Postprint

MANAGING COMPLEXITY AND UNCERTAINTY IN A MULTIPROJECT ENVIRONMENT

Mike Danilovic, Ph.D., Assistant Professor,
Jönköping University, School of Engineering
Department of Industrial Management
Box 1026, SE-551 11 Jönköping, Sweden
Phone: +46 36 157588, +46 708 157588,
E-mail: Mike.Danilovic@ing.hj.se

Bengt Sandkull, Ph.D., Professor,
Malmö University
School of Teacher Education
SE-205 06 Malmö, Sweden
Phone: +46 46 13 46 77
E-mail: Bengt.Sandkull@mail.eat.lth.se

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ABSTRACT

In complex product development, corporations are running product development in many different projects. The number of more or less interdependent projects creates a web-like multiproject situation. It is characterized by the multitude of relations and dependencies that exist among projects, comprising tasks, people, knowledge, technologies, products, and components. In this paper we present a tentative framework, built on the assumption that complexity creates uncertainty that management has to handle. In multiproject situation the sources of complexity are: functionality of the product, people performing management and engineering work, chosen technology to fulfill functional demands, and shared resources in projects. The dimensions of uncertainty in multiproject situation that management has to handle are: the design of the process to transform functionality and technology to complete product design, organizing people in dual organizational settings basic as well as temporary projects, designing the product architecture based on functionality, technology and project interdependencies.

This paper will shed some light on these problems and investigate how a participatory approach based on the Dependence Structure Matrix (DSM) as a process enabling tool can be used to manage complex multiproject situations. The results show that even a single project needs to be understood in the light of the situational and organizational complexity that is the actual outcome of project-based product development work. The analysis shows Who, What, Where, When, and Why coordination and integration need to take place in a complex multiproject situation on different levels of the organization. The process of communication among people creates a mutual understanding of the situational visibility and of why communication is essential in problem solving.

Key worlds: Multiproject, Complex project, Dependence Structure Matrix

INTRODUCTION

Background

For many years, corporations have been performing product development in dual organizational settings. One setting is long lasting and is labeled the basic organization, which often has a functional structure. The other setting is temporary and is labeled the project structure, which, in contrast to the first, often nowadays tends to be an integrated set-up in cross-functional teams. In the mainstream literature on project management and product development, product development has been seen as conducted in a single-project situation. However, in complex product development situations, corporations are running product development in many different projects. Each of these projects is focusing on different functional aspects of the final product. Due to the complexity of the product and the scarcity of resources, projects are run concurrent, sequenced, or overlapped. Many times people are participating in projects on part-time basis, which means that they are performing engineering work in several projects at the same time and they are moving from project to project and between the projects and the basic organization. Very often projects share common resources, which forces management to separate projects in time, and there is a huge demand for exchange of information between people in projects and the remaining basic organization, the customers, and the suppliers. Projects recall demands on common resources with special knowledge. For this reason, each project has as its environment all the other projects taking place during the same time span. Apparently these numbers of more or less interdependent projects create a web-like multidimensional structure that may be difficult to grasp for management as well as for personnel in the course of their everyday duties. This kind of environment may be labeled the multiproject situation. It is characterized by the multitude of relations and dependencies that exist among projects, comprising tasks, people, knowledge, technologies, products, and components.

Such complex situation is creating uncertainty for engineers as well as for management. For engineers performing the engineering work it is vital to understand the product specifications and the functional demands that they have to act upon in their engineering work. They are dependent to other people performing other interrelated tasks somewhere else in other projects, departments, or organizations. This delicious situation is creating uncertainty for management in making decisions in designing the project organization and planning the tasks of engineers. How to delimit one project from one other and one set of tasks from the other? How to design the work break down structure in order to enable high level of concurrency and cross-functionality and at the same time keeping the balance between the demands made by the basic organization and the temporary organization? How can management make projects autonomous in order to enhance adaptation to changes and at the same time keep track of the total fulfillment of specifications and functionality of the final product? In such complex multiproject situations there are many questions that need to be answered, one way or the other.

Research questions

In this research we recognize the delicate situation that management and engineers have to cope with multiproject situations. Our ambition is to provide more knowledge underlying the complexity and uncertainty in order to develop understanding and more effective approaches to handle complex multiproject situations. Therefore, we will build a conceptual framework in order to be able of understanding how complexity and uncertainty is affecting corporations working in the multiproject situation, and to investigate how Dependence Structure Matrix

(DSM) can be used to make the complex situation less uncertain by engaging management and engineers in a dialogue event communicating about the product specifications, functionality, and dependencies between people within one project, and between departments in the basic organization, and between all ongoing projects that are interrelated to each other.

Approaches to multiproject situation

The traditional approach to project management is to consider projects as being independent of each other. Recently, the multiproject situation has been recognized as a major issue for corporations and the focus in research has shifted towards the multiproject situation. Several authors have attempted to create an increased understanding of the multiproject situation. Some indicators suggest that up to 90% (by value) of all projects are conducted in the multiproject context The vast majority of these projects share resources with other projects and thus the major issue is to find ways of handling resource scarcity according to the overall strategic direction of the corporation (Payne, 1995).

However, there is a need to find a balance between the focus applied in one particular project and the long-term strategy that is conducted in a stream of different projects in which differences in goals, visions, and direction may be seen between projects and long-term strategy (Cusumano et al., 1998). Hendrix recognizes the multiproject situation as focusing on the problem of allocation of scarce resources such as people to the different project portfolio (Hendrix et al., 1998). They suggest flexible resource planning based on long-term, medium-term and short-term planning taking into account the availability of scarce resources and the need for special knowledge. The multiproject situation is seen by Grey (1997) as a nominal umbrella grouping, mainly of projects on the basis of interdependencies among projects, sub-projects, or any kind of project-type work activity. Grey suggests that these inter-relationships need to be recognized in terms of vertical and horizontal relationships in order to create a proper coordination of project-type work among different projects. The issue of inter-relationships between organizations, individuals and projects is also recognized by Merwe (1997), who suggests a similar solution to Grey (1997) in terms of the coordination of activities among projects in a matrix-based analysis. The relations between projects are recognized by Payne (1995) as a major problem in terms of choice of technical solutions, cost and resource planning, and control.

