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MODELING PERFORMANCE IN COMPLEX PRODUCT DEVELOPMENT - A PRODUCT DEVELOPMENT ORGANIZATIONAL PERFORMANCE MODEL

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The area of performance has challenged scholars from different functional backgrounds resulting in rich and deep streams of functionally specialized research, with little cross-fertilization. As a result, it is difficult for researchers to build on previous work. Further, succeeding with new products is vital in today's changing business environment. Product development (PD) is therefore considered an important process, making performance in PD of even greater importance. The contribution of this research is the Product Development Organizational Performance Model (PDOPM), making it possible for managers to reason about performance in PD. The model consists of three generic levels of activities: product strategy, project management and product activities. Each level of activity uses resources to transform input to output under the direction of goals and constraints. This view of an activity is based on the familiar IDEF0 concept. The goal of the product strategy activity is related to the business strategy and the output of the activity is the goal for the project management activity. Project management translates the goal into outputs that become goals for the product activities. This way of modeling the PD process with three generic levels of activities makes it possible to analyze performance from the three perspectives. Effectiveness, efficiency and uncertainty are defined for the three generic levels of activities. Effectiveness can be expressed as how the output relates to the goal of the activities whereas efficiency can be defined as the difference between output and input divided by the used resources. The uncertainty can be viewed as the difference between the goal and the input. A first verification of the PDOPM has been performed by a root cause analysis of three problem areas selected from a previously conducted case study. Furthermore, the PDOPM can be used as a way of discussing the effect these three levels of activities have on PD as a whole (i.e., from a holistic view, aligning product strategy, project management, and product activities).

Keywords: Performance, Decision-making, Uncertainty, Complex product development, PDOPM, Measurement

Introduction

Product development (PD) is, for every technology driven company, an important business process to secure future growth and sustained success in the marketplace. In today's changing business environment characterized by technological advances, intensified global competition, as well as changing customers and needs (Goffin and Mitchell, 2005), the need for a successful PD is greater than ever. PD is a process and like any other management process, it can be improved to achieve better results (McGrath, 2004). Unfortunately, while the academic literature has made numerous contributions to the understanding of how PD should work, less attention has been paid to the question of why organizations so often fail to execute their PD processes as desired (Repenning, 2001). This paper studies Complex Products and Systems (CoPS), defined by Hobday (1998) as high cost, high technology, engineering intensive, business to business capital goods, used to produce goods and services. The PD process itself is known as being complex, often characterized by non-

programmed decision situations as well as uncertainty. The stock market's obsession with quarterly earnings forces companies to minimize cost and time to market, often at the expense of the value creation (Koller *et al.*, 2005). As a result, performance measures tend to focus on cost and time delays rather than the value progress. This may be the reason why performance often is equaled to efficiency. Focus, in the PD process, tends to be on finishing the project and not in creating the best possible product. Consequently, early phases of PD are frequently mistreated because of fire fighting activities within in old projects (Repenning, 2001).

It could be argued that performance measurement is not and can never be a field of academic study because of its diversity (Neely, 2005). With this in mind, this research views the PD process from three different perspectives: decision making, uncertainty, and performance to manage this diversity. The research question this research ultimately will try to contribute to is: How can performance in PD be improved? This paper however, takes a PD manager's perspective by emphasizing a holistic system view of the performance in the PD process. Thus, the research question in this paper is:

How can performance be modeled in the product development process?

To address this research question, a conceptual PD model involving decision making, uncertainty and performance is presented. The proposed Product Development Organizational Performance Model (PDOPM) can be used as a tool for further research, but also as a conceptual model for PD managers to reason about performance. Further, this paper aims at developing a general syntax within PD performance that allow companies to define their own performance measures, according to their specific needs.

Methods and Methodology

This paper is the first in a series of several, aiming at describing the ongoing development of the PDOPM. Blessing's (2002) Design Research Methodology (DRM) is the base for the research and this paper is a result of the research clarification stage of the DRM. To deal with the complexity of PD, a combined systems theory with an actors' approach has been adopted, in accordance with the views of Arbnor and Bjerke (1997). Increased complexity stresses the need for models that could be used for teams to develop a shared understanding (Katz and Kahn, 1978). Systems theory is a promising effort to deal with this problem, where an understanding of a system cannot be based on knowledge of the parts alone. In systems theory, the whole could be greater than the sum of the parts. The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity (Senge, 1990). Instead of adopting a rational approach where only one correct explanation exists for how data is connected to theory, a systems approach is adopted where knowledge is built up from the studied indicator effects. This means that the forces influencing the system are important. Further, the relationships are not necessarily deterministic or stochastic. It is also important to see the processes of change for the system, rather than taking snapshots.

