:6), 1993, pp. 5-12.

Markowitz, H.M. "Portfolio Selection," Journal of Finance (7), 1952, pp. 77-91.

Steuer, R.E. Multiple Criteria Optimization: Theory, Computation, and Application. New York: Wiley, 1986.

Stewart, T.J. "A Multi-Criteria Decision Support System for R&D Project Selection," Journal of the Operational Research Society (42:1), 1991, pp. 17-26.

Weistroffer, H.R., and Narula, S.C. "The State of Multiple Criteria Decision Support Software." Annals of Operations Research (72), 1997, pp. 299-313.

Weistroffer, H.R., and Smith, C.H. "Decision Support Models for Portfolio Selection," Proceedings of the Eighth Americas Conference on Information Systems, August 9-11, 2002, Dallas, Texas.