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VIEWING PRODUCT DEVELOPMENT AS A DECISION PRODUCTION SYSTEM

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ABSTRACT

Product development includes many different types of decision-making by engineers and managers. Design decisions determine the product form and specify the manufacturing processes to be used. Development decisions control the progress of product development projects by specifying which activities should happen, their sequence, and who should perform them. This paper introduces the concept of a decision production system to describe a product development organization as a system of decision-makers who use and create information to develop a product. This perspective does not advocate any particular type of product development process. Instead, it looks at the organization in which the product development process exists and considers the decision-makers as a manufacturing system that can be viewed separately from the organization structure.

KEYWORDS: *product development, decision-making*

INTRODUCTION

It is agreed that product development includes decision-making. The design engineering community has spent much effort on understanding how design is a decision-making activity. Primarily, researchers have focused on making better design decisions (e.g., selecting the best design alternative) and have employed the methods used in operations research, including optimization and decision analysis. Proponents of decision-based views of design are, for the most part, not advocating abandonment of traditional engineering analysis techniques. Rather they encourage expansion of engineering methods to recognize the equivalent need for education and research in decision-making. However, there remains a gap between this view and design practice.

In practice, there exist many different interpretations of what designers should be doing. A study of Volvo engineers responsible for the final development of new engines revealed that some engineers believed that their job was to make the engine meet performance specifications, others thought that they needed to resolve trade-offs between performance categories, and a third set wanted to make the engine provide the customer with a good driving experience (Sandberg, 2001). The engineers have different goals because they have different perspectives of the product development organization and their role within it.

The academic training of engineering students, which emphasizes engineering science, lays the foundation for the attitude that design is problem-solving. An organization's hierarchy decomposes the enterprise-level mission (with goals such as maximizing profitability and market share) into smaller design activities. Design engineers solve the problems that their superiors give to them, which reinforces this attitude.

The disconnect between design research and practice fosters resistance to teaching decision-making as an essential skill of engineers. We believe that this gap can be bridged by first understanding how we came to accept the view of engineering design as problem-solving (not decision-making) and how that notion is reinforced by the very organization structures of our manufacturing enterprises. Only a change in the view of the product development operations within a corporate environment will help clarify the role that both engineering analysis and decision-making must play in effective product development.

This paper presents a new perspective for understanding product development organizations. A product development organization is a network of individuals who process information and make decisions under time and budget constraints. The paper describes such organizations as decision production systems.

This paper briefly examines the traditional view that product design is problem-solving and discusses information flow. The paper then describes the types of decision-making that occur in product development and introduces the concept of decision production systems. The paper describes decision-based design and its role in decision production systems. The next section describes how this perspective can enhance engineering design education. The paper concludes with a summary and some interesting questions that this perspective raises.

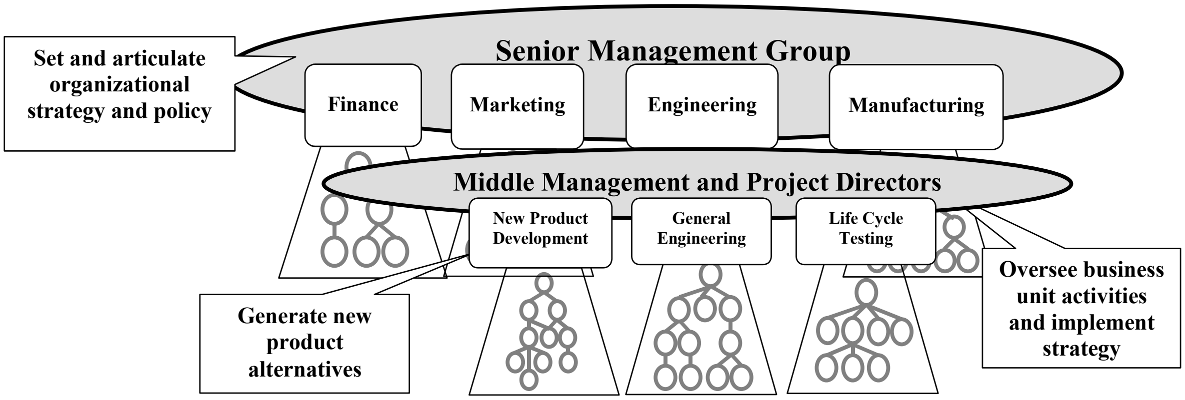


Figure 1: Organization chart of a manufacturing enterprise with details about the engineering organization

PRODUCT DESIGN AND PROBLEM-SOLVING

One can view product development as a process that seeks to select for design variables those values that maximize the expected profitability of the product over its life cycle. In practice, product development organizations have sought to achieve this goal promptly and inexpensively through the decomposition of the process into a sequence of steps performed by a variety of experts. This section discusses this practice, the hierarchical nature of product development organizations, and common responses to the associated limitations.