Several extensive studies on uncertainty management, part of one of the authors PhD (Olsson, 2006), has served as a foundation for this research. The starting point of this

research was first developed through a workshop together with senior PD managers in seven different high-tech industrial companies. The companies are all international companies, based in Sweden. They all have extensive experience in developing CoPS within telecommunications, automotive and automation. This formed the initial ideas and problem statements on PD, including factors affecting performance. This research then continued through identification of gaps in literature by reviews within decision-making theory, uncertainty management, and PD performance. Twenty semi-structured and open interviews were held at 4 companies to identify the need for change within the management of PD at different levels in the organizations. These results were then incorporated into the PDOPM. Further, the authors professional work experience within complex PD was also used for reasoning during the development of the PDOPM. The first results are presented in this paper.

Theoretical Foundation

The body of knowledge within the area of PD and performance is vast but diverse. Clark and Fujimoto (1991) argue that PD is critical because new products are becoming the nexus of competition for many firms. Thus, PD is among the essential processes for success, survival, and renewal of organizations, particularly for firms in either fast-paced or competitive markets (Brown and Eisenhardt, 1995). The importance of PD and its interdisciplinary nature has attracted scholars from different research communities; contributing to the body of knowledge within PD. Krishnan and Ulrich (2001) argue for at least four common perspectives of PD in the literature: marketing, organization, engineering design and operations management.

Different aspects of product development

The following definition of PD by Ulrich and Eppinger (2003) has found broad acceptance within the research community:

"Product development is the set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product."

This research acknowledges this definition; however it is suggested to include the tools and methods that are used to perceive the market opportunity. A PD project is successful if its products not only fulfills the needs and requirements of the customers, but also creates value to its stakeholder at large. Successful PD is fundamentally a multidisciplinary process. Olson *et al.* (2001) show especially that higher project performance is demonstrated when cooperation between marketing and R&D, and cooperation between operations and R&D is high during the early stages of PD. With the definition of PD in mind it is suggested to view the PD process as three generic levels of activity; product strategy, project management, and

product activities. These generic levels of activities require different organizational capabilities in order to be successful. There has been extensive research within each of these generic levels of activity, but instead of bringing them together in a system view of the complete PD process, a tendency to divide and separate them from each other is common. However, a few authors (e.g., Hansen and Andreasen, 2004) argue for a change of the view of PD, from a problem-solving activity based view to a decision-making view. The decision-making view is commonly focused on the relations between decision and their impact on several aspects of overall PD performance. The decision-making view aims at supporting non-programmed decision situations and enabling decision-makers to consider the decision at hand in a holistic PD context, resulting in less sub-optimizing decisions. In the following sections the literature in strategy, project management, and product activities is briefly reviewed.

Product strategy in product development

The basis for a strategy in the PD process should be the business strategy. A business model is defined by Zott and Amit (2008) as a structural template of how a focal firm transacts with customers, partners, and vendors. It captures the pattern of the firm's boundary spanning connections with product markets and other factors. Peter Drucker, recognized as a pioneer in business strategy and one of the first to recognize that the purpose of a business is external in creating and satisfying customer needs (Koch, 2006). By aligning the strategy of PD with the business strategy, it may be easier to get senior management support. Senior management support has been identified by many authors as an important success factor in PD (See e.g., Ernst, 2002). Moreover, Zott and Amit (2008) describes product strategy as the pattern of managerial actions that explains how a firm achieves and maintains competitive advantage through positioning in product markets. It could be argued that the role of the product strategy is to identify the needs of the chosen market and to decide which products to develop in order to satisfy those. According to Krishnan and Ulrich (2001) there are five generic questions at the product strategy level: What is the market and product strategy to maximize probability of economic success?, What portfolio of product opportunities will be pursued?, What is the timing of PD projects?, What assets (e.g., platforms), if any, will be shared across which products?, and Which technologies will be employed in the product(s)?

An example of a strategic decision within PD is of becoming a first mover or a fast follower. A first mover to the market may face considerable uncertainty about what product features customers will ultimately desire and how much they will be willing to pay for them (Schilling, 2006). Mechanisms that promote first mover advantages include proprietary learning effects, patents, preemption of input factors and locations, and development of buyer switching costs (Lieberman and Montgomery, 1988). Porter (1996) distinguishes between strategic positioning which means performing different activities from rivals or perform similar activities in different ways and operational effectiveness which means performing similar activities better than rivals perform them.

The PD portfolio should have a strategic focus which gives an overall direction to individual PD projects (Ernst, 2002). In Cooper and Kleinschmidt's (1995) study, the construct of 'new product strategy' is the second most important success factor for the PD program. Firms that include an explicit strategy step in their PD process are more likely to produce successful

new products (Griffin, 1997). It is also essential to keep the product strategy updated, to balance the tendency of just focusing on finishing the current active PD projects. This phenomenon is acknowledged by many authors as their focus turn from the project level to a more strategic view. Kaplan and Norton (1992) introduced the Balanced Scorecard and, since then, their focus shifted towards introducing strategy maps. Cooper introduced the Stage Gate model (Cooper, 1993) and today he emphasizes the importance of strategic buckets.