However, in order to fully understand how to handle multiproject situations, in terms of managing and organizing, we need to understand certain underlying aspects of complexity and uncertainty that organizations have to deal with in their project-based product development. In our view, complexity itself needs to be understood as an analytical issue, while the effects it creates in terms of uncertainty need to be seen as the issue facing us in our daily life in corporations. Uncertainty in product development is the issue that management has to deal with when designing basic as well as temporary structures, defining the process for product development, organizing tasks in work break down structure and work packages, and deciding what features the next product is to contain in order to keep up with the time schedule. Management does not normally deal with complexity itself, but the impact that complexity has in terms of uncertainty.

Basic dimensions of complexity in product development

In this paper, we consider complexity as originating from three major sources: functionality of a product, chosen technology, and people involved. These three dimensions are woven together in a mesh. However, we consider that the prime source of complexity is the nature of the work being carried out – the demands made by the product specifications and the

functionality demands on technical solutions and the effects of chosen technology on the corporate structure and people (Scott, 1992). Complexity in product development can be understood in terms of the technology underlying a product, an aircraft or a truck, the technology chosen for components and technical subsystems in the product architecture, and the corporate and social context in which product development takes place. Complexity refers to the number of different items, components or elements that must be dealt with simultaneously, to specific measures such as multiplicity of relations (Scott, 1992; Perrow, 1984). Complexity is a collection of entities interconnected by a complex net of relations and dependencies between people, their tasks and activities (Buckley, 1967; Simon 1957, 1969). Some researchers go even further, claiming that complexity resides in the minds of people! In this perspective, complexity is a consequence of our perception and the interpretation of the situation, such as the product specification and functionality of a product and the implications of technology. Complexity is mainly technology-related and product-oriented. It is a consequence of the functionality demands and the number of possible combinations of technical solutions, variations in material, components, articles, technical subsystems, relations, and technical disciplines that are involved in the product development.

**Figure 1:
Basic Dimensions of
Complexity**

People

Technology

**Sources of
complexity**

Functionality
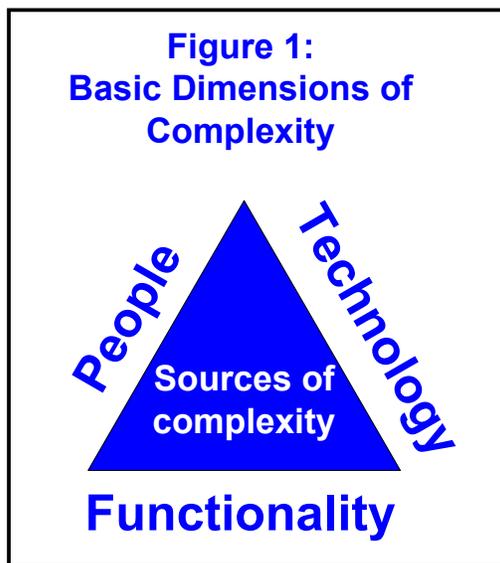
The concept of technology has been used in a variety of meanings in the literature, frequently to describe the production process or the throughput of an organization (Woodward, 1965; Thompson, 1967). Technology has been seen as *"a practical application of science to address a particular product or manufacturing need, or to an area of specialized expertise".* In some cases, the social processes are included in the definition of technology (Dussauge et al., 1987). Technology is often used to encompass techniques, machines, tools, pen and paper, computers, procedures, knowledge utilization, and information transfer. Sometimes, technology refers to the knowledge underlying the utilization of techniques. Technique is sometimes seen as something simple and easy to learn and put into practice. Technology is something complex and comprises techniques enhanced with knowledge and reflection on these techniques. In some cases, technology is seen as the practical application of scientific or engineering knowledge or as situated between science and commercial products or processes derived from the application of scientific knowledge. Technology is also considered as the theory of techniques (Ibid.).

Technology is business-related and combines different techniques, processes, and knowledge, focusing on tasks performed by people. The concept of technology therefore needs to refer to the context of a business situation and only where there is a production of tangible objects. Research and development are the functions and activities that define technology by linking science, technique, and production. However, technologies are not confined to a specific application, business or industry, and technologies do not consist of individual know-how, craftsmanship, art or basic techniques. Technology in general goes beyond the product, comprising knowledge aspects of many different techniques, departments or people. Thus, technology comprises technical as well as organizational and social aspects. Consequently, in the design and development of a product, transforming information within specialized units and transmitting that information to other units for further transformation and transmission is

essential. At the end of that process, the information (techne) has been transformed by technology into a product.