Hierarchical Product Development

A product development organization is a set of people working together to develop new products that will, when manufactured and sold, generate revenue for the manufacturing enterprise. Like other institutions, such organizations often have a hierarchical structure. Figure 1 illustrates a hypothetical, but typical organization chart.

Information processing studies from economics claim that the hierarchical nature of corporations (including those that design and produce goods) evolved naturally out of the need to process information efficiently. For instance, Malone (1997) argues that the economic benefits of centralized decision-making motivated the rise of large organizations. Centralized decision-makers can integrate diverse kinds of remote information efficiently and make better decisions than unconnected local decision-makers.

The appropriateness of the hierarchical structure is a topic of ongoing research in economics. A recent review paper by Borland and Eichberger (1998) concludes that hierarchies are structured so that agents of an enterprise can reduce the time necessary for completing tasks and reduce the risks associated with making decisions based on imperfect or incomplete information. The authors of that review call for more research on applying theories of bounded rationality to organizational design.

Thus, product development organizations developed hierarchical structures in part because the rest of the manufacturing enterprise used this type of structure. Other factors contributed to the hierarchical structure as well.

In practice, product development organizations have sought to develop profitable product lines through the decomposition of a complex problem into a sequence of steps that a variety of experts perform. Some of them solve more manageable subproblems. This decomposition is a natural way to overcome human limitations and find satisfactory solutions directly.

It is convenient to view a product as a hierarchy of subsystems, subassemblies, and components. Since designing a product requires designing all of these elements, a product development project involves a hierarchy of decisions. A decision at one level sets targets and constraints or provides information for decisions at another level. A typical example is aircraft design (see, for instance, Kalsi *et al*., 2001). The conceptual design phase selects wing area, fuselage length, wingspan, take-off weight, and installed thrust, and the detailed design steps must respect these constraints. Setting these constraints makes component (or subsystem) design easier, though the constraints prevent system-level optimization (cf. Hazelrigg, 1996, page 218; or Keeney, 1992, page 61).

Information Flow in Product Development

Although the hierarchical organization chart is a natural way to structure a product development organization, it is not the best way to structure information flow in a product development process. Product development activities generate information such as drawings, solid models, test results, and process plans. The flow of information from one activity to another creates precedence constraints between activities (cf. Smith and Eppinger, 2001).

If information flow were restricted to the paths on the organization chart in Figure 1, the product development process would operate using the “throw-it-over-the-wall” mentality. (Each business unit performs their part of the development process alone, making decisions suited to their objectives, and then passes the design-in-progress to the next business unit.) Good product development practice led designers away from that restrictive model years ago, as discussed below.

The business of product development in a manufacturing enterprise is quintessentially different from other businesses because most types of products achieve the required performance from the coupled behaviors and complex interactions of various subsystems. Managing the development of such products is different than overseeing independent business units (as in a large retailer, for instance).

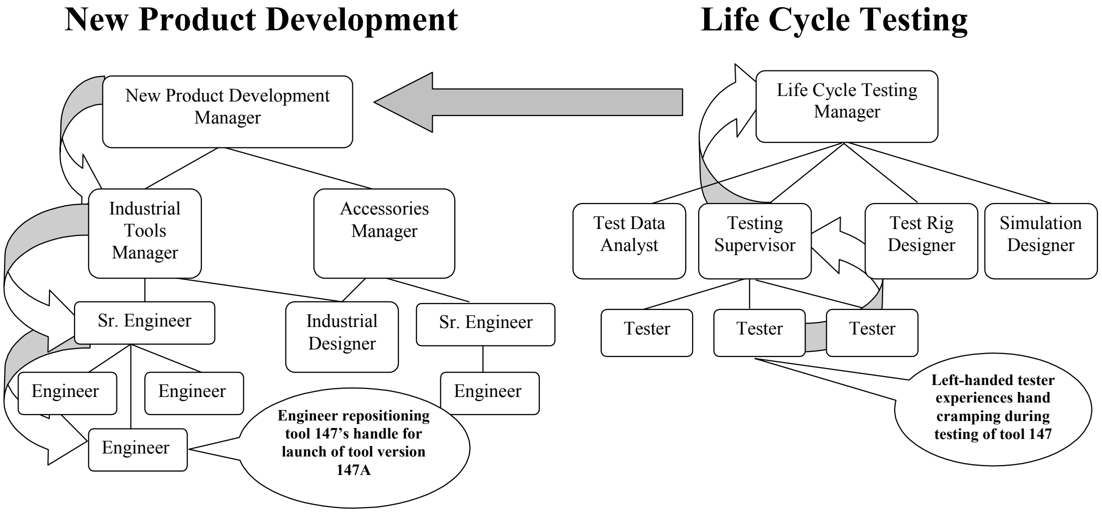


Figure 2. Communication distance in a hierarchical organization structure.