Project management in product development

Requirements and product complexity are increasing, PD schedules are shrinking, and the competitive environment among customers and suppliers is on the rise. As a result, projects become more complex. In addition, higher demands are placed on the performance of projects both internally and externally. In essence, project management is the process by which a project is completed successfully. However, there are several aspects of project management to consider. In order to better understand project management, it is important to understand what a project is. Obviously, several definitions of a project exist. PMBOK (2004) defines project as *a temporary endeavor undertaken to create a unique product, service, or result*. A frequently referenced definition is the one of Turner (1993):

An endeavor in which human, material and financial resources are organized in a novel way, to undertake a unique scope of work, of given specification, within constraints of cost and time, so as to deliver beneficial change defined by quantitative and qualitative objectives.

The definition states some characteristics that need to be further explained. First, the project is organized in a novel way, hereby implying that a project is not part of the original organizational setting. The project is set up for the limited period of time necessary to achieve the set objectives of the project. Second, the scope is stated to be unique. This is understood to mean that one project is not easily compared to another. The scope of a project differs depending on the objectives to be met. Furthermore, because the project is unique, it involves a level of uncertainty. Finally, the project should deliver beneficial change. Here, a clear distinction is made between the temporary project and the more standard operations. We undertake projects because we cannot produce, or achieve, the benefit by performing routine activities, and the expected benefits from doing the project outweigh the risk (Turner, 1993).

Product activities in product development

When studying PD at a product activity level, the analysis is often focused on engineering design and the activities that directly impact the design of the product. While there is a vast amount of PD activity models (e.g., Pahl and Beitz, 2007, and Ulrich and Eppinger, 2003), these models vary their approaches depending on what is being developed. Other authors argue for the importance of different aspects of PD, e.g., integration of work procedures, information management, and support tools, such that the complexity of PD can be managed in an effective and efficient way (Norell, 1992). Ottosson (2004) argues for Dynamic PD

(DPD) which aims at supporting real-time communication of qualitative information. DPD also facilitates control and guidance in real-time, reducing unwanted events.

However, design is not the only activity on a product activity level adding value to the overall performance of a PD organization. In a PD project, there are several aspects which contribute to the success of a product and its overall goal, e.g., revenue and market share. These aspects are impacted through decisions being made on a product activity level. Hansen and Andreasen (2004) argue for the aspects of: use process, project tractability, product, business, and product life cycle. These aspects cannot be separately handled from the project management and product strategy level and must be viewed holistically when making decisions in order not to sub-optimize.

Uncertainty versus risk

It is apparent that uncertainty exists in everyday life, in organizations, and in projects. Uncertainty in a business situation is often expressed verbally in terms such as "it is likely", "it is probable", "the chances are", "possibly", etc. There are several attempts to classify what uncertainty is. Frank (1999) describes uncertainties as either aleatory or epistemic. Aleatory uncertainty cannot be foreseen (from the Latin alea, meaning die (pl. dice), having to do with chance). Epistemic uncertainty, on the other hand, is defined from a lack of knowledge (could have been foreseen given more knowledge). Hillson and Murray-Webster (2005) assert that the two aspects of uncertainty are variability and ambiguity. Here, variability means when a measurable factor can have one of a range of possible values. Such uncertainty is, as described by Frank above, known as aleatory. The event is defined but the outcome is uncertain because it is variable. Ambiguity, on the other hand, is defined as uncertainty of meaning. It can be applied to determine whether a particular event will happen at all, or whether something else unforeseen might occur. Also, this type is described as epistemic uncertainty since there is incomplete knowledge about the situation under consideration. Pender (2001) argues that uncertainty applies when there is no prior knowledge of replicatability and future occurrences defy categorization (i.e. aleatory uncertainty).

In decision modeling, uncertainty is defined as the amount of lacking information that can become knowledge (i.e. epistemic uncertainty). It is not possible to see the link between uncertainty, risk, and opportunity from this. Instead Hillson (2004) attempts to link risk with uncertainty based on the distinction between aleatory and epistemic uncertainty in the following couplet: ***Risk is measurable uncertainty; Uncertainty is unmeasurable risk.*** This implies that an uncertainty is to be considered a risk when measurable. However, Hillson considers risk as having both positive and negative consequences on project objectives. This also follows Lefley (1997), who argues that although risk results from uncertainty, risk and uncertainty are theoretically not synonymous. Risk involves situations where the probability of outcome is known. Uncertainty is when the probability of outcome is unknown. It is obvious that different opinions exist regarding what to consider as uncertainty, risk and opportunity. Hence, in this paper, it is argued to view risk and opportunity as being derived from uncertainty.

Performance in product development

In organizations, project and process metrics are measured and acted upon. Since some activities are far too complex to be measured, processes, models and other simplifications provide the possibility to measure performance. Often, performance is perceived primarily in terms of dimensions that can be measured, such as time and cost, or particular aspects of quality (Chapman and Ward, 1997).