The idea of organizations as information processing and decision-making entities was introduced by Simon (1957). If organizations are viewed upon as being composed of people and if emphasis is placed on information-processing and decision-making, then the most important issue is how to get people together to process information and to solve problems in conducting tasks. There are relations among people creating dependencies among tasks that must be considered and handled in some way in the product development. To solve problems and to handle uncertainty, ambiguity and complexity in product development, a great amount of information needs to be processed to achieve coordination. The more uncertainty there is, the more information is needed to be processed (Galbraith, 1973). Thus, coordination of specialized units and people is essential in the decision process in which the transformation of information is conducted through communication (Karlson, 1994, page 157).
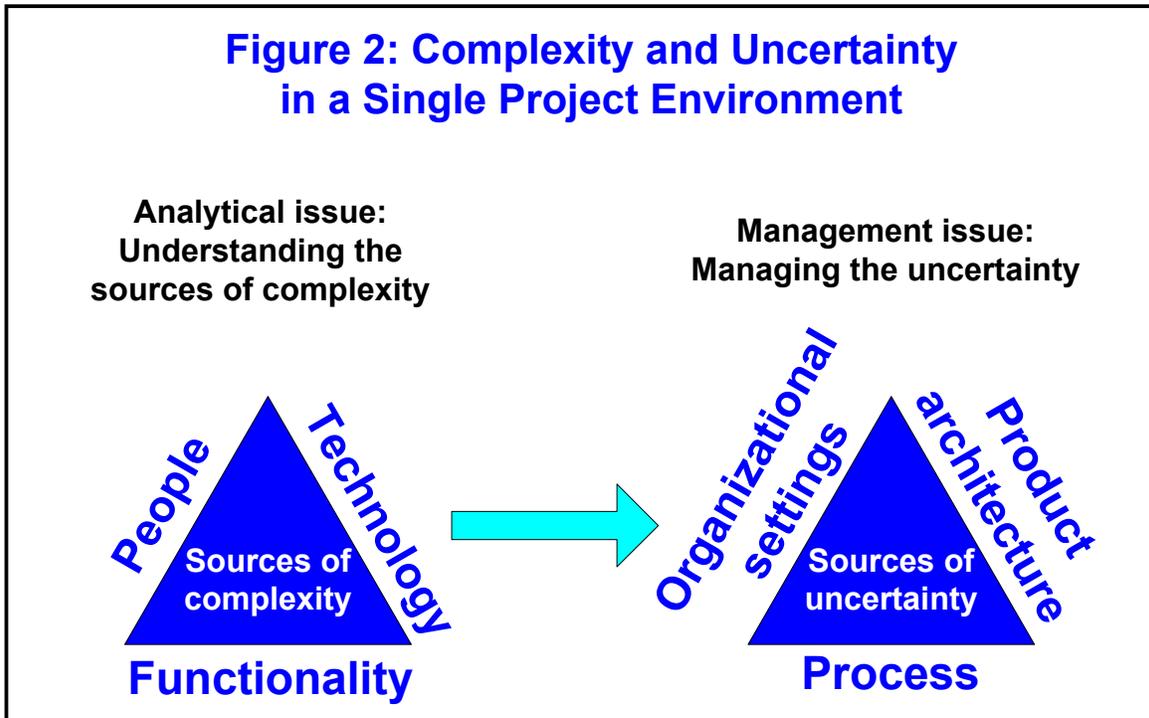
Uncertainty refers to the variation of the items or elements upon which work is performed or to the extent to which it is possible to predict their behavior. Some measures of uncertainty include uniformity or variability of inputs, the number of exceptions encountered in the work process, and the number of major product changes experienced (Scott, 1992). Product architecture is the basis for creating a task structure to be performed by engineers. The structure of the task is a series of actions that people have to perform, which essentially constitute the development process leading to an end product. If we can analyze the task structure according to the relations between product structure and task structure, we may achieve the information needed to redefine the product structure. This new product structure may help us create a different process, i.e. a set of tasks in a task structure that is more effective in terms of time and cost and performance.

Complexity and uncertainty in a single-project situation

From the discussion of complexity in general, we can see that the most important dimensions we need to understand concern the sources of complexity; functionality of a product, chosen technology, people involved in the process. Figure 2 presents the three dimensions of complexity as an analytical issue that management needs to understand and consider prior to taking action on the dimensions of uncertainty in a single-project situation. To the extent management is seen as processing uncertainty, management is affected by the dimensions of complexity. The traditional reaction to complexity is to ignore it.

The functionality related dimension of complexity affects how the process of performing product development is organized in terms of cross-functional problem solving and transformation of product specifications into product architecture. When this is done by adopting a set of technological solutions the product development process may adopt the ideas of multi-functional teams and concurrency of performing tasks, i.e. concurrent engineering. The process aspect of uncertainty focuses also on how the available knowledge base is used to analyze the functionality demands into feasible technical solutions. One criteria of successfully and efficient product development is how well functional demands are met by the chosen technical solutions (cf. Adler, 1999). The technology related complexity dimension affects the product architecture design, the choice between making a product modular or integrated, and the tasks that have to be conducted to fulfill technical decisions. The people related complexity dimension affects decisions on how to organize people in the basic organizational structure and the temporary project structure, and how to determine who to put into each of these structures. Organizing product development is also a question of choosing people with the education matching the product specifications and its functionality and

**Figure 2: Complexity and Uncertainty
in a Single Project Environment**

**Analytical issue:
Understanding the
sources of complexity**

**Management issue:
Managing the uncertainty**

People / Technology / **Sources of complexity** / **Functionality**

Organizational settings / Product architecture / **Sources of uncertainty** / **Process**

technology, educating those who do not have a matching education, and finding a balance between working in projects and working in the basic organization. While the former focuses on delivering products in the short term, the latter focuses on long-term technology and knowledge development. The organizing of tasks is influenced by the chosen technology and the people involved in a particular project, but there is still considerable freedom of choice. We can prioritize sequencing tasks or strive to parallelize tasks, we can organize tasks following the functional logic, or we can strive to follow the logic of relations and dependencies among tasks in order to create a high degree of integration of departments and even suppliers and customers (Danilovic, 1999, 2001a).

Complexity and uncertainty in a multiproject situation

What happens if we apply the conceptual framework introduced in Figure 1 to the multiproject situation? What are the similarities and what are the differences between the single- and multiproject situations? All the three dimensions introduced in Figure 1, and elaborated in figure 2, are evident in the multiproject situation. The first difference to be observed is that all these dimensions are more complicated and create a higher level of complexity and uncertainty in the multiproject situation compared to the single-project situation due to the number of ongoing projects and their interdependencies. This will be explored further. The second difference to be observed is a new dimension of complexity concerning the resources available to all projects. People are the scarce resource in corporations. This is especially evident if we consider that there is a resource scarcity regarding people possessing special knowledge in certain technologies shared by several projects. This means that management has to organize projects in such a way that projects can use these people simultaneously but separated in time, sequencing of projects. At the same time as several projects are running and are developing different technologies, different kinds of people have to be found who possess knowledge of new technologies. Alternatively, people have to be trained in new technologies or more people are to be engaged in the product development simultaneously. Time is the dimension that makes the difference - it separates tasks according to delivery schedules and makes it possible to differentiate technology

development between projects. Thus, the process design becomes crucial in order to organize projects according to the product specifications and functionality demands, resource scarcity, delivery status and interdependencies among projects. Interdependencies between projects may concern people, functionality, technology (product), tasks and the need for information exchange between projects or people. These project interdependencies need to be handled at different levels, both within each individual project, between projects and basic organization, and between projects on the overall multiproject level. Division and standardization of labor is a way of simplifying and standardizing the process of product development. We have seen from the research that labor and technology differentiation is probably one of the most important driving forces behind organizational differentiation as the people are specialized and educated narrow to the technology base (Oscarsson, 1993). In complex project environments, such as in typical multiproject situations this may lead to redundancy of parts in the product architecture and functions.