To illustrate the difficulties in communication that may arise in a purely hierarchical organization, consider the example described by Figure 2. Here a left-handed tester experiences hand cramps while performing manual tests on tool 147. This information is important to the design engineer (in New Product Development) who is redesigning a handle to launch a companion version of tool 147. The arrows in the organization chart indicate that the tester's observation must take six communication steps to reach the appropriate member of the design team. Communicating this information through managers wastes valuable time. In addition, this example assumes that the tester is aware that reporting such things as discomfort in use is an appropriate action. But this is unlikely to occur because the tester's responsibility is to test certain samples of tool 147 in a prescribed mode until one fails. It does not include reporting any difficulties in using the tool. Personnel at the bottom of the organization chart have the least decision-making authority and are the furthest away in the communication chain from those individuals who make strategic decisions. Yet, they are performing the most fundamental information processing tasks necessary to the objectives of their unit.

Under the pressure of time and budget constraints, product development organizations have found that information must flow through channels outside the organization chart. One common solution is to form interdisciplinary project teams, which are ad hoc groups created for specific product development projects. Every product development textbook mentions some of the different forms of product development teams. For instance, Schmidt *et al.* (2002) describes functional, modified-functional, balanced, and independent teams. Smith (1997) reviews a variety of techniques that organizations have developed to improve product development.

Figure 3 depicts how an interdisciplinary or cross-functional product development team is formed. The team members come from multiple business units and have different levels of experience and decision-making authority. Such teams meet regularly to share project-related information, and members communicate information between the team and their respective business units. The team will dissolve when the new product has been established in the marketplace, and responsibility for the product will return to the appropriate place in the organization.

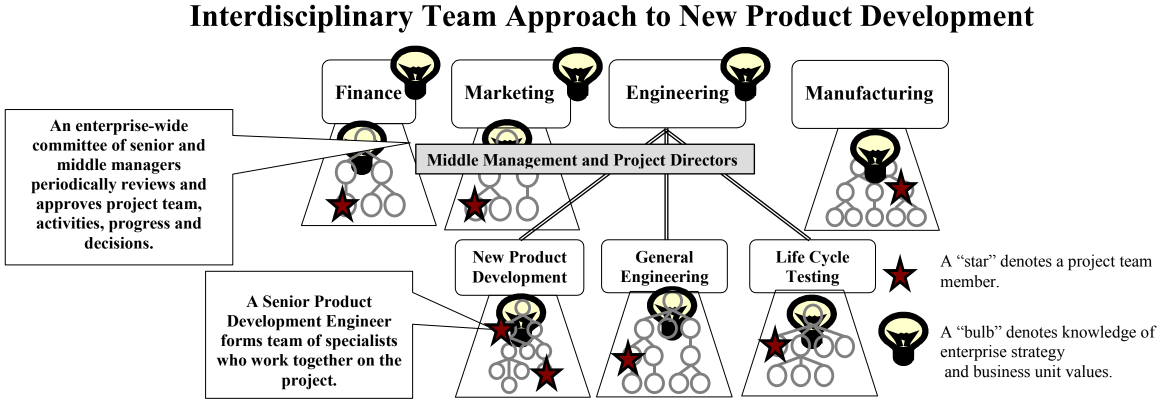


Figure 3. An interdisciplinary team approach to new product development.

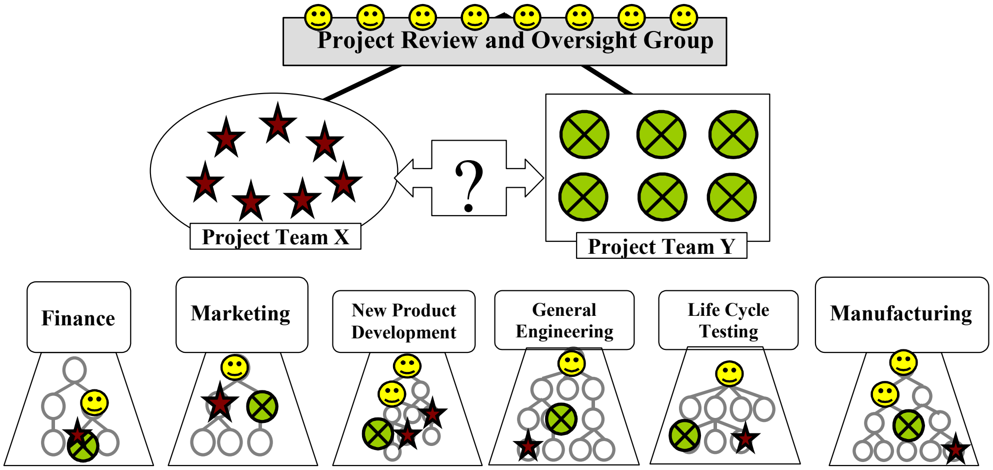


Figure 4. Communication isolation between ad hoc project teams.