Nowadays, many companies have identified a number of key processes to ensure success in achieving project objectives. Project management involves several processes utilized to achieve the best possible management of a project. Different objectives of processes, both transactional (e.g., strategy processes, risk, and opportunity management) and operational (e.g., manufacturing), imply differences in there ability to measure their performance. Although most processes have some type of metric to measure performance, their impact on the overall PD performance is difficult to measure. The basis of the process view is embodied in the following principle: for organizations to be more efficient and effective, the various functional areas need to work together towards a common goal (Sandhu, 2004). Since both transactional and operational processes interact and support the project management process, several sources of uncertainty are present which can influence the project outcome. The successful business will be the one that manages its projects most effectively, maximizing competitive benefits while minimizing the inevitable uncertainty (Hillson, 2003).

The outcome of these processes depends on their ability to appreciate the presence of uncertainty. Measurements of the performance of a PD process are associated with some implications. This is mainly due to the reason that uncertainty itself cannot easily be measured against a business related value (i.e. the presence of uncertainty cannot easily be defined in terms of time, cost and quality).

There is a lack of consistency in the definition of performance in the literature (O'Donnell and Duffy, 2002). Within PD, effectiveness and efficiency are often common denominators in the various definitions of performance. Sink and Tuttle (1989) describe effectiveness as doing the right things at the right time, with the right quality. Efficiency is similarly described as doing things right, often expressed as a ratio between resources expected to be consumed to resources actually consumed. The process of measuring performance has triggered a substantial amount of research attention. The most commonly cited article and the most widely accepted performance measurement system is of the Balanced Scorecard (Neely, 1999). A more recently introduced performance measurement system is the Performance Prism. This system is organized around five distinct but linked perspectives on performance: stakeholder satisfaction, strategies, processes, capabilities and stakeholder contribution (Neely *et al.*, 2001).

In manufacturing, as an example, inventory turnover and gross margin percentage can be used as metrics of the manufacturing process (McGrath and Romeri, 1994). However, PD is

more difficult to measure and there are no broadly accepted performance metrics as there are for other business processes. O'Donnell and Duffy (2002) have developed a design performance model, based on IDEF0 (Colquhoun *et al.*, 1993), which tries to clarify the performance syntax. A basic but general activity model is shown in Figure 1.

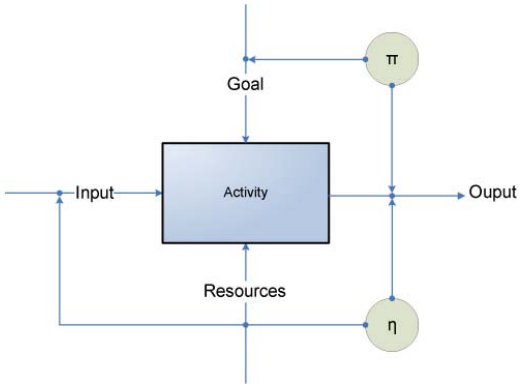

Figure 1. An activity uses resources to transform input to output under the direction of goals and constraints. The relation of effectiveness (Π) and efficiency (η) to the input and output variables is also shown. (O'Donnell and Duffy, 2002)

An activity uses resources to transform input to output under the direction of goals and constraints (O'Donnell and Duffy, 2002). Input refers to the initial state of knowledge while output is the final state of the performed activity. Resources is not just the people involved in the activity but also other resources like computer tools, materials, techniques and information sources. Goals are specific elements of knowledge that direct the change in the state of the activity from the initial input to the final output state. Further, O'Donnell and Duffy (2002) use this model of an activity to define efficiency (η) and effectiveness (Π).

The Product Development Organization Performance Model (PDOPM)

In this section the PDOPM is introduced, see Figure 2. The PDOPM is a holistic model based on three generic levels of activities in the PD: product strategy, project management, and product activity. Each of these generic levels can be modeled as an activity according to the IDEF0 (Colquhoun, *et al.*, 1993).