In the multiproject situation, different projects focus on different functional solutions utilizing different technologies that need to be coordinated and integrated in the final product. In many cases, projects are organized according to the technologies underlying business decisions and are separated into different projects. For example, in the automotive industry, one project may concern a truck chassis, another engine and driveline, and a third the electronics, computing, software and wiring. Each of these projects is different in regard to the chosen technology, the people working in projects and the tasks they perform. The most these projects have in common is that the final output is not a question of delivering chassis, engines, computers or software. The customers want a complete vehicle according to the technical specifications. It is up to management to organize product development in such a way that the products can be delivered on time.

The timing of different projects, the tasks to be performed, and assignment of people in different organizational setups fulfilling the functionality demands of the product are possibly

Figure 3: Complexity and Uncertainty in a Multiproject Environment
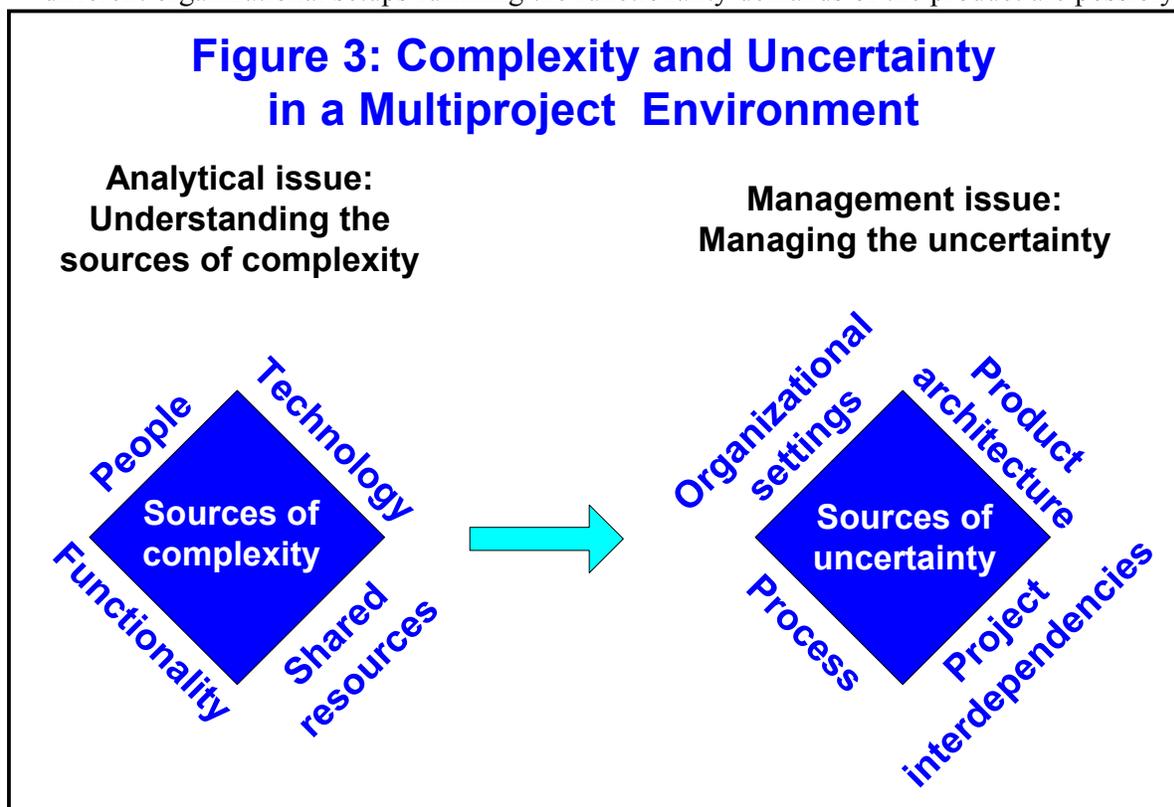
the most important tasks management has to consider, understand, and address. It is close to consider the multiproject situation as floating. The interdependencies among projects must be considered and handled by understanding the relations that exist between people, technologies and projects in order to be able to develop and deliver a complete product to the customer according to the specifications.

Figure 3 captures the dimensions of complexity and uncertainty that are observable in the multiproject situation and that are described in the text. Managing uncertainty in the multiproject situation means that tasks are separated in time and organized in different projects according to functional and technological demands. The existence of interdependencies among projects creates uncertainties in between projects that management and engineers has to deal with. Managing the multiproject situation means that we first of all have to understand and handle the system of projects (project portfolio) in the multiproject situation before trying to understand and handle each of the projects within the system of projects. This is of course interplay between the analytical and the uncertainty levels in the multiproject as well as in the single project situation. It is necessary to understand and to handle both levels at the same time.

The complexity of chosen technology creates relations and dependencies that in some way need to be understood and handled by coordinating people and integrating their tasks and activities. If there were no dependencies, for example between components, tasks, activities, people, and knowledge, there would be no need for coordination and integration.

One way of handling the complexity of a product is to apply systematic decomposition of a product into its components and elements and to integrate components into chunks and subsystems (Pimmler & Eppinger, 1994; Ulrich & Eppinger, 1994). Product development therefore requires careful planning of the decomposition and integration of components and coordination of people and integration of tasks once the functionality of the product is defined. The core elements in integration are the relations and dependencies that exist amongst components in the architecture of the product or in the basic organizational structure between people, groups, departments, or functions.

The product architecture reflects the complexity of the chosen technology. Technology is a complex phenomenon and functions as the basis for relations and dependencies that demand coordination and integration (Browning, 1997). The division of labor into separate tasks, and relations and dependencies between these tasks, form the basis for the need to coordinate. On the other hand, the decomposition of a product and the dependence structure among components constitutes the basis for integration.