Product development teams of this type report periodically to a group of more senior personnel who have decision-making authority over all aspects of the project. Product development review systems come in many forms. Typically, the project review and oversight group formally reviews each project at predetermined points in the development process (e.g., stage-gate or phase review). See also McGrath (1996) and Reinertsen (1997). A manufacturing enterprise has many different project teams operating at any one time. While the project teams report to the oversight group, they may not communicate directly with each other. This yields a new (albeit shortened) hierarchy of independent organizations (as shown in Figure 4).

One advantage of the project team approach is that team members (who will eventually be on multiple teams) have a greater chance of becoming aware of the key objectives of all relevant business units because they are no longer insulated from these units. Because project teams are temporary, the communication channels mentioned before lack the permanence and stature of an organization chart reporting line. Still, over time, the collection of these channels, along with the relationships formed on interdisciplinary project teams, fashions a network through which information flows. This network overcomes the limitations of the organization's hierarchical structure, and it more accurately represents the organization's behavior.

PRODUCT DEVELOPMENT AND DECISION-MAKING

The information flow in product development is controlled by the decision-makers in the organization. Product development includes many different types of decision-making by engineers and managers. Some decisions are *design decisions* and others are *development decisions*. Design decisions determine the product form and specify the manufacturing processes to be used. Design decisions generate information about the product design itself and the requirements that it must satisfy. Development decisions, however, control the progress of the design process. They affect the resources, time, and technologies available to perform development activities. They define which activities should happen, their sequence, and who should perform them. That is, what will be done, when will it be done, and who will do it.

Types of Decisions

In studying design projects, Krishnan and Ulrich (2001) provide a long list of questions that follows the typical decomposition of product development. Though most of them are development decisions, their list includes the following design decisions: What is the product architecture? What will be the overall physical form and industrial design of the product? What are the values of the key design parameters? What is the configuration of the components? What is the detailed design of the components, including material and process selection?

Although they may not realize it, design engineers are making decisions. Identifying the "best" product design commits the organization to this choice (though later steps may require a change of plans), and this decision generates information that other activities then use. The nature of the design engineer's decisions reflects the ambiguity in the design task assigned.

When the design task is extremely well-formulated (a clear set of alternatives, inflexible constraints, and a single objective), the design engineer's decision-making process is the solution of an optimization problem. Here decision-making is problem-solving. In contrast, when the set of alternatives, constraints, performance objectives, and business goals are vague, uncertain, or unknowable, design engineers are less able to apply formulaic numerical techniques to "solve the design problem." In these cases, the design engineer's decision-making process is a collection of heuristics that generate and evaluate solutions until a satisfactory one is found.

For many products, an important decision is the specification of the product architecture, which defines the primary modules (or subsystems) and the interfaces between them. This decision not only affects the design of the product but also the process that will be followed during the rest of the product development project. If the architecture uses decoupled modules with well-defined interfaces, many remaining activities can be done in parallel and with little information flow between them. Designing interdependent subsystems will require greater information flow, leading to a process with many iterations. (Reinertsen, 1997, discusses the important role of architecture in more detail.)

Kidder (1981) describes the development of a minicomputer by Data General. The development team included the following people: Tom West, Carl Alsing, Ed Rasala, Chuck Holland, Steve Wallach, and dozens of other engineers. The process began in the fall of 1978 and ended during the spring of 1980, a duration of approximately eighteen months. The team created microcode, diagnostic programs, system software, flow charts, schematics, videotape, and two functioning computers.

The book's scope includes not only the history, personalities, and thoughts of the people involved but also more general topics about designing, testing, and debugging computers, including the hardware and the software. As part of the narration, the book describes many of the decisions that the development team made during the computer's development. Tables 1 and 2 highlight some of those decisions. (Many of the design decisions that were made during development are not listed because either the book did not describe them or describing them would require too much room.)

Each item in the tables describes the decision made and who made it. References are to the pages in the book where the decision is described. Both types of decisions occur at different levels in the organization structure. Higher development decisions affect more people and more of the process, while higher design decisions affect more of the computer.

Models of Product Development Organizations

There is some related work on modeling various aspects of product development organizations. Adler *et al.* (1995) use capacity analysis and discrete event simulation to evaluate the performance of a product development organization. The organization is modeled as a queueing system. Jobs representing product development projects are processed by workstations representing groups within the organization. The models are used to evaluate resource utilization and project cycle times.

Table 1. Selected development decisions for a new computer (Kidder, 1981).

1. The vice-president of engineering approved the project (page 47).
2. West decided to hire inexperienced engineers who had just graduated (page 59).
3. West decided to have two teams: one for designing the hardware, one for designing the microcode (pages 59, 105).
4. West decided that Wallach should be the architect (page 68).
5. Wallach decided to begin designing the architecture by organizing the memory (page 76).
6. West reviewed the designs (page 119).
7. Rasala created the debugging schedule (pages 130, 145)
8. West approved using microdiagnostic programs (page 134).
9. West approved building a simulator for testing microcode (page 161).
10. Alsing picked Dave Peck and Meal Firth to write simulators (page 163).
11. West decided who would work on which new projects (page 232).
12. Rasala decided to work in the lab to increase morale (page 256).