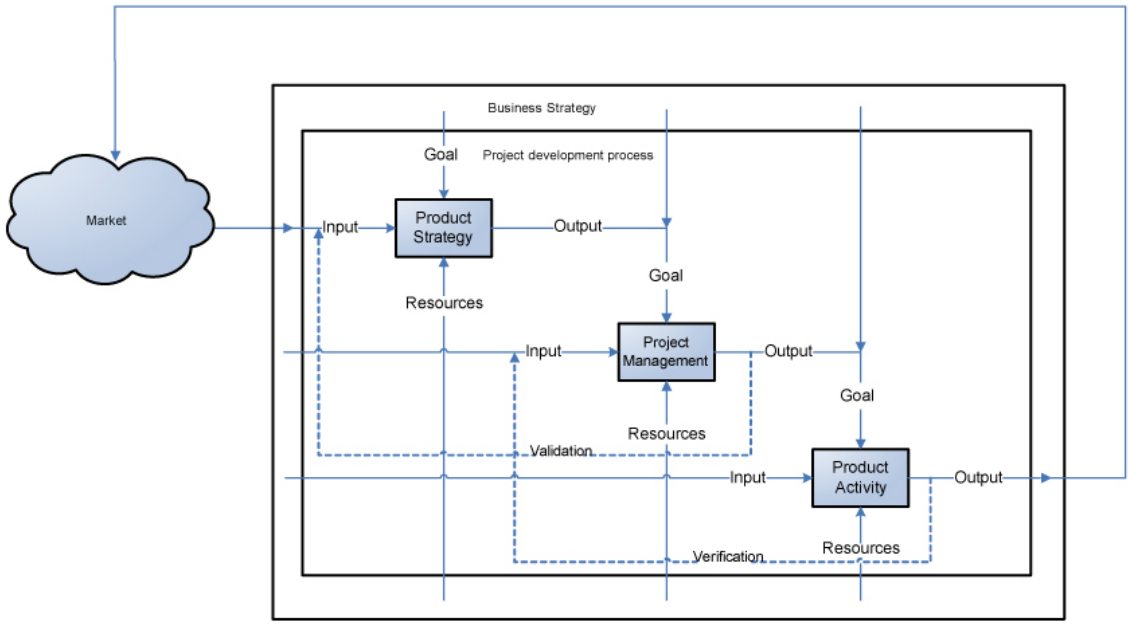

Figure 2. The proposed PDOPM model with the three generic levels of activities: product strategy, project management and product activity. The validation and verification loops illustrate the knowledge fed back to the product strategy and project management.

Each of the three generic levels of activities uses resources to transform input to output under the direction of goals and constraints. In the product strategy, the decision of what product to develop is made and a PD project is initiated, realizing the selected customer needs. The project management activity, then, translates the selected customer needs into a product specification, serving as a goal for the product activities, where the product is created according to the specification. As for every activity, it is important to acknowledge the associated uncertainty. The PDOPM appreciates the inherent uncertainty in PD, as well as the uncertainty in activity input and in the decisions on output. In the next section, this model will be further detailed on the different generic levels of activities and how performance, including uncertainty, can be modeled in the PDOPM.

Three Views on PDOPM

The PDOPM is based on three generic levels of activity identified in the PD process. These are further described below.

Product strategy in PDOPM

Within military strategies it is common knowledge that a strategy and its objectives (i.e. output) does only survive until the first contact with the enemy. This reasoning and understanding stems from the experiences gained in warfare. This shows that although a comprehensive and, at the time, accurate plan is developed, uncertainty affects the strategic planning and cannot be disregarded. Thus, the effect of uncertainty in PD performance must be appreciated in goal setting and in the input needed to create an efficient and effective output.

In business, value creation is typically measured by profitability and long term growth. In order to achieve these goals, a company must establish a continuous process for developing and deliver a steady stream of products, based on its business model, which offers unique and differentiated benefits to a chosen set of customers (Spitzer, 2007). The objective of the PD portfolio needs to be defined and the meaning of their attainment for the overall goals of the organization must be clearly communicated (Ernst, 2002). The first step in the product strategy is to overview all the current stakeholders. Neely *et al.*, (2001) propose a broad perspective, in contrast to the Balanced Scorecard, on stakeholders encompassing employees, suppliers, regulators, alliance partners, and intermediaries e.g. all parties that can have a substantial impact on the performance and success of the PD process. In this research, product strategy is viewed as a pattern of decisions and actions performed today to ensure future success. The product strategy activity with the definitions of goal, input, resources and outputs are further discussed below.

Goal: The primary objective of the product strategy activity is to fulfill the business strategy. It is important that the product strategy is aligned with the business strategy since it is the chosen path for overall company success. The goal of product strategy is to implement the business strategy. By having a clear link to the business strategy it will be easier for senior management to be more active in the PD process.

Input: The initial knowledge about the business strategy's targeted market needs. These needs can be divided into unsatisfied needs and needs fulfilled poorly by today's solutions. Knowledge about new technology development, both internal, within the company, and external, outside the company, is an important factor in deciding what product should be developed.

Resources: The main resource and responsibility of this activity is of the product manager. In many companies there is a steering committee assisting the product manager with this activity. Normally, senior management from marketing, sales, manufacturing, finance, etc is involved in the product strategy.

Output: The chosen market needs, are the output from the product strategy. These serve as the goals for the project management activity. Hence, the output functions as a specification of what to develop in addition to budget and time-plan for market introduction.

The product strategy is a complex and important activity in the PD process. In this paper, the PDOPM is simplified by covering the design of one product through one project, i.e. having a single-product and project perspective. It is important to acknowledge that the product strategy activity is not completed when a PD project is initiated. Once a new project is

started, product management should secure that the right product is developed and monitor that the targeted customer needs still are of interest. Both of these tasks are important in securing a successful PD process.

Project management in PDOPM

PMBOK (2004) describes an objective as *something toward which work is to be directed, a strategic position to be obtained, or a purpose to be achieved, a result to be obtained, a product to be produced, or a service to be performed*. The objective of a project can be described in different ways. The most common manner is by using the iron triangle of time, quality and cost. Turner (1993) defines five project objectives: managing scope, organization, quality, cost and time.