EMPIRICAL ILLUSTRATION

This paper is empirically based on research in a collaborative study in a real time situation at a large international, European based, truck manufacturing corporation. One of the characteristics of this corporation is that it has succeeded in modularizing its entire range of trucks. Modularization made it possible to introduce continuous product development in each of these modules that in one way or another were independent of each other. On the other hand, all these modules are interdependent since customers may order new modules but always expect that complete trucks will be delivered. Some years ago, a major product renewal program was undertaken: new chassis and new truck cabins were developed together with several new engines, gearboxes, and drivelines. At the same time, a higher content of electronics was introduced throughout the range. The great amount of engineering work needed was performed in a dual organizing structure. The basic functional structure was long

lasting, and as much development work as possible was performed in a cross-functional and temporary project organization. The major problem facing top management was the question of how to organize all the projects simultaneously while each of these comprised different technologies in different modules of the truck system, and how to coordinate all the tasks and activities among people in projects and in the basic organization in order to maintain the time schedule and deliveries to the end customer. On the project management level, one of the major problems was to develop a communication plan to help people perform their engineering work and maintain the time schedule. For engineers in different projects, there were major tasks in developing knowledge and keeping track of what different people were doing in different projects and understanding the whole picture of the system of product development for the new generation of trucks in which each person had only a limited role.

RESEARCH METHODOLOGY

General research approach

The research approach underlying this paper is action based research. We were actively involved in the process and we were intervening with the actors influencing some events. We tried to help management solve problems of increasing coordination between people creating the communicative arena using DSM as process tool. The collected empirical data was then used to reflect upon the issues of the multiproject situation that management and engineers were involved in. At the time of this study, the truck manufacturing corporation was already running a series of interrelated product development projects. Within the major large truck development program, this contained many different projects, such as new truck cabins and manual and automatic gears. Several projects were initiated with the aim of developing new engines, ranging from V6 to large V8. Following an invitation from a project manager in one of these engine development projects, we undertook to support the truck corporation and in particular this project in order to develop more efficient communications among engineers in order to utilize the common knowledge base more efficiently. There was a need to avoid rework due to the lack of understanding the complex situation and communication among people within the project and among other related projects, as well as between projects and the rest of the basic organization. The approach to this issue entailed the introduction of Dependence Structure Matrix methodology as a process-enabling tool. The DSM approach was introduced in the project when it was initiated. During the kick-off in this project, with approximately 60 people, three different DSM analyses were conducted in three simultaneous workshop groups. One focused on relations among tasks within the engine project, another on relations between tasks in the project and the basic organization, and the third on relations between the project and 10 related major projects. One week after this one-day workshop with three groups, the material was collected, compiled and presented to all the participants in order to share results, influence their actions and discuss the relevance of such an approach to similar situations. One result was that project management was inspired to use the material for creating a communication plan together with the people in the project. One another result of this approach was this paper.

The Dependence Structure Matrix (DSM)

Product development is fundamentally a question of problem solving based on information exchange. The need for information exchange is a consequence of complexity, the potential relations and dependencies that may exist between people involved in the product development process, the tasks they perform, or relations between components in a product structure or chosen technology. The Dependence Structure Matrix (DSM) methodology is

Figure 4: The Principles of Dependence Structure Matrix
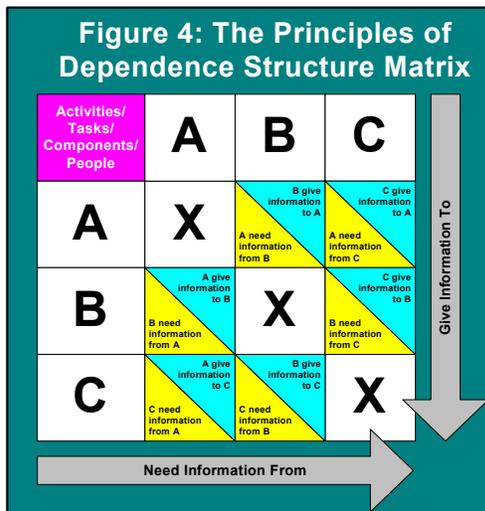
based on a problem-solving foundation using analyses of relations, constraints, and dependencies to define a problem (Steward, 1981). DSM represents and visualizes relations and dependencies among tasks and activities, components and subsystems, and among people and teams. These relations are mapped in a matrix. Figure 4 shows the principles of matrix-based analysis where the information is plotted in rows and columns. The intersections between rows and columns contain the identified relation and dependency information. A DSM analysis shows how the design of tasks can be organized for effective problem solving in team-based work and the communication required within and between teams (Eppinger et al., 1994). The information captured in a DSM analysis is similar to that in a directed graph or a PERT chart. However, the matrix representation makes it possible to create a complete model of the information flow and dependency analysis in describing and analyzing complex projects. Unlike the PERT technique, DSM allows tasks to be coupled or independent.

DSM has been applied in a truck manufacturing company as a group discussion tool exploring dependencies in an engine development project, dependencies among all other related ongoing development projects, and dependencies between the engine project and the prevailing basic organization. The questions asked during the workshops were: WHO needs to communicate to WHOM? About WHAT and WHY, and WHEN and HOW this communication should take place in order to handle dependencies among aspects of our concern. The focus in this analysis was on the information flow between people in relation to the tasks they perform and the actions required from them.

In this paper, we present only the final DSM results of all three workshops.

RESULTS

Figure 5 illustrates three major aspects of uncertainty that our research focused and is presented in this paper. We show how we have applied our tentative framework of complexity in a multiproject situation in order to explore, understand and handle complexity and uncertainty in this particular multidimensional DSM analysis. The top left figure illustrates the prevailing basic organizational structure, which follows the traditional departmental and functional logic. The top right figure illustrates the specific organization of the engine development project. In this case, the dominant logic in the project organization was following the logic of the product architecture. The lower figure illustrates how the engine development project was embedded in a network of ten other development projects.

