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Dr. Custos, Dr. Opponent, Ladies and Gentleman

In any organization, there are more uses for recourses than there are resources available. Examples of such uses are development projects, infrastructure investments, maintenance activities, and conservation of forest sites, just to name a few. Common to these uses, referred to here with the generic term project, is that they consume resources and are thus expected to deliver value. The basic decision to be made is clear enough: which of the project candidates should be chosen so that the group of selected projects, that is a portfolio, offers the best possible value with the resources used?

Defining portfolio value is not a straightforward task for two reasons. First, the performance of a portfolio is often measured with regard to several value criteria, which calls for methods to combine these criterion specific values into an overall value. Second, if the projects values are highly uncertain, it is also important to minimize the risk of low portfolio value. Already in the 1950s Harry Markowitz, who later received the Nobel price in economics, identified portfolio diversification as a tool to minimize risks when investing in market traded financial assets, such as stocks. Diversification can be used in the project portfolio context too if external uncertainties, say oil price for instance, affect the values of several projects: A balanced combination of projects that benefit from high oil prices and projects that benefit from low oil prices hedges against the uncertain oil price and thus minimizes the risk of low portfolio value.

Decision Analysis helps the decision maker to systematically consider her evaluations and preferences on multiple value criteria and risk, and to quantify them as parameters in a mathematical model that provides decision recommendations. For instance, these parameters may correspond to probabilities for scenarios capturing uncertainties, importance weights for the value criteria or the criterion specific values of the decision alternatives.

Decision analysis dates back to the utility theory developed by von Neumann and Morgenstern in the 1940s and is fundamentally a prescriptive theory: it does not aim to describe how decisions are made or to forecast which choices an individual makes in a certain decision settings. Instead it derives the decision behavior of an idealized rational person that is characterized by a set of rationality axioms. Decision analysis methods help us to mimic this rational decision maker by offering decision recommendations that are based on treating the evaluations, preference statements and available data in a manner that is consistent with the rationality axioms.

Whether or not we want to follow the recommendations given by a decision analytic model in our personal decision making is thus ultimately a question of whether or not we accept the axioms of rationality. I, for one, do, but admit that most people succeed in life by making decisions with out any knowledge of Decision Analysis. However, decision makers acting in organizations are often obligated to make well-grounded and defensible decisions. Since decisions are always made in face of uncertainty, the quality of a decision cannot in all intellectual honesty be evaluated ex post, that is, after the realizations of uncertainties are known. Rather, the emphasis should be put on evaluating the quality of the decision making process, namely, does it transform the information that is available at the time of making the decision into decision recommendations in a transparent, rational and logical matter. Prescriptive decision analytical models offer a basis for building such decision making processes.

The prescriptive roots of decision analysis do not suggest that the methods should be developed in isolation from practice. Quite the opposite, the methodological development has benefited extensively from experiences from applications. One such finding is that although decision analysis in its purest from builds on transforming the decision maker's preferences and evaluations into precise numerical parameter estimates, the information elicited from the decision maker is often imprecise. This has lead to the development of methods that capture and model incomplete information about the model parameters. Even with incomplete information these methods produce useful decision recommendations, for instance, by identifying a subset of alternatives that certainly contains the optimal one.

These methods cannot be directly applied in project portfolio selection, where the alternative portfolios are not explicitly defined but rather implicitly as project combinations that satisfy resource and other feasibility constraints. As the number of project combinations increases exponentially in the number of project candidates, the number of alternative portfolios quickly becomes overwhelming. With 33 projects the number of possible portfolios exceeds the number of people on the earth. With 60 projects there over one billion billion portfolios, which is roughly equal to the number of insects on earth. Thus, it is not surprising that relying on intuition to choose projects usually yields a suboptimal portfolio, even when considering only one value criterion and a single resource constraint.

In the late 1940s George B. Dantzig was faced with a similar combinatorial explosion in the number of alternative when looking for ways to compute the deployment, training and logistical supply program for the United States Air Force. His solution, the simplex algorithm to solve such linear programming problems established optimization as one of the most important fields of applied mathematics. Over a half a century of research and increase in computational power of computers has resulted in variety of algorithms that can solve relevant size project portfolio selection problems in reasonable time. However, the questions of whether algorithms exist, that are efficient for all sizes of project portfolio selection problems, remains unanswered. Indeed, developing such an algorithm or a proof that such an algorithm does not exist, would solve one of the seven greatest open problems in mathematics as defined by the Clay Mathematics Institute and yield one million dollars to the developer.