When the product strategy activity output is decided, a PD project is initiated to ensure that the selected customer needs are realized in an efficient and effective way. The responsibility of managing the design belongs to the project management activity. The activities at the project management are the product manager's direct interface to the project. The Stage Gate model is a tool, commonly used by product managers to supervise and secure that the right products are developed (Cooper, 1993). The role of the project manager is to act as a catalyst between the output from the product strategy and the resources involved in the product activity. The project management activity should be performed in an iterative way, in close interaction with the product activities.

The essential purpose of uncertainty management is to improve project performance via systematic identification, appraisal, and management of project-related uncertainty (Chapman and Ward, 1997). After all, the management of uncertainty does not in itself, as a process, bring value to the project, but rather assists other processes to bring value to the PD process. The input, goal, resources and output of the project management activity, as modeled in Figure 2, are further discussed below.

Goal: The goal is derived from the chosen customer needs and what type of product should be developed e.g., the output from the product strategy activity. There is a budget and a schedule for when the product should be realized by the project. One important task for the project management is to agree to and clarify the goal of the initiated PD project with the product manager. There should be an agreement between product managers and project mangers on the PD project's objective in the beginning of the project.

Input: Previous knowledge of project management and newly developed products serve as input to this activity. Also, previous knowledge of the project management processes serves as input. Companies developing CoPS often use some type of platform or architecture that can be used by the project. Knowledge about the limitations and possibilities is also an important input for the project management activity. The s-curve is argued to be useful as a tool for predicting when a technology reaches its limit and when to move for a more radical one (Foster, 1986).

Resources: For smaller projects, it is common to only include the project manager. In more complex PD projects there is often a project core team to assist the project manager in managing the project.

Output: Is a project requirement specification with concrete activities that will function as goal for the product activity. It is important that the specification is complete since it will function as the goal of the project management activity. There should also be a project plan, including a schedule for activities that will be performed in the product activities.

The project management activity serves as a bridge between the product strategy and the product activities. To do this successfully it is important that the project manager understands and is able to communicate the requirement specification. If this is not performed in an effective way there is a risk for designing the wrong product.

Product activities in the PDOPM

The product is designed during the product activities. The product activity includes all activities requested by the project management. The role of the product activities is to solve and realize the initiated activities as efficient and effective as possible. The product activities should be performed in close cooperation with the project management since it is an iterative process. The product activity, as modeled in Figure 2, with a goal, input, resources and outputs is further discussed below.

Goal: The objective with the product activity is to fulfill the requirement specification developed in the project management activity.

Input: Includes, e.g., knowledge about prior projects and product activities, development processes and working tools. A new product is not often developed from a blank paper rather than starting from a previous product or architecture. Therefore, it is important that the people involved in the product activities are familiar with this previous knowledge.

Resources: All resources used by the product activities are included. Primarily this involves the personnel but also computer tools, materials, techniques, and information sources.

Output: Is not just the finished product, it also consists of the deliverables, specified in the product requirement specification, which together make up the product. The finished product normally involves different parts that are integrated to a final product.

Within a PD project, it is important that the goals from the project management activity are broken down into well-defined activities that can be realized in an efficient and effective way. To be successful in the product activity it is important that all activities are performed in close cooperation with the project management activity. This is especially important for two reasons. The first, involves ensuring that the right product is developed. The second reason is to monitor the progress to make sure that the budget and schedule are kept. If there are deviations it is important to be aware of them early to be able to address them.

Product Development Performance in PDOPM

Performance in PD is seldom defined and there is no consensus about what performance is (O'Donnell and Duffy, 2002). The proposed PDOPM makes it possible to define efficiency, effectiveness and uncertainty (see Figure 3) within the three generic levels of activity: product strategy, project management, and product activities. Measurement, when done properly, i.e., linked to a purpose or goal, that managers and employees have accepted, can drive and motivate performance improvement (Sink and Tuttle, 1989).

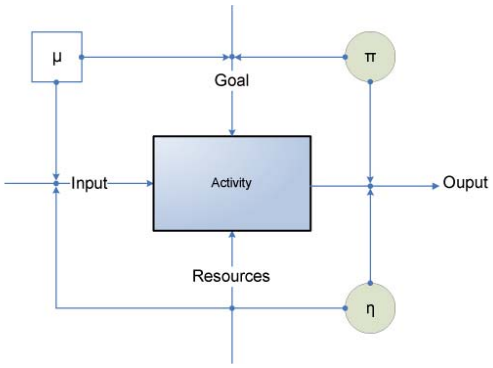

Figure 3. Illustrates the relation of uncertainty, effectiveness and efficiency to the input and output variables of an activity.

Performance and product strategy

Product strategy effectiveness (Π) is defined as how the output meets the goal. In this case, the goal is to fulfill the business strategy and thus, it is important that the output is clearly linked to the business strategy. To do so, ownership from upper management is encouraged and it is, as previously stated, an important success factor. By achieving effectiveness in the product strategy, a foundation for successful PD is established.