In this case, we adapted the model introduced in Figure 3 according to the actual circumstances. Our model identifies four major dimensions of complexity: people, technology, functionality, and shared resources. We applied the "people" dimension to the basic organizational structure (top left figure in Figure 5) as well as to the project's organizational structure (top right figure in Figure 5) since people are organized in both the basic and the project organization. The product architecture is mapped in the top right figure as the project organization of engine development is mirroring the product architecture of the

Figure 5: Applying Three DSM-analysis in a Multiproject Environment
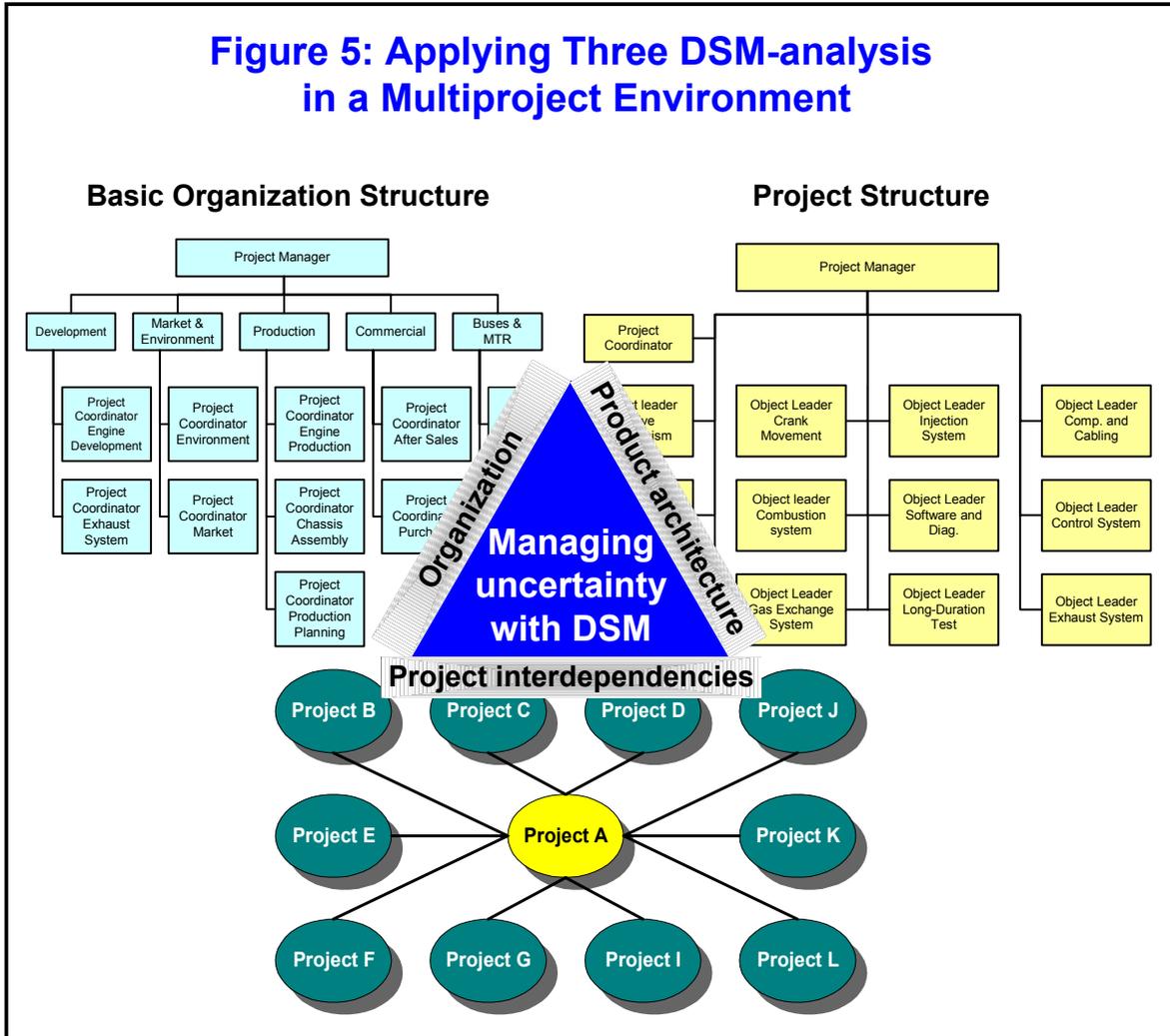
development project. The project organization in the top right figure in Figure 5 is basically a functional (organization even if the organizing principles follow the logic of the product architecture. The cross-functionality was obtained on the managerial levels and in daily life since people met each other informally. The functionality is handled by division the overall product performance into a series of different projects which is reflected in the bottom figure in Figure 5. There have been many other projects that we have not included in our analysis.

Three different DSM analyses

According to the logic in Figure 5, we applied three different DSM analyses following the logic of basic organization, project organization and the multiproject situation. Figure 6 shows the results when DSM analysis was applied. The top left and top right figures are of the square matrix type since rows and columns are equal. The numbers in the boxes indicate the level of dependencies identified. The number 3 signifies that the identified dependence between a specific row and column intersection was of great importance, while the number 2 indicates a medium level and the number 1 a low level of dependence. No numbers in row and column intersection mean that no relevant dependence could be identified. The lower figure is rectangular since the rows and columns are not identical. In this figure, the rows reflect the product architecture of the engine development project, while the columns refer to ten other related projects. The numbers have similar meaning as mentioned above.