Reinertsen (1997) discusses methods that use sensitivity analysis to estimate how development expenses, unit costs, product performance, and development delays affect the profitability of a product development project. This analysis can be aggregated to understand how these factors affect the profitability of the entire enterprise. This approach is useful for helping managers make specific decisions that make small changes, but they don't predict performance differences due to more significant changes.

McGrath (1996) and Reinertsen (1997) discuss methods for managing a pipeline of product development projects. However, these methods and models do not address how the behavior of human decision-makers affects the performance of the product development organization.

There exist information-based models of product development. The design structure matrix represents the activities in a product development project, their duration, and the probabilities of repeating them. See, for example, Smith and Eppinger (2001), Carrascosa *et al.* (1998), and Yassine *et al.* (2000) for more information.

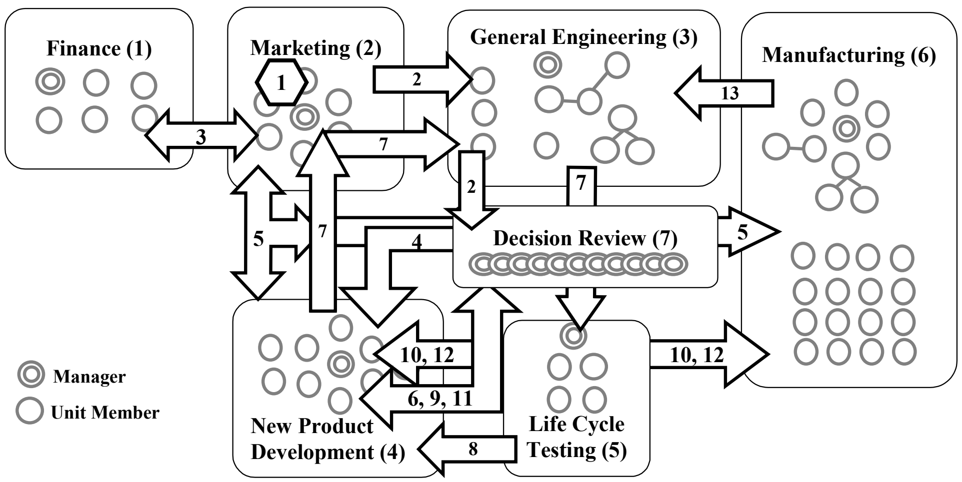
Using a more abstract model, Natter *et al.* (2001) represent product development organizations using two agents (one called marketing, one called production) that can learn but have limited knowledge and computational ability. The model uses neural networks to model each agent's learning and a life cycle model to predict the organization's profitability over time. Experimental results suggest how the organization structure, search techniques, incentive schemes, and other factors affect profitability.

Ford and Sterman (1997) describe a model that represents the dynamics of a product development project. The system dynamics model includes development processes, project resources, scope, and targets. Khurana *et al.* (2001) use a Markov decision process to determine optimal policies for managing a product development project.

Table 2. Selected design decisions for a new computer (Kidder, 1981).

1. West decided that the new computer should be a 32-bit computer that can run older programs written for another computer (page 42).
2. Wallach decided to worry about preventing accidental damage, not malicious theft (page 78).
3. Wallach decided that the memory protection scheme should use the segment number as the security level (page 80).
4. Wallach defined the instruction set (page 83).
5. Engineers negotiated the design details (page 116, 159).
6. West decided that the computer would use PAL integrated circuits (pages 118, 121, 268).
7. The engineers wrote the microcode and the schematics (page 121).
8. Holland organized the microcode (page 158).
9. West and Rasala decided to keep the ALU on one board by limiting its functionality (page 213, 255).
10. West decided which cables and connectors should the computer use (page 230).
11. West decided how the machine should be started (page 230).

Decision Production System



Flow/Routing of Product Design Decisions

1. **Marketing creates New Product Sales Forecast (2)**
2. **Technical Feasibility Study (3)**
3. **Financial Feasibility Study (1, 2)**
4. **Project Approval and Scheduling (7)**
5. **Conceptual Design (2, 4, 6)**
6. **Design Review (7)**
7. **Detail Design (3, 4, 5)**
8. **Prototyping & Testing (5)**
9. **Design Review (7)**
10. **First Build (6)**
11. **Final Review (7)**
12. **Product Launch (6)**
13. **Release to Engineering (3)**

Figure 5. Information flow for new product development.

Decision Production Systems

A product development organization has a formal organization structure like the one depicted in Figure 1. Usually, this structure groups employees by functional area. This hierarchical structure is necessary for a variety of management and administration purposes. Organizations also create cross-functional groups to develop products (as illustrated in Figures 3 and 4), and this results in a network of information flow that is independent of the formal organization structure.

A single product development project requires many related activities and decisions. A product development organization may concurrently execute different activities in the same project. This resembles a factory that simultaneously fabricates different components that will be combined in a single final assembly. Moreover, the organization conducts multiple projects that yield a stream of new products over time.