Product strategy efficiency (η) is defined as the difference between output and input divided by the resources used, i.e., the cost to realize the output. The output of the product strategy is what market needs the new product is satisfying and the input is the initial knowledge prior to the activity. Therefore, it is important that the difference is not too complex and can be managed by the resources, i.e., senior management, involved in the product strategy. Efficiency of the product strategy is often forgotten and not explicitly measured.

Product strategy uncertainty (μ) is defined as the difference between the goal and the input. This means that the uncertainty in product strategy is a measure of the new knowledge that is required in the PD project. This uncertainty measure could be used in the portfolio evaluation to make sure there is a mix between incremental and more radical PD projects. Within the PD portfolio, there should be a mix of uncertainty in order to get the most return of the investment.

Performance and project management

Project management effectiveness (Π) is defined as how the output meets the goal, e.g., how the selected customer needs, output from the product strategy, are transformed to a product specification. Effectiveness within the project management is, therefore, a measure of how the project is realizing the scope of the project. Effectiveness is achieved when all the selected needs from the product strategy have been fulfilled. Hence, it is important for the project manager to act as a bridge between the product strategy and the product activities.

Project management efficiency (η) is defined as the difference between output and input divided by the resources used to realize the output. Efficiency is closely related to the project planning. If there are problems with the efficiency in the project management activity, it is noticed in budget and time overruns as a result of product activities with to much complexity. Project managers tend to focus on finishing the specified activities on schedule and budget, i.e., the efficiency aspect. It is, therefore, important to remember that if the effectiveness of the project management activity cannot be guaranteed, everything else is of minor importance.

Project management uncertainty (μ) is defined as the difference between the goal and the input. Hence, it is a measure of what has to be created by the PD project. If there is a lot of new knowledge needed in the project, the product activities tend to be complex and will therefore affect both efficiency and effectiveness. Project management uncertainty can be viewed as a leading indicator of the effectiveness and efficiency.

Performance and product activities

Product activities effectiveness (Π) defined as how the output, i.e., the realization of the activity, meets the activity's goal. This is an important measure, often is focus turned to the output and the goal is forgotten. It is when the product activity effectiveness can be accounted for that focus can turn to measuring and securing the efficiency. An ultimate failure of the PD process would be to have product activities that are managed in an efficient way, on time and budget, but they do not meet the goal. It is therefore vital that a project manager within PD always focuses on securing the product activity effectiveness by communicating a clear and well defined goal for the activity.

Product activity efficiency (η) is defined as the difference between output and input divided by the resources used to realize the output. Thus, efficiency in product activities may be used as a measure to make sure that the invested resources are used in the best possible way. Improving the product activity efficiency is often done by improving the PD processes, tools, or competences. Often, the product activities do not begin with a blank piece of paper when developing a new product. A shared platform or architecture is often available for the product activity to be used as a base and starting point. Product activity efficiency is dependent on the existence of a platform or architecture, supporting the implementation of the specified product. It is a difficult task to know when a new platform or architecture should be developed in order to secure product activity efficiency.

Product activity uncertainty (μ) is, as previously presented, defined as the difference between the goal and the input. It is therefore a measure of how complex the activity is, and, therefore, what type of resources is required for an efficient and effective implementation of the activity. By measuring the product activity uncertainty, it is possible to manage the uncertainty and to discover potential problems early, when there is still time for changes without risking any substantial costs.

Performance in the product activity is achieved when uncertainty, effectiveness and efficiency are being managed. The objective of increasing performance may be accomplish by identifying weaknesses and address them early in the PD project.

Verification and Validation in the PDOPM

Every company seeks to fulfill the customer needs of the targeted market. As a result, the company needs to manage certain market specific constraints in order to be successful. Within the defense industry, for example, there may by a lead time of many years for a new PD project. This could be compared with, e.g., the mobile phone industry where time to market is a deciding factor on the success of a new product. The time factor within the PDOPM is not explicitly shown in the model. However, there is strong time dependence in the PDOPM, which is incorporated in the verification and validation loop, see Figure 2. The two feedback loops also represent the learning's that can be drawn from each generic level of activity in the PD process. Validation and verification may be used by PD management to ensure that the correct activities are being performed, and the different outputs match the specified goals.

Validation in the PDOPM

The validation loop represents the feedback from the output of the project management and it is modeled as an input to the product strategy. The validation represents the possibility for the product manager to see the progress of the PD project. Also, the validation could be viewed as a representation of the time to market constraint of the chosen customer needs. The task of developing the right product is often taken for granted and therefore not questioned once a project is started. It is possible that the customer needs change during a PD project, especially when the cycle-time is measured in years. If the customer needs have changed, it is important, if necessary, to terminate the project and focus the scarce recourses on the other projects in the PD portfolio. The lead-time of the validation loop differs between markets and products. As mentioned, in the defense industry, a lead-time of many years for a PD project is common, compared to the mobile phone industry where the introduction of a product a week too late, can be the difference between success and failure of a new product. The validation

loop influences the verification loop since, if there are changes in the customer needs, they must be reflected in the PD activities.

Verification in the PDOPM

The verification loop in the PDOPM is modeled as the feedback from the product activity output to the input of the project management activity. By representing it this way, it shows the possibility for the project manager to view the progress and the output of the product activities. Through verification, it is possible to ensure that the produced output from the product activities is aligned with the goal, e.g., the output of the project management activity. The verification loop can also be viewed as a representation of the lead-time of a company's internal product realization capability. The product realization capability is constrained by the timeframe of the validation loop. If the chosen market is expecting new products every year, the PD lead-time within the company must be within that limitation. It is important to monitor the verification loop during the PD cycle to secure that the output from the PD project is aligned with the output from product strategy. If the selected customer needs have changed, it is important to understand these changes and to act accordingly. The timeframe of the verification loop differs depending on the validation loop, as the verification timeframe is linked to the validation loop. Hence, changes in the market put constraints on the verification loop in order to fulfill the validation time frame.

Applying the PDOPM in an Industrial Setting

As a first attempt to verify the PDOPM, it has been used to analyze some problem areas identified during a previously performed case study. The PDOPM can be used as a tool for identifying the root cause of problem areas within PD. To verify the PDOPM the following problem areas where selected from the result of the case study:

(i) Complicated solutions are often selected, even when there is no obvious reason. This prohibits reuse of known solutions and standard products. As a result, an unnecessary amount of, e.g., special cables are used by the different products. A discussion to reduce the number of components has started, but there is a lack of long-term thinking, as everything is short-term oriented.

(ii) It is not unusual to have overload in the PD process, both in the PD project and in the project portfolio. As a result, overruns in budget and schedule are a recurring phenomenon. An illustrative quote from one of the respondents: *"In a normal distribution with the expected value of five it is still possible to get twelve but over time you still get five. We run the company as if we could get 12 in average."* The effect is that at the end of the PD project, requirements that have not been fulfilled are cancelled in order to deliver on time. This is a process that is well known within the case company but difficult to change. One respondent expressed it: *"It is like obesity; we know it is not good but we keep eating anyway"*.

(iii) The view of PD performance is focused on shortening cycle-times, deliver on time, and reduce time to market. Looking at the NPV calculations in the business case it is clear, in

order to receive a positive cash flow as quick as possible, reduced cycle-times and time to market are essential. Quality is also mentioned together with performance. The case company has substantial costs related to products delivered to customers and not working properly.

Root cause analysis of the three identified problem areas

The first problem area is related to the product strategy activity in the PDOPM, see Figure 2, but in the case company it is not managed as one. The necessary decisions are pushed away and end up in the project management activity. As a result, the decision has to be made by the project management activity within each project. The outcome is a PD project making decisions based on the knowledge and the needs of the projects. Sub-optimization in the perspective of the case company may be the result, when a PD project makes their decisions without clear and well defined goals from the product strategy. The lack of long-term product thinking is a natural phenomenon when the product strategy activity is not managing this issue properly. Expressed in terms of the PDOPM, the output from the product strategy is missing important strategic information, needed to guide the project management activity. Ideally this would be discovered by the product management through the validation loop.

Project management is involved in the second issue. Overload of the project in the early phases and running the company faster than it is possible, is a phenomenon that can be analyzed in the validation and verification of the PDOPM. The capacity of the resources employed by the PD project is a vital input for the project planning, within the project management activity. Moreover, it may solve overload issues in the PD pipeline by thinking of the validation and verification loops and using the gained knowledge to initiate changes in the output of the product strategy activities. Discussion of project management uncertainty may also be useful in order to reason about the complexity required by the PD project. Project overload can be interpreted as failing to manage the product strategy and project management uncertainty, since it represents the new knowledge needed to create the decided output from the product strategy.

The third problem area is of PD performance and the need for a holistic view. To improve performance, focus should also turn to the product and project management activities and not exclusively focus on the product activity output. It is of course important with decreasing cycle-time, deliver on time and shorten time to market, but when the complete PD process is managed accordingly, it may lead to incremental updates and PD projects characterized by low uncertainty. The issue of not being able to deliver on time may be the result of overload and poor knowledge, as illustrated in the second issue. Reducing time to market and cycle-time of PD projects is easily achieved by focusing on incremental instead of radical updates. An important factor might be to forecast the capabilities of the resources and how they should be managed to achieve maximum potential. The performance of PD, illustrated in this issue, is focused on the efficiency aspect of performance in the project management and product activities of the PDOPM. If uncertainty and effectiveness aspects of these activities were included together with performance of the product strategy, the focus of maximizing the value contribution of the PD budget could be achieved.

Conclusion and Future Research

The PDOPM suggested in this paper enables PD managers to adopt a holistic view and to analyze the PD process from the perspectives of product management, project management, and product activities. The model can be used as a conceptual tool to reason about performance, thus, making it possible to question the performance within each level of the PD process. It is argued that, by modeling the three generic levels as activities, it makