

Engineering Management Decision Making Using the Decision Analysis Paradigm

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Abstract

The engineering management decision making (DM) environment in modern organizations is becoming increasingly complex. This is partly due to the technical complexity of systems being developed and the managerial complexity of orchestrating the activities of multi-disciplinary teams, usually with conflicting goals and objectives. Systematic approaches, such as decision and risk analysis (DRA), can play a critical role in improving engineering management DM methods and procedures by providing capable, efficient, effective, predictable, repeatable, and communicative DM processes, procedures, and guidelines. In this paper, we propose the use of the decision and risk analysis (DRA) paradigm to provide a standard and repetitive methodology for engineering management DM environments.

Keywords: Engineering Management, Decision Making, Decision & Risk Analysis, Uncertainty, Multiple Objectives, Decision Management & Maintenance.

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1. Introduction

Engineering managers face continuous pressure to reduce development lead time, reduce costs, and improve value of products and services. They routinely make decisions with incomplete information in the presence of significant uncertainty [Schrader et al., 1993; Courtney et al., 1997]. In addition, many of these decisions involve multiple conflicting objectives [Hammond et al., 1998]. The decision-making (DM) challenge is further complicated by interacting with other parts of the organization bringing different perspectives to the problem [Kusnic and Owen, 1992]. Decision-makers must, therefore, not only make good decisions, but also be able to justify their choices and where possible, obtain buy-in upfront.

Systematic approaches can play a critical role in improving engineering management (EM) decision-making (DM) methods and procedures by providing capable, efficient, effective, predictable, repeatable, and communicative DM processes, procedures, and guidelines. This paper proposes the use of decision and risk analysis (DRA) paradigm [Clemen, 1996] to deal with complex, multifaceted engineering management decision-making problems.

The use of DRA techniques is well established in many areas ranging from energy [Keeney and McDaniels, 1999], medical [Krischer, 1980], to public policy decisions [Keeney, 1988]. However, its potential has not yet been widely recognized in engineering management [Chelst, 1998]. In this paper, we show that DRA techniques are useful in structuring and analyzing many engineering management decisions. We do so by providing an overview and a discussion of the decision making environment, process, and elements for typical EM problems. We propose a structured approach that includes decision framing, making, improvement, implementation, and maintenance. The paper describes in details each of these phases and the associated DRA tools used in the analysis.

The design of complex engineering systems is primarily a process of discovering, analyzing, and resolving tradeoffs, and very often involves the simultaneous determination of several design variables. Design decisions regarding one subsystem (or component) influence decisions made by other subsystems (or components). So, these design decisions must be made in concert with other decision makers (i.e. **multiple decision makers**). It is sometimes unclear how exactly a design decision (or a design change) in one subsystem would impact other subsystems. This **uncertainty** complicates the decision problem further, especially when it carries into other systems resulting in the involvement of **multiple stakeholders**. Furthermore, any decision to improve the design of a system (or one aspect of the system), may worsen other aspects of the system or negatively impact other systems (i.e. **multiple conflicting objectives**). Therefore, the engineering management (EM) DM environment is characterized by uncertainty, multiple objectives, multiple experts & stakeholders, decision makers, and layers of upper management (see Figure 1).

Table 1 provides a non-exhaustive list and a summary of several representative classes of engineering management decisions that the paper is concerned with. Within

each class, we define one or more specific illustrative decision and the related alternatives. The final two columns list some of the relevant objectives and uncertainties. The table shows the existence of two main problem types. The first is a decision problem where uncertainty is the key decision driver, and the second is a decision problem where multiple objectives dominate the decision making environment.¹ In this paper, we present a structured decision making process that deals with both problems of uncertainty and multiple objectives for decision making in EM environments.

Table 1: DRA Engineering Management Applications

Problem Type	Alternatives	Objectives	Uncertainties
Go / No-Go Launch new product Late design change Process upgrade	Yes or no	Reduce production cost Reduce warranty cost Improve customer satisfaction	Implementation time Performance of new design New problems with new design
Make / Buy	Make in-house or Outsource	Reduce Cost Improve quality	Production costs Outsourcing cost Quality Delivery
Project Management Task execution Task crashing	Parallel vs. sequential Normal vs. accelerated	Min. completion time Min. Project cost Improve probability of Completion	Time Cost Performance
Prototyping Product Process	Comprehensiveness Timing	Reduce development time/cost Test market demand	How much prototype represents reality Learning and Improvement
Product Planning Product mix Product features Cannibalization	Products to offer Features to include Price points	Increase customer satisfaction Improve sales Reduce production cost	Demand Customer acceptance Market penetration
Capacity Planning Size Location Flexibility	Expand an existing facility Move to another facility Design-in flexibility	Meet future demand at lowest cost Maximize profit	Future demand Production costs Yield or throughput Downtime Productivity
Selection Problems Suppliers Technology Locations Projects Design alternatives Customer attributes	Select amongst alternatives Rank order Alternatives	Best in terms of: Cost Performance Quality Service etc...	Quality Cost Delivery speed Performance

The rest of the paper is organized as follows. In the next section we describe the decision making environment that is characterized by the surrounding uncertainties and the existence of multiple objectives. In Section 3 we introduce and describe the four phases of the decision making process. Section 4 explores alternatives, limitations and

¹ Of course, a third type can result from the confounding of both uncertainty and multiple objectives in the same decision problem.

barriers to the Use of the proposed DRA paradigm for engineering Management decision making. Finally, we conclude the paper in Section 5.

2. The Engineering Management Decision Making (EM-DM) Environment

The engineering management decision making (EM-DM) environment is characterized by the surrounding uncertainties, the existence of multiple objectives, and the contribution of various players. These players include multiple experts (i.e., technical, manufacturing, marketing, and finance), multiple stakeholders (e.g., organizational entities, suppliers, customers, etc.), a single or a group of decision makers, and upper management. The relationships between these different elements and players are displayed in Figure 1.

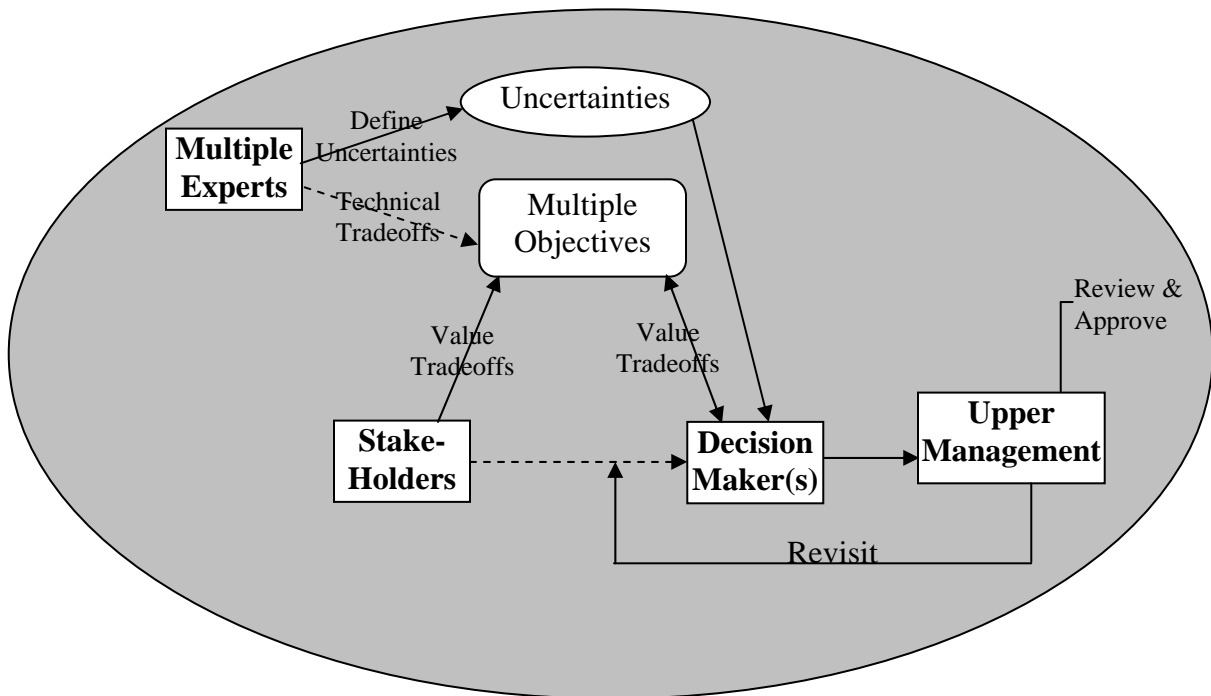


Figure 1: Engineering Management Decision Making Environment

The figure shows that uncertainties are usually defined by multiple experts. Multiple objectives are generally defined by technical and value tradeoffs made within the decision making environment. While technical tradeoffs are made by technical experts, value tradeoffs are carried out by the stakeholders. Stakeholders can also be decision makers (this is represented by the dotted arrow connecting the “stakeholders” box and the “decision maker(s)” box). Decision makers, when different from stakeholders, can also contribute to the list of multiple objectives as depicted by the double-headed arrow.

Another key aspect of the engineering management decision making environment is the tendency (i.e., high likelihood) to revisit decisions. Any decision made is usually

presented to upper management for review and approval. Even if a decision is approved at one point in time, it is usually revisited at future times due to environmental changes (e.g., changes in customer needs and requirements) or managerial changes (e.g., changes in upper management). Then, the uncertainties and objectives are reevaluated and the decision may be revised, changed, or re-approved again.

2.1. Uncertainties Surrounding Engineering Management Decisions

Uncertainty is an inherent characteristic of most complex engineering systems [Browning, 1999]. There is uncertainty whether or not a launch or delivery date can be met and what resources it will take. There is uncertainty whether or not a new design can meet its targets for performance and cost. There is uncertainty in the performance of a product when new unproven technologies are introduced into the development or production of that product. The list goes on, but what do all of these uncertainties have in common? Experience indicates that in almost every instance, the engineering managers challenged with these uncertainties were able to determine a relatively short list of possible outcomes and assign probabilities for each based on either historical data or their past experiences [Courtney et al., 1997]. A generic set of key uncertain elements common to a variety of engineering management decisions is described next.

Time: The element of time is part of every decision. It always confronts managers as a key uncertainty; except in routine processes with a long track record. Time uncertainty could appear at the single-activity level when the decision-maker is considering alternative ways to complete activities and wonders “How long it takes to complete a task?” Or at the project level, when the team questions: “Can the project deadline be met?” In general, the closer the technology utilized is to the cutting edge (or the more novel the design is), the more uncertainty exists with regard to time.

Cost: Uncertainty with regard to cost is similar to time uncertainty. The more experience with similar projects the less uncertainty. Estimates of variable production costs for a totally new product can involve significant uncertainty especially in the early design phase. This uncertainty would be compounded if the technology of the production processes were unproven.

Performance: As a design team is given a complex new design challenge, they are unsure that they can deliver a design that will meet specifications within the given time and budget constraints. Consequently, the performance of the product upon release could be viewed as uncertain. For example, in software products there will be uncertainty with regard to the number of unfixed bugs at release. For a car, the ultimate NVH (noise, vibration and harshness) or ride/handling will be uncertain until physical prototypes are on the test track.

Resources: The uncertainty surrounding the resources required to complete a project is closely linked to the above three variables. If the targeted time of completion and performance are almost inviolable, then the resources required to meet these goals will be uncertain. If resources are fixed, then "time" will be the key uncertain variable. If time and resources are fixed, then performance will be the major uncertainty.

Demand: Demand uncertainty may be broken into long-term (i.e. overall demand over product life) and short-term (i.e. month-to month demand) uncertainties. Long-term demand uncertainty directly influences all production technology and capacity decisions. Short-term demand uncertainty complicates the production planning process. Demand uncertainty can be caused by our inability to predict customer acceptance or needs in a new product. Alternatively, it could be the result of unanticipated competitive actions or economic conditions.

Globalization: Globalization introduces an added level of complexity to all of the above uncertainties. Cost uncertainty increases dramatically when currency fluctuations need to be factored in. Demand for a global product is subject to vagaries of national and regional politics and economics. Designing a product to meet the needs of diverse global markets increases the performance uncertainty.

2.2. Fundamental Objectives in Engineering Management Decision Making

The previous section described various ways in which uncertainty complicates engineering decisions. Another major complication results from multiple fundamental objectives that may need to be traded off. These multiple objectives arise whether the decision is which supplier to choose, which technology to utilize or what design alternative to pursue. Some objectives could have simple scalar measures such as dollars, computation speed, or weight. Other objectives such as “ease-of-use” may require the construction of an arbitrary scale [Keeney, 1992]. Common fundamental objectives can be grouped into six major categories with many sub-objectives [Keeney and Raiffa, 1993; Keeney 1999].

Financial: Almost every decision has a financial component. The objective is either to maximize profit or more often to minimize cost. Two dimensions of cost that are frequently traded off are capital cost and annual operating cost. In theory, it is easy to integrate these two into one single cost function; in practice these are distinct costs to be explicitly traded off because they fall within different corporate budget categories.

Performance: The performance objective covers a broad range of issues that relate to the primary function of the system under consideration and is of special interest to engineering managers. If the decision were the choice of computer, performance would include measures such as speed, storage, and battery technology. If the challenge were engine design, performance would include horsepower, torque, and fuel economy.

User Needs: User needs capture those issues that may be of unique interest or concern to the decision maker and the decision context. These could include objectives such as (a) maximize ease-of-upgrade (b) maximize compatibility, and (c) minimize time of delivery. Other user needs may relate to the speed of delivery of a new piece of equipment or completion of a design change.

Operational Needs: The class of objectives that we call “operational” is meant to cover aspects of the decision that impact day-to-day operations that are not totally captured by the cost of operations. For example, in the purchase of equipment, operational needs

would include the number of personnel required to operate and maintain the equipment. Although this variable could also have been included in cost, many companies treat head count as a separate variable with its own corporate controls. Operational needs would also include power requirements, allowed ambient dust, frequency of maintenance, and training requirements.

Management Issues: The decision alternatives may need to be evaluated in terms of their impact on senior management and other parts of the company. Consequently, this class of objectives may include (a) minimize need for senior management involvement and (b) minimize impact on other parts of the organization.

Environmental Impact: Some decisions have an impact that extends beyond the organizational walls. Almost all major facility location decisions will have an environmental impact. The impact could relate to pollution levels, bio-diversity, traffic congestion, land-use patterns or the local economy. Even narrow decisions with regard to the choice of manufacturing technology would sometimes warrant the inclusion of objectives such as “minimize pollution / hazardous waste” [Wenstop et al., 1988].

3. The Engineering Management Decision Making Process

The decision making process, we propose, is divided into four major phases, as shown in Figure 2: (1) framing and structuring, (2) decision making, (3) short-term decision management, and (4) longer-term decision maintenance. In the framing phase, the uncertainties, objectives, and alternatives are captured. The later phases include finding the initial best alternative, followed by decision improvement, implementation, modification, tracking, and update. Each of these phases will be discussed in more detail next.

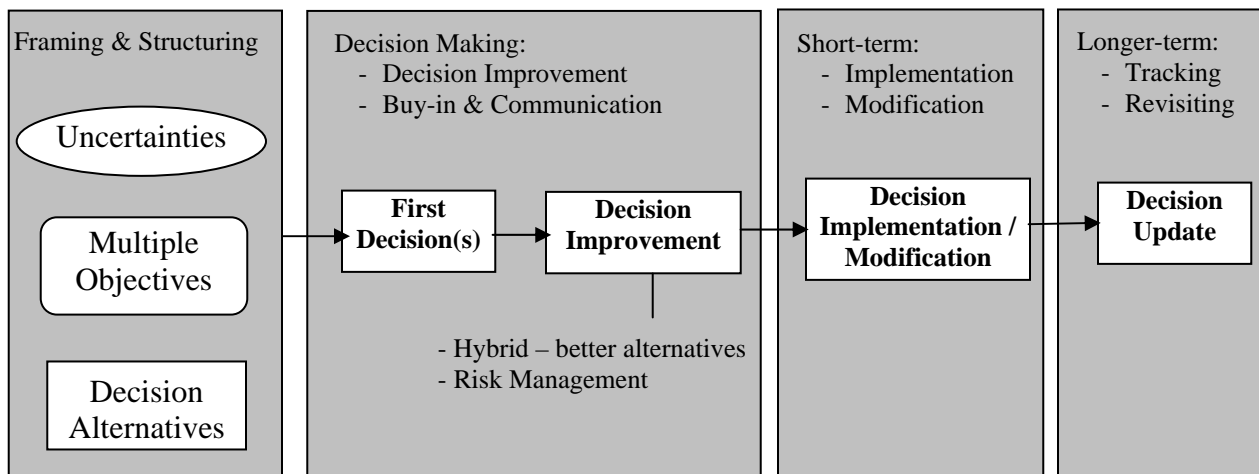


Figure 2: The Engineering Management Decision Making Process

3.1. Framing & Structuring

The framing phase of a decision problem starts by identifying the complicating factors in the decision problem, which are either uncertainties, or multiple objectives, or both. For

those problems that uncertainty is the major complicating factor, influence diagrams are used to facilitate framing [Clemen, 1996]. If multiple objectives were the paramount complicating factor, then objective hierarchy trees are used for framing [Keeney, 1992]. Indeed when the decision environment is subjected to both elements of complexity, then problem framing requires the use of both tools before proceeding with the decision making process.

Decision framing is conducted by a team of experts and stakeholders.² The team will be able to gather valuable information regarding the decision making process under investigation. While the technical experts, within this team, can contribute to the process by arguing what is possible and at what cost, the stakeholders provide key value tradeoffs. An added value for this team approach is to obtain agreement on decision context and issues. Each expert explicitly contributes to a piece of the puzzle by identifying technical uncertainties and their associated ranges. The multiple stakeholders will allow for the inclusion of various objectives and their weights.

The value of the framing and structuring phase is derived from the ability to explain the decision to multiple levels of less technical managers. Particularly from:

- The use of a common language to express decision elements.
- Explicitly accounting for and expressing uncertainty.
- Explicitly accounting for and expressing multiple objectives.
- Explicitly expressing importance weights to tradeoff objectives.
- Explicitly addressing both the strengths and weaknesses of each alternative.

3.1.1. Framing Decisions when Uncertainty Dominates the DM Process

Influence diagrams are usually used as a framing tool when uncertainty is the key decision driver and the main complicating factor [Clemen, 1996]. Framing the decision problem with an influence diagram provides a superior approach in terms of presenting the problem and communicating its structure and elements to other stakeholders (compared to spreadsheets or mathematical models, for example). The influence diagram may then be used as a basis for discussion to include or ignore other decision elements.³

As an illustration for the use of influence diagrams, consider a typical Go / No-Go decision.⁴ Figure 3 reflects the basic decision and the related uncertainties. In general, there are three types of nodes in an influence diagram: a decision node (represented by a box), an uncertainty node (represented by an ellipse), and a value node (represented by a rounded-edge box). In Figure 3, for example, there is one decision to make as depicted by the square box named “Make Change”. Even though there are two alternatives here (i.e., to make the change or not), they are not apparent in an influence diagram and will

² This process usually takes the form of a workshop with the appropriate stakeholders represented.

³ Alternatively, framing may be performed with the use of a schematic tree to represent a sequence of decisions interspersed with a collection or random events [Cohan et al., 1984].

⁴ Engineering managers often face decisions with just two basic alternatives: maintain status quo or change in attempt to improve. Some examples of these Go / No-Go decisions include whether or not to: (a) introduce a new product, (b) make (or buy) a component, (c) incorporate a late design change, (d) shut down a production line, (e) upgrade an existing manufacturing process, or (f) adopt a new technology.

explicitly show up in the corresponding decision tree model (as discussed next). The elliptic nodes in the figure convey the existence of five uncertainties. There is uncertainty as to whether or not the late change will actually achieve its intended goal of improving performance (i.e. “Performance” node). Performance simultaneously influences “Demand” for the product and “Warranty Cost” estimates. The next uncertainty is related to how long it will take (or cost) to implement the change: “Implementation Time” node. A delay in launch could result in lost production and sales as represented by the “Cost of Lost Production” node. Finally, the consequence of each alternative is measured, in this example, by “Revenue”, which is influenced by uncertainties in warranty cost, demand, and cost of lost production.

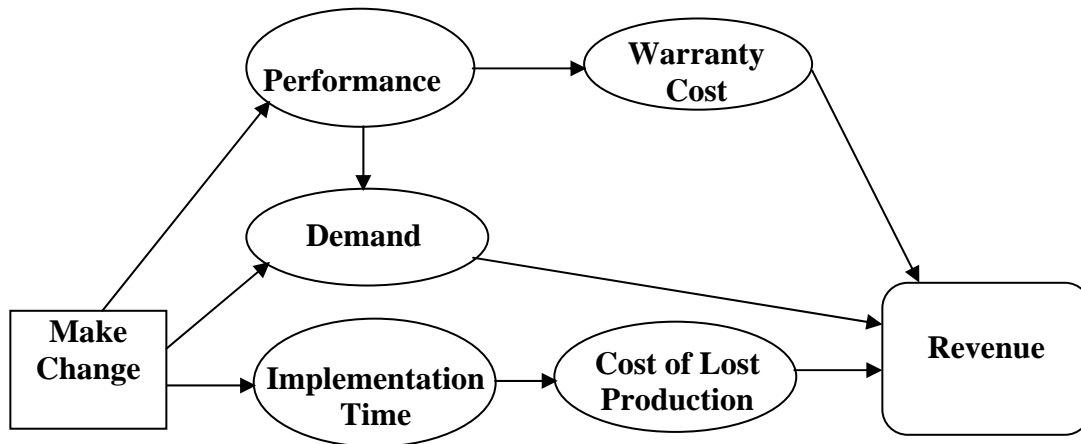


Figure 3: Late Design Change Influence Diagram

3.1.2. Framing Decisions when Multiple Objectives Dominate the DM Process

The first step in modeling a decision problem, where multiple objectives dominate the decision making environment, is the creation of a fundamental objectives tree. The key challenges in constructing a useful fundamental objectives tree is to create a parsimonious list that is complete but not cumbersome and for which measures can be defined. In some instances, an artificial scale may need to be constructed [Keeney, 1992] to reflect an important objective. Although every decision warrants a unique objectives tree, in almost all cases, there will be at least the following three major groups of objectives: a) cost, b) timing and c) performance. These categories are often at the top of a hierarchical list of objectives. Cost might be further divided between capital and operating. This sub-categorization makes sense as long as these costs come from distinct budget categories that at times are traded off. Performance is the broadest category and can cover a wide range of measures. In the choice of powertrain, this could include hp, torque, fuel economy, and NVH.

In Figure 4 we present a scaled down version of an objectives tree that would be used to select a full service supplier (FSS) for a major subsystem such as an automotive seat supplier. The five major categories of objectives include a) design process, b) manufacturing capability, c) product characteristics, d) supplier management stability,

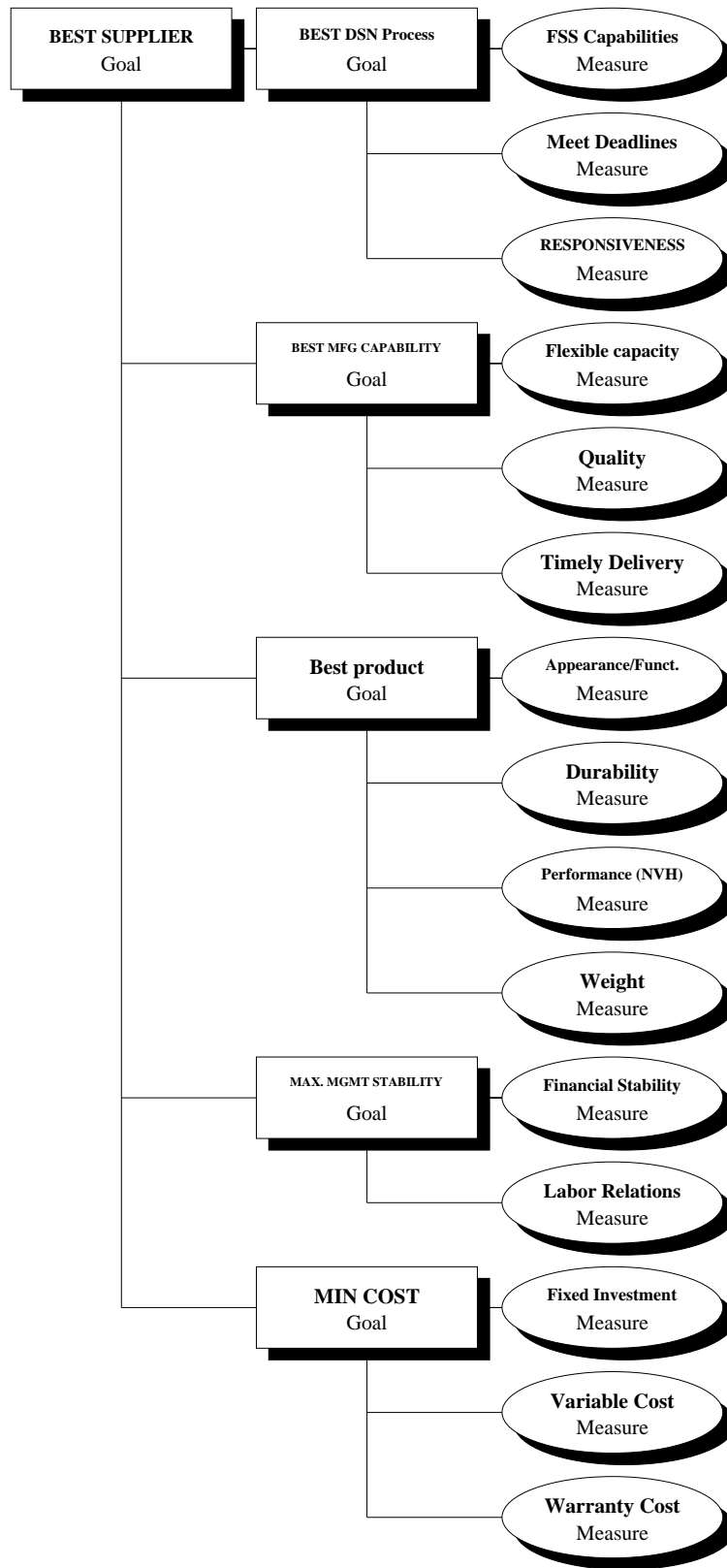


Figure 4: Supplier Selection Objectives Tree

and e) cost. In this day of total supply chain management, manufacturing includes not just quality but also timely delivery and flexible capacity. The quality of the design process is included since at the time the particular choice is being made the details of the design may not have been finalized. In addition, one purchase will often lead to the purchase of future products that are only in the planning stages. Thus they must also consider the long-term stability of the supplier organization [Gurusami, 1998].

3.2. Decision Making

Once a decision problem is framed and structured, the decision maker is ready to move to the data collection and analysis stage. Data collection includes the specification of probabilities for uncertainties, the quantification of payoffs for various alternatives, and the assessment of weights for various objectives. The selection of the best alternative is then made using some pre-specified criterion, such as the maximum expected value [Clemen, 1996]. Furthermore, sensitivity analysis and response to “what-if” analyses (i.e., weights and values changes) are performed during the decision making phase and are easily and quickly determined using a wide range of readily available software tools.

3.2.1. First Decision – Building and Solving Decision Trees

Building influence diagrams is an exercise in brainstorming the main decision elements. Converting influence diagrams into decision trees represent the progress from the framing phase to the data collection and analysis phase. Each node in the influence diagram is represented in the decision tree, but with more explicit information regarding alternative actions, probabilistic distributions for each uncertainty, and precise outcomes for different combinations of alternatives and uncertainties. Figure 5 represents the decision tree corresponding to the design change influence diagram in Figure 3. The two decision alternatives are shown as two branches emanating from the decision node. Following the “No” branch, the demand is shown to have two possible outcomes; for example, high and low. The warranty cost is also shown to have two possible outcomes conditional on the different demand outcomes. In total, there are six different scenarios; each resulting in a different revenue shown as a terminal value at the end of each branch.

Following the “Yes” branch, results in a different set of uncertainties as shown in the figure. First, the outcome of the “make change” decision may or may not result in performance improvement over the current design.⁵ In either case, there is a question about the implementation time for this change, which may result in many possible outcomes (i.e., two or more) as depicted by the two-headed circular arrow following the “Implementation Time” node. Similarly, the “Cost of Lost Production” node has many possible outcomes and is shown to be appended to every branch emanating from the “Implementation Time” node. Finally, the whole section of the tree referenced by “(a)” in the “No” branch is appended to all branches emanating from the “Cost of Lost Production” node.

⁵ Other possible outcomes can easily be included (in this or any other uncertainty node) as required by a particular decision problem.

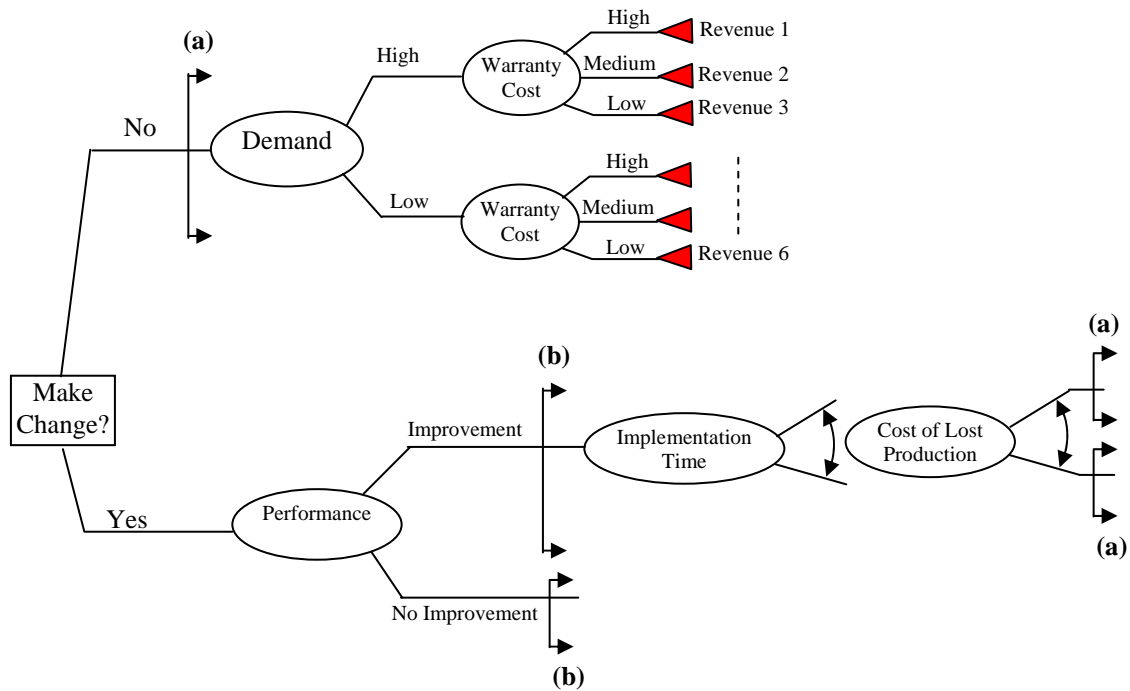


Figure 5: “Late Design Change” Decision Tree

3.2.2. First Decision – Solving and Analyzing Objectives Trees

If the objectives and their associated measures are quantifiable and there is data or expert opinion for each alternative, multi-attributed utility theory (MAUT) [Keeney and Raiffa, 1993] would be the preferred analysis tool. If the objectives and measures are hard to quantify and there is little specific data on the alternatives, then the Analytic Hierarchy Process (AHP) [Zahedi, 1986] could be used. Both MAUT and AHP are capable of integrating several different types of data into a single decision model. This is important in an engineering environment because decisions are usually based not only on quantitative financial data (such as cost or profit) but also on non-financial quantitative data (such as torque or horsepower output of an alternative engines) and on qualitative judgmental /subjective measures [Weber, 1993].

3.2.3. Decision Improvement: Hybrid Alternatives & Risk Management Strategies

Another key step (and advantage of DRA) in this phase, which is usually overlooked in DRA texts, is the development of hybrid alternatives. That is, once experts see the strengths and weaknesses of each alternative (and the selected alternative), they can focus brainstorming to develop hybrid alternatives that were not considered initially. Hybrid alternatives are combinations of features and pieces from existing alternatives, taking the best aspect of each alternative and assembling them in a viable new alternative.

In addition, risk management must also be performed in this phase. Risk management is a process of planning and strategizing to reduce the downside risk (i.e. its impact, probability or both) of less favorable outcomes associated with the preferred (i.e.

selected) strategy [Chelst and Bodily, 2000]. Risk management is intended to trigger a focused brainstorming session to search for specific strategies to manage targeted risks. The key in any risk management strategy is the realization (by management) that the probabilities of various uncertainties and payoffs, that were initially assessed to produce the “first decision(s)”, could be modified through concerted management oversight and control. For instance, if the probability of a specific supplier meeting a delivery deadline is low, management can improve this (initially assessed) probability by closely overseeing its interactions with this supplier. In addition, procedures may be put in place to remove some “usual” excuses, such as late design changes, that suppliers use to justify not meeting previously agreed upon deadlines.

3.3. Short-Term Decision Management

Besides embracing uncertainty and trading-off multiple objectives, personal goals and motives of decision makers may result in an even more complicated and time consuming decision making process; especially after a decision moves from the analysis/selection stage into implementation. Several layers of management must sequentially accept the decision, while putting their own “spin” on the project, before total decision approval can be reached. This process can be found to be very politically motivated and sometimes biased towards the personal goals of each manager (i.e., decision maker / stakeholder). Therefore, it is extremely important to gain management support before proceeding with implementation. This can be accomplished by conducting an exercise in “political mapping” and performing “implementation risk” analysis [Giordano et al., 1999].

Buy-in from stakeholders and upper management is established at this phase before proceeding with implementation. This process is sometimes referred to as political mapping of the decision makers and is usually performed during the decision makers’ interviews. During such interviews, all decision makers can be rated as to their perceived acceptance of the different decision alternatives under investigation. These ratings can be defined as their “present position”. The perceived “needed position” can also be determined for each decision maker and a plan to increase (or move) the “present position” rating to the “needed position” rating can be formulated for each decision maker. This approach can be invaluable in determining the tasks necessary to gain acceptance and commitment of all stakeholders before proceeding with implementation.

When implementing a decision obstacles may arise. This is referred to as implementation risk, which reflects the ability of an organization to do what they intend to do. Normally, the literature on decision analysis does not incorporate such uncertainties when building a decision model. Uncertainties related to implementation can be identified and managed during this phase. Plans should be in place to mitigate any of these uncertainties that are related to implementation and not necessarily to the core decision problem. The process proceeds as follows:

- Schedule a decision implementation meeting to immediately follow (within 2 weeks) the final decision making meeting.
- Identify the failure modes in transitioning from decision to implementation.

- Construct a separate influence diagram that incorporates influence implementation uncertainties.
- Get the implementation people involved in the decision making process early on. (implementation people are usually excluded from the decision making phase).
- Provide/allocate/commit resources that enables implementation (not simply make a decision).
- Empower implementers and relieve them from other responsibilities (make sure they have time, budget, and resources to implement).

3.4. Longer-Term Decision Maintenance

The final stage of the decision making process is long-term maintenance of a decision, which involves two key steps: implementation tracking and revisiting the decision.

Implementation tracking involves tracking key uncertain variables and continuing risk management. As uncertainties unravel, it is important to track them in the future after the decision has been made and implemented. When more information is obtained about a particular risk/uncertainty, the decision may need to be revisited or reevaluated in light of the new information. Tracking and monitoring all risks associated with a decision problem becomes an integral part of a continuing risk management process. However, since it is prohibitively expensive to continuously track and assess all possible risk elements, only those most critical to the decision environment must be tracked and managed [Pennock and Haines, 2002].

Risk may not be the only thing to track and manage; decision makers may change over the life span of a decision. This will result in changes in the weights of the multiple objectives and attitudes towards uncertainty/risk. With a structured decision model at hand, the influence of all these changes can easily be evaluated.

4. Alternatives, Limitations and Barriers to the Use of DRA in Engineering Management Decision Making

What are the realistic alternatives to using Decision Analysis when faced with significant uncertainty and/or multiple objectives in a wide range of common engineering management decisions? At one end of the spectrum are the non-analytic processes that discuss creating a list of pros and cons and somehow integrating this list to come up with a decision. At the other end of the spectrum are more sophisticated tools that are harder to understand intuitively and require more expertise to implement. Simulation is one alternative to decision trees and would be appropriate for modeling complex stochastic systems. Multi-objective optimization such as goal programming would be appropriate if there were large numbers of decision variables (such as design parameters) with a potential wide range of values. However, for a decision with a limited number of discrete alternatives MAUT or AHP would be far easier to understand and explain.

DRA techniques are not appropriate for every engineering management decision problem. For example, MAUT can be used to rank order a set of distinct alternatives. However, if the challenge were to select a set of two or more alternatives that may

interact or overlap, a portfolio model would be more appropriate than MAUT [De Maio et al., 1994]. Furthermore, a complex set of sequential decisions such as what would arise in a multi-year capacity expansion problem might better be modeled with dynamic programming techniques. Finally, DRA techniques would be less appropriate if there were a large number of decision alternatives to be evaluated or if the decision variables were continuous. If the problem included more than a few constraints, the analyst would need a procedure that creates feasible solutions before attempting to find the optimal solution. Analogously, decision trees and MAUT would be of limited value in modeling complex systems, whether or not there was uncertainty. Simulation, systems dynamics or theory of constraints might then be the more appropriate analytic approach. However, it should be noted that decision tree software is now capable of interacting with sophisticated spreadsheet models that extend their ability to model complex systems.

In our experience the most significant barrier to the use of this structured decision process is the feeling that it will take too much time and effort. This problem is compounded by the positive reinforcement executives receive as they rise through the ranks making the “right” decisions all along the way. This is coupled with a growing sense that decisions have to be made faster and faster and that all that is needed for a good decision is the right group of experienced managers to get together in a large meeting and hammer out a preferred strategy. However, such an approach is riddled with well-documented biases, is heavily influenced by personalities and is not reproducible. If the decision may need to be revisited because the situation or decision makers have changed, there is no foundation to build upon. In essence one executive’s lament best summarizes the situation: “We never have enough time to make the right decision the first time but we always have enough time to revisit the decision over and over again.”

A second barrier is that engineers are trained to be analytical with honed quantitative skills, but not steeped in probabilistic thinking [Hammond and Keeney, 1999]. They tend to avoid converting opinions and subjective judgments into basis for decision-making [Luman, 1998], instead they prefer to use quantitative decision models [Cabral-Cardoso and Payne, 1996]. Additionally, addressing and admitting uncertainty among a group of technical experts might be perceived as a sign of weakness or ignorance: “if you are the expert, then you should know all the right answers without any ifs or buts”. This is related to what decision analysts refer to as the “Expert Bias”. In some other situations management penalizes their experts for reflecting uncertainty in their answers or estimates. Management expects a single certain answer instead of a range of possible outcomes/answers regardless of the decision situation and the uncertainties that might surround it.

Lastly, formal and expert MAUT analysis faces a different challenge. With spreadsheets, managers have found it easy to create a list of objectives and assign weights. The ease of the task undermines the need to really understand the fundamental principles of MAUT. Errors can include a) poorly defined objectives that may overlap resulting in double counting, b) use of linear scales when the value function is non-linear, c) lack of care in obtaining expert assessments and d) assignment of weights without understanding how the weights interact with the scale used to measure performance on

each objective. Thus although MAUT (or AHP) is likely to find a more receptive ear than decision trees, engineering managers may not appreciate the difficulty in applying the concepts correctly and believe that expertise or training is not required to use MAUT.

5. Conclusion

The paper demonstrated the opportunities of decision analysis in modeling and solving a wide range of engineering management decisions. To establish the connection between the DRA paradigm and engineering management decision-making, we proposed a decision making process (Figure 2) while exploring the various uncertainties and multiple objectives that complicate engineering management decisions. We have also described in details both the decision making environment and the proposed decision making process for engineering management decision making.

We believe that with the use of a structured approach as provided by the DRA paradigm, companies will not only facilitate decision making for inexperienced decision makers, but also allow for the development of best practice repositories that help in preserving the company's decision-making expertise over time. Moreover, the use of DRA techniques in engineering management decision making will add value indirectly through:

1. Providing a “common language” and “shared vision” for a group to discuss all elements of a decision problem and explore areas of specific disagreement. In turn it helps build consensus which speeds decision implementation.
2. Documenting a decision experience that enables future justification and reuse. As Ullman [2002] noted, most engineering decisions are either totally unrecorded, or at best only the conclusion is captured in a memo. However, the logic behind the decision, the alternatives considered, and the criteria used are lost.⁶
3. Providing a system to track “critical” uncertainties during both the decision making and implementation phases.

⁶ In engineering design research, the flow of decision making is often called design rationale capture and is still the topic of much research [Ullman, 1994].

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