We define a decision production system as an information flow governed by decision-makers who make both design decisions and development decisions under time and budget constraints. The term refers to the fact that a product development organization creates new product designs and other information that are the results of decisions. Hopp and Spearman (2001) define "manufacturing system" as "an objective-oriented network of processes through which entities flow." We believe that this accurately describes product development organizations as well as factories.

One advantage of viewing product development as a decision production system is the focus on information processing and decision-making flows instead of personnel reporting relationships. The decision production system view can be used to help organization members understand the flows of information and decisions in the same way that an organization chart describes administrative authority relationships and a process plan (routing) describes the flow of material through a factory.

Different processes launch different sets of information-processing and decision-making activities. The flow of information depends upon the project underway. For example, in Figures 5 and 6, the decision production system resembles a manufacturing system that has functionally distinct units dedicated to specific tasks. (These figures are only illustrations, not formal models.) Figure 5 depicts the information flow for a typical new product development project, while Figure 6 highlights information flow among the units producing a design change. Each figure lists the route that the information follows. Each step requires information exchange and decision-making by members of the units shown in parentheses.

In a decision production system, individuals make decisions based on information received from other units and information processed internally by other members of the same unit. For example, in Figure 5, when the Marketing unit receives a request for a sales forecast, a manager assigns the job to a staff member who performs the task by studying the history of similar products and information about the market and potential competitors. The staff member may include projections based on experience of the senior members of the team or contact a member of New Product Development to determine the results of a similar product.

Some participants make decisions and some do not. A decision-maker gets some information, makes a decision, and consequently generates new information. Part of the "makes a decision" step may involve sending and receiving information from others. For example, in Figure 6, as part of the Testing and Redesign step, a designer in New Product Development sends a solid model of a component to the Life Cycle Testing unit, where a finite element analysis expert determines how the part will behave and returns a report to the designer.

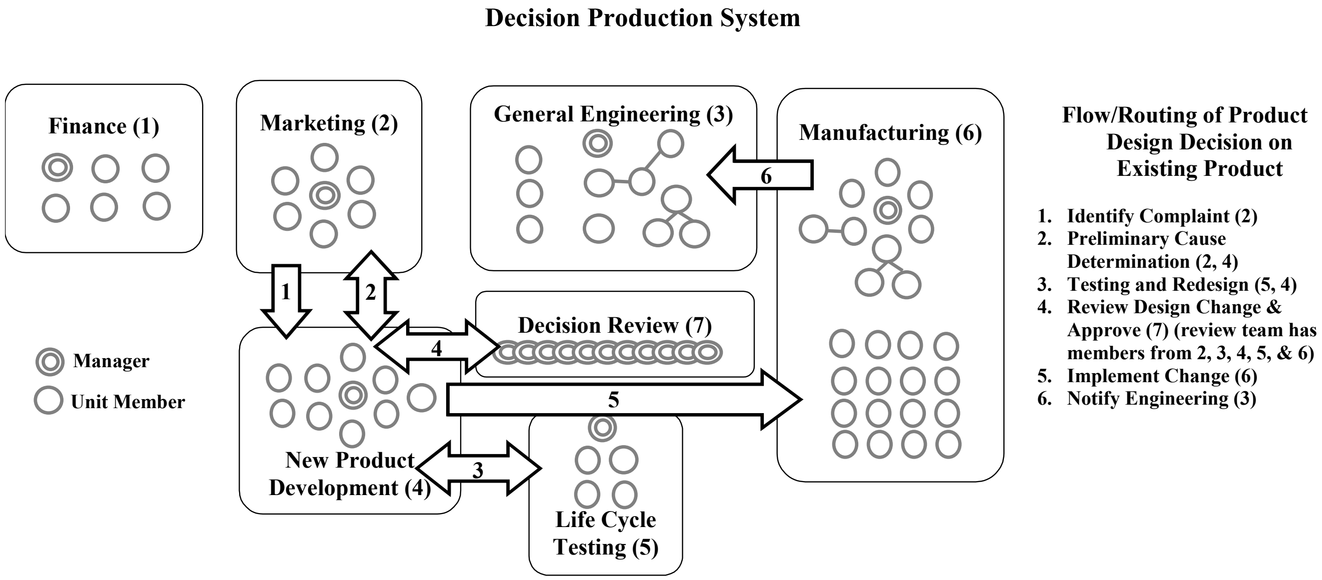


Figure 6. Information flow for producing a design change.

The decision production system view puts all decision-makers on the same level, because they are all working on the same virtual shop floor. The decision production system perspective builds upon and goes beyond other models of product development organizations by recognizing that the various types of decisions are interrelated and coupled with the information flow. Development decisions that affect the management and scheduling of the design process set constraints on design decision-making by limiting the time and funds available to generate, evaluate, and compare alternatives. Design decisions like the product architecture have significant project management implications. Decision-making requires information, generates information, and determines who gets which information.

DECISION-BASED DESIGN

The previous sections have described how product development occurs in practice and have introduced a new way to view these activities. Consider now the research that seeks to improve engineering design. We will use the decision production system perspective to examine one active area of design research. Note that, in this section, decision-making refers to the overall product design decision.

The design engineering community has focused much effort on understanding design as a decision-making activity. This work has yielded Decision-Based Design (DBD), a perspective that views design as a decision-making process involving values, uncertainty, and risk. (Details on DBD can be found online in the Decision-Based Design Workshop at http://dbd.eng.buffalo.edu/). The research on DBD includes a wide variety of approaches. The following reviews two aspects of DBD: work on decision-making methods and work on integrated approaches to engineering design.

Decision-making Methods

DBD researchers have studied methods for making better design decisions (e.g., selecting the best design alternative). Because decision-making often involves multiple objectives, some DBD researchers have developed techniques for helping decision-makers make tradeoffs among competing objectives and methods that quantify and combine the multiple objectives into a single objective. The techniques of decision analysis, especially utility theory, are an important component. Thurston (2001) gives an overview of DBD and discusses the role of utility theory in DBD. Research in this area continues. For example, Bleichrodt *et al*. (2001) discuss the inconsistencies of traditional utility measurements and use the ideas of probability transformation and loss aversion suggested by prospect theory to develop improved utility-elicitation procedures that correct for biases and deviations. For an overview of rational decision-making, including subjective expected utility theory and prospect theory, see, for example, Hastie and Dawes (2001).

This type of research gives decision-makers in product development organizations tools for systematically evaluating alternatives in a rational way. Thus, decision-makers can use these methods to avoid bad choices and justify their choices to others in the organization. These methods are not popular in product development practice, however.

The decision production system perspective gives some insight into the disadvantage of these techniques. Though powerful, these methods do require more effort, especially if they involve determining utility functions. The decision-maker, as a participant in the product development organization, must make the decision under time constraints. Decision-making heuristics require less time and are preferred.

Integrated Design Approaches

Some research on DBD includes efforts to illustrate how engineering design should be done. That is, they claim that there is an alternative to the traditional decomposition of design. Specifically, researchers have developed approaches that integrate numerous design decisions and solve large optimization problems whose objective function is to maximize expected profit (see, for instance, Hazelrigg, 1998; and Li and Azarm, 2001). Because this simplifies the process, product development will take less time. Also, the integrated model includes all of the competing performance measures and maps them to more fundamental objectives that are important to the manager of the manufacturing firm. These include profitability and market share.

Li and Azarm (2001) describe an integrated design approach for designing a product line that maximizes the net present value of the revenues and expenses and the average market share. (The product design is a conceptual design; for instance, the design variables of a cordless screwdriver are the motor type, the cell type for the battery pack, the number of cells, the gear type, and the gear ratio.) The approach has two basic steps: (1) conduct a marketing survey and use conjoint analysis to determine customer utility functions for product attributes; (2) formulate and solve a design optimization problem that yields the optimal product line. Note that step (2) involves a design decision that integrates two (usually distinct) sets of decisions: determine the attributes that each product should have and find the product designs that meet these attributes.

As described above, selecting design variables to maximize expected profitability is the objective of any product development organization. There are many ways to approach this problem. The integrated design approach, which formulates and solves a large-scale design optimization problem, is an extreme position, representing the complete integration of the product design phase of a product development project. The concurrency (indeed, simultaneity) that this integration achieves is generally viewed as superior to a traditional sequential design process.

However, this integration requires models and information that must be built, maintained, and updated during the project and from one project to the next. These off-line activities and costs affect the decision production system, though they often go unmentioned. Thus, the decision production system perspective links the (on-line) project-specific activities and decisions with the (off-line) research and support activities that generate information and models that will be used in future projects. This inventory of knowledge makes feasible integrated design approaches, and its importance can be understood from this new perspective.

From this perspective, it is clear that implementing integrated design approaches in a product development organization requires wide-ranging changes to the existing decision production system. Moreover, if personnel think that decision processes follow the information channels in the organization chart, communicating the necessary changes becomes more difficult. It requires that design engineers understand the role that decision-making plays in their part of the overall product development process. Transitioning an organization structured around the traditional (hierarchical) decomposition of product design to an integrated design approach requires new ways of seeing and thinking. The non-hierarchical, network-like decision production system view of product development enables this.

ENGINEERING DESIGN EDUCATION

The decision production system perspective is a paradigm for improving product development research and practice. It will also improve engineering design education, according to the results of our teaching experiences.

Results from an Engineering Design Course

We tested our idea of decision production system in a graduate system engineering design course. In the course, students formed four design teams. Each team was responsible for the design of a particular system during the one-semester course. We deliberately chose a wide variety of projects: a wireless local-area network in a multipurpose campus building; a manufacturing system for high-volume production of electronic packages; a miter saw emergency braking system; and a university library electronic research facility.