Figure 6: Applying Three DSM-analysis in a Multiproject Environment

Basic Organization Structure

DSM-Analysis, Coordinator-Coordinator Project 1, Original

	After sales	Bus engine	Chassis assembly	Engine production	Environment	Market	MTR	Production planning	Purchase
After sales	X	2	1	1	1	2			
Bus engine	2	X		2	1	3	3	2	
Chassis assembly			X	3		3	3		
Engine production	1	3	2	X	1	2			
Environment		2	2	2	X	3			
Market	2	3	3	2	3	X			
MTR		3	3			3			
Production planning			3	3		3			
Purchase		3	2	3	1				
Development	2	3	3	3	3	3			

Project Structure

DSM-Analysis, Object - Object Project 1, Original

	Analysis and strength	Engine structure	Valve mechanism	Crank movement	Combustion system	Gas exchange system	Injection system	Software and diag.	Comp. and cabling	Control system	Long-duration test	Exhaust system
Analysis and strength	X	3	3	2		1	2					
	3	X	3	3	3	3	3	3	3		3	
	3	3	X	3	3	3	3	2	3		3	
	2	3	2	X	3	2	2	2	2	3	3	
		3	3	3	X		2		1	3	3	3
		3	3	3	3	X	3	2	3	3	1	3
		3	3	2	3	3	X	1	1		3	
		1				3	1	X	3	3		
		1	3	2	3	2	3	X	3	1	1	
		1	3	3	3	3	1	X		1		
		3			1	3			1	X		
		3	3			1	1	2	X			

Organization — Product architecture — Project interdependencies

Managing uncertainty with DSM

|	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	Project 9	Project 10	Project 11
Analysis and strength	1	1	2	1					1	
Engine structure	3	3	2	3		2			1	3
Valve mechanism	1			1					2	3
Crank movement			2	2		2	1			3
Combustion system		3						3		3
Gas exchange system	3	3	1	2		1		2	2	3
Injection system	3	3		3		1		2	2	3
Software and diag.			2		3	2	1	3	2	3
Comp. and cabling	3	3	2	3	3	3	1	2		3
Control system	3		2		3	3	1	3	2	3
Long-duration test										3
Exhaust system		3	1	3		2		3		

After the dependencies are explored, as we see in Figure 6, the next step is to elaborate the patterns of dependencies in order to investigate where the most critical intersections occur and to find out where special efforts are needed in order to enable coordination.

In Figure 7, we can see the results of DSM analysis when rows and columns are altered in order to cluster them according to identified dependencies. The colored areas indicate intersections of rows and columns that may require special attention regarding coordination and integration.

We can see from these DSM figures that there are extensive number of relations between physically oriented object structures in the engine project, between this project and the permanent organization, and between this project and some of the other projects. The focus by the management of this company has for several years been directed towards establishing the project structure enabling higher levels of cross-functional engineering work, focusing on time and delivering products to customers, and increasing the influence of project managers in development work.

The next step in this development should be to shift the focus from the single project situation concentrating on one project at a time to the entire range of projects that are run

Figure 7: Modified DSM-analysis in a Multiproject Environment
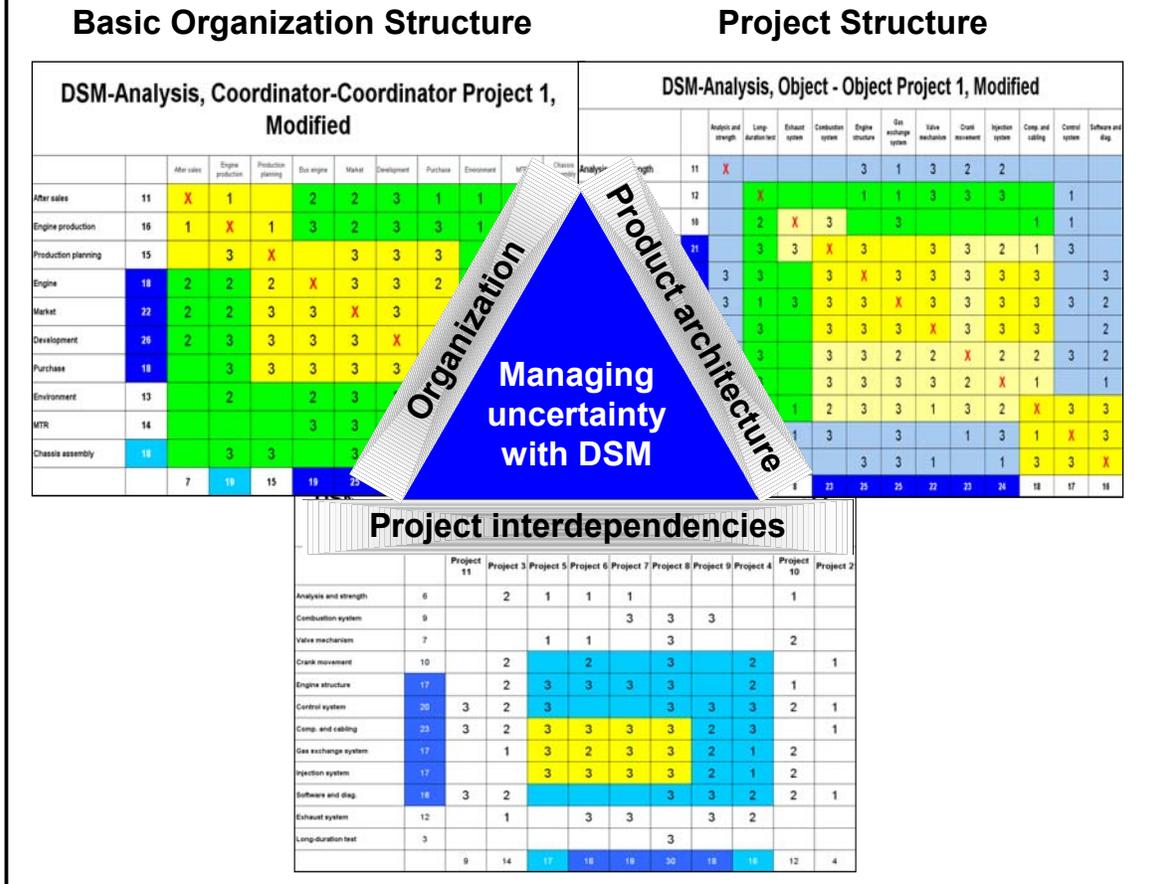
simultaneously. If these projects were independent, the problems taken up in this paper would not be evident as they are today. The reason is that there are a large number of dependencies among projects that need to be explored, understood and handled. Otherwise, product development will not be as effective as we may expect.

The information gathered in these workshops was presented to all people, management and engineers that participated in the workshops. The results of modified DSM analysis shown in Figure 7 was discussed in order to evaluate the approach and the underlying assumptions that organizing of complex product development has to consider dependencies among people in the project, between the project and the basic organization, and between the project and other related projects. This means that organization of product development needs to be differentiated as the Figure 7 indicates. The colored areas shows the patterns of intensive dependencies and thus this area have to be managed more intensively that the areas where dependencies are less dense. The dialogue with participants showed that this approach was reasonable. Management used the material to define a formal communication plan among people on the basis of identified dependencies. Engineers used the information to develop an understanding of the whole picture of the product specification and its functionality in terms of what they were doing in relation to other people, projects, and departments of the basic organization.

DISCUSSION

From a product development perspective, the process of performing development work is an equifinal process, while the process of organizing the product development work is a multifinal process. This means that there are no final answers or that there is no single answer to how product development activities can be organized. Many different organizational solutions can be adopted. However, the outcome of product development is directed towards delivering a specific product. No matter how we organize product development, there will always be intersections between components, subsystems, departments, projects, groups and individuals who need to share information in order to fulfill their tasks, since there will always be dependencies that need to be handled. This problem has been recognized by von Hippel (1990), who claims that a characteristic of product development is partitioning into small tasks, activities or elements and that the characters of these relations influence the way in which product architecture is organized into chunks or handled by teams and individuals.

> *Precisely where the boundaries between such tasks are placed can affect project outcome and the efficiency of task performance due to associated changes in the problem-solving interdependence among tasks. The core function of many innovation projects and project tasks is precisely problem solving and the generation of new information (von Hippel, 1990, p. 407).*

He argues that problem-solving dependence among tasks can be predicted and managed by strategies involving adjustment of the task specifications and reduction of the barriers to problem-solving interactions across task boundaries. It is reasonable to state that our approach is in line with this thinking and that our introduction of DSM as a process enabling tool and an analytical tool was intended to explore dependencies and relations between people, departments and projects.

The cross-functional team concept is widely used in practice. Employing cross-functional teams in product development has important consequences for the organizational structure and the activities of individuals. The cross-functional team concept is an overlying, temporary and project-based structure. Implementing cross-functional teams does not eliminate the old basic structure, which is often functionally based. In practice, these two structures exist simultaneously as two superimposed structures, focusing on different issues. The team-based structure is variable and temporarily organized, whereas the functionally based form is more prevalent. A strong dependence on thorough technical skills is supported by a functional organization which can ensure that technical competence is maintained at a high level. This form of organization not only leads to the coexistence of dual structures, but also denotes an important shift in focus from functionally oriented to flow-oriented work.

The basic structure is often long-term oriented, focusing on functional processes such as developing technical expertise, knowledge and skills, methods and procedures, while the cross-functional teams seem to be short-term, product and flow-oriented, focusing on flow processes and product development. This gives rise to tensions between these coexisting structures, stressing strong dependence in product development work and the need for collaboration amongst all team members, without respect to their functional affiliation or physical location. The indistinct and sometimes vague distribution of identities, authority, tasks, powers, responsibilities, and rights amongst participants in the team causes anxiety, role ambiguity, conflicts, dissatisfaction, and reduced commitment and involvement.

Organizations can be seen as systems with boundaries that separate a system from its situation and delineate the parts and processes within that system, determining the relatedness and relationship within and between systems. Boundaries need to be defined, but at the same time to be flexible, and sometimes even constructed.

Decomposition and integration of elements into chunks or projects has to take into account the dependency structure among elements and chunks. Planning and organizing product development is based on systematic dependency analysis among elements and tasks. In this approach, the goal of product development is to minimize the number of design and manufacturing interfaces in order to save time, reduce design and development costs, and to make it possible for partners to be involved early in the process. This view is based on the assumption that task boundaries and interfaces are stable and predictable, and that the solution lies in minimizing interfaces and establishing distinct and clear boundaries. Almost by definition, product development is an iterative process, but the iterations in the process of product development need to be minimized. Iterations are necessary due to changes in input information (upstream), updating of shared assumptions (concurrent), and discovery of errors (downstream), (Eppinger et al., 1994; Eppinger, 1994; Smith et al., 1992; Smith & Eppinger, 1997). Overlapping of tasks depends on the quality of downstream and upstream information. Eppinger have shown that information between upstream and downstream tasks depends on the upstream information evolution and downstream sensitivity (Eppinger et al., 1994). The first refers to the situation where some upstream tasks quickly develop certainty in the evolution of their output information, and others develop certainty slowly. Downstream iteration sensitivity refers to the tasks that are very sensitive to changes in input information that are transferred at an early stage, while others may be insensitive.

Integration is the process of combining components, tasks or activities into subsystems, or chunks. Different international mechanisms need to be applied in order to find the most effective integration process. Mapping information dependence may reveal the underlying structure for systems engineering and an organizational team setting can be designed on the basis of this structure. However, tasks, specifications and interfaces change during product development or when new information is introduced. From this point of view, we need to focus on uncertainty and ambiguity in product development, as well as the difficulties in identifying all the possible dependencies and iterations that take place.

> *The loose coupling of project phases also makes the division of labor, in the strict sense of the word, ineffective. Project members are expected to interact with each other extensively, to share everything from risk, responsibility and information to decision-making, and to acquire breadth of knowledge and skills (Imai, Nonaka & Takeuchi, 1985, in von Hippel 1990, p. 413)*

This quotation stresses the ambiguity and uncertainty in product development concerning information processing and points out that these problems have to be managed by creating flexible organizational structures, less clearly defined development phases, and a multi-level, web-like cross-functional team setting. Product development is a process of uncertainty reduction. Our approach in this paper emphasizes the uncertainty and ambiguity, and takes this as the normal state we have to face in complex product development. This view stresses that other principle than the established must be identified and used for creating organizational settings in order to achieve a high degree of coordination and integration, and thereby manage complexity. The flow of information and communication in product development needs to take into account relations and dependencies on different levels of the product architecture, between different organizations, among people, their activities and tasks

in problem solving. This is difficult in a single project situation and in a multiproject situation even more so. That is easy to claim but of course more difficult to manage in real life. This paper is an attempt to focus on these issues and to introduce a possible approach to managing the multiproject situation. We have tried to show that systematic analysis of dependencies can serve as the basis for designing such a web-like team network, even in a highly complex multiproject organization.

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