Portfolio Decision Analysis builds on these two streams of research: First, decision analysis offers the calculus of rationality to take into account the decision maker's preferences on multiple value criteria and risk. Second, mathematical programming identifies the portfolios that are optimal in view of the preferences and limited resources. My thesis develops portfolio decision analysis methods that first model incomplete information about the model parameters capturing the decision maker's preferences and evaluations, and second, give decision recommendations that are robust in view of the incomplete information.

In the Thesis, incomplete information is modeled by means of set inclusion in which sets of feasible parameter values are used instead of precise values. This approach is motivated by its ability to utilize decision maker's imprecise evaluation or preference statements in a readily understandable and simple way. For instance, statements such as "project's present value is between 600 and 800 thousand euros" or "the pessimistic scenario for the gross national product is more likely than the neutral scenario" transform directly into constraints for the feasible parameter values. Also, set inclusion can capture incomplete preference statements concerning the importance of value criteria, for instance, "A 20 000 ton reduction in CO2 emissions in preferred to profit increase of 100 000 euros" or incomplete statement concerning risk preferences, for instance, “a certain profit is preferred to an uncertain one with equal expectation”.

With incomplete information there does not exist a single optimal portfolio. However, a set of non-dominated portfolios can be identified which includes the optimal portfolio for any feasible parameters values: A portfolio is non-dominated if no other portfolio has a greater overall value for all parameter values allowed by the incomplete information. Focus on the non-dominated portfolios is well justified: A rational decision maker would not choose a dominated portfolio, as if she did, a non-dominated portfolio could be identified that has a greater overall value for all parameter values within the feasible sets.

The Thesis shows that the dominance relation is very flexible in capturing the special characteristics of a specific portfolios selection setting. For instance, if the total amount of resource to be used is not fixed, the definition of non-dominance extends readily to cost-efficiency: a portfolio is cost-efficient if any portfolio that dominates it is also more expensive. Furthermore, use of expected utility instead of overall value to establish dominance allows incorporating portfolio risk as a criterion to be minimized.

The computation of non-dominated portfolios leads to an integer linear programming problem that has several objective functions, each with possibly interval valued coefficients. The algorithms presented in the Thesis are - to my knowledge - the first ever for to solve such problems.

The Thesis shows that in portfolio decision analysis even incomplete information usually leads to conclusive decision recommendations for some individual projects. Based on the computation of non-dominated portfolios projects are classified into three groups. Core projects are included in all non-dominated portfolios and are thus certain choices. Exterior projects are not included in any of the non-dominated portfolio and can be discarded.

Further analysis, efforts of obtaining more precise information or negotiation can be focused on the remaining borderline projects that are included in some but not all non-dominated portfolios. The Thesis shows that additional information on the criterion specific value estimates of projects can reduce the set of non-dominated portfolios only if it is applied to the borderline projects. If no additional information can be obtained, the Thesis develops robustness measures to identify portfolios that hedge against the remaining uncertainty in the sense that their overall value remains relatively high across the feasible parameter values.

Using all cost-efficient portfolios as a basis for this three-way-classification of projects gives insights into what marginal value could be achieved with additional resources. This supports cost-benefit analyses of projects and portfolios, and helps the determination of the optimal level for total resource usage. The classification can also be used to identify projects whose selection is contingent on the level of acceptable portfolio risk.

The methods developed in the Thesis have been used in several applications. One of these applications, the formation of a product portfolio for a telecommunication company is reported as a part of the Thesis. Decision support processes that do not require precise parameter estimates seem to be more readily accepted in practice, but when building such processes, overly complex models to produce decision recommendations have to be avoided to ensure transparency. The experiences from the applications suggest that the methods of the Thesis achieve a reasonable balance between modeling imprecise parameters and transparency in generating decision recommendations.

The methods balance between project and portfolio level modeling. Optimization is performed at the portfolio level to enable explicit modeling of multiple resource constraints and portfolio risks, but analysis is focused on the implications of portfolio optimization for project-specific decisions as they are readily understood by the decision makers. Also the effects of incomplete information are best communicated by explicitly showing which project decisions are contingent on the exact parameter values.

In organizations the implementation of any decision is a task that involves several people. The methods of this Thesis can be used as a basis for participatory decision making processes in which different opinions within the organization can be considered simultaneously rather than require agreement on the model parameters. Such processes help to focus negotiations on the borderline projects and to identify good compromise portfolios that the whole organization is motivated to implement.

I ask you Professor Don N. Kleinmuntz, as the opponent appointed by the Faculty of Information and Natural Sciences to make any observations on the thesis which you consider appropriate.