In addition to other requirements, each team had to track the decisions that they made during the project. Each decision was described by the following information: the nature of the decision, the person(s) who made the decision, when it was made, the alternatives considered (and the selected alternative), the criteria on which the alternatives were compared, and the method used to make the selection. Each team submitted lists of decisions at multiple points during the project. At the end of the project, each team wrote a short report discussing their decision-making.

This information showed that students understood the role of decision-making in engineering design. The teams realized that they made different types of decisions. One group listed decisions about the design itself, the models used to evaluate design alternatives, and administrative decisions about allocating finite resources. Another team classified decisions based on the type of information used to make the decision. The teams often discussed decisions with their customer to get information about preferences. Because they worked in teams, they often used informal discussion and consensus to make decisions. Sometimes, the teams used more quantitative techniques (such as the Analytic Hierarchy Process). The teams viewed tracking the decisions as a useful way to understand how they arrived at their final system design. Note however, that the students had no pre-existing hierarchical organization to overcome.

These results indicate that there exist multiple attributes useful for classifying decisions. In addition, because they require less effort and are more familiar, decision-making heuristics are popular even when more sophisticated procedures are available. The teams iterated between information-gathering and decision-making. They were unable to formulate precise problem formulations at the beginning of the project and thus did not acquire all the relevant data. As they explored design alternatives and learned about the customers' desires, they discovered that they needed more information.

Decision-Making in Engineering Education

The decision production system perspective can help engineering design students understand product development and the role of decision-making in that environment.

In practice, product development organizations perform decision-making. Returning to Figure 1, we can imagine the usual way that the responsibilities for decision-making are delegated throughout a manufacturing enterprise's traditional organization chart. Since only the senior management group is privy to the discussions of strategic objectives of the enterprise, it is difficult for design engineers who are participating in the generation of new product alternatives to recognize and integrate these objectives into their work. As discussed previously, designers doing key design tasks are insulated from the decision-making process. Instead of considering broader objectives in their work, they assume that they are "problem-solving" and the higher-level considerations will be handled further up the organization chart. The authors have heard engineering students express this perceived separation of design work from product development decisions. In response to being asked to make design decisions according to the strategic goals of a business, students say, "That's not going to be my problem; I will be the engineer doing the design analysis." This attitude is the antithesis of the DBD philosophy.

However, the decision production system perspective makes clear that the design engineers are indeed participating in a decision-making process. The focus on individual decision-making (in design engineering research) can be confusing because a decision-making process may require multiple participants. Some of these participants will provide information (e.g. engineering analysis) while others will make decisions. The decision production system perspective makes this obvious.

SUMMARY AND CONCLUSIONS

Traditional product development organizations follow a hierarchical organization structure. This structure is a natural and efficient way to make decisions. However, this hierarchy insulates design engineers from decision-making. Thus, design engineers have viewed their task as one of problem-solving. They solve the problems that others give to them.

Under the pressure of time and budget constraints, however, product development organizations have found that information must flow through channels outside the organization chart. Cross-functional teams and other concurrent engineering techniques are examples.

A product development organization is (independent of its formal structure) a network of people using information, making decisions, and generating information. Thus, product development is an information flow governed by decision-makers who make both design decisions and development decisions under time and budget constraints. It is a decision production system.

The decision production system perspective does not advocate one particular type of product development process. Instead, it looks at the organization in which the product development process exists and considers the decision-makers as a manufacturing system that can be viewed separately from the organization structure.

This perspective builds on the central idea of decision-based design that design is a decision-making process. However, it views product development organization as a system of decision-makers and looks to understand and improve engineering design by considering the environment in which the decision-making occurs.

One insight is that decision-based design not only is compatible with traditional product development organizations but also provides tools to improve them. First, DBD provides techniques for improving decision-making by individuals throughout the product development organization. Second, some DBD research proposes integrated design approaches. These would require changes to the product development organization. One can understand and evaluate these changes by considering how they impact the information flow and decision-making in the organization. Thus, the decision production system perspective provides a way to reconcile product development practice and engineering design research. This perspective not only helps observers understand the organization's behavior but also gives participants fresh insight into their role in the organization.

More work remains to investigate certain questions that this perspective raises. Are there ways to represent complex decision production systems? Can these representations be used to improve organization behavior? To help managers and engineers understand their role in the organization? To teach engineering design?

Does the decision production system perspective help explain why some design decision support tools are useful and effective while others fail to improve product development? Can models of decision production systems be used to develop and deploy more effective tools?

What are the costs and benefits of using integrated design approaches in product development? What support activities are needed to create and maintain the models needed for such approaches? What performance measures can be used to evaluate decision production systems?

Does the decision production system perspective help explain the methodology that a product development organization used to search for profitable products? Can this methodology be applied to other domains? Is the hierarchical decomposition the best way to manage the uncertainty and ambiguity present in problem development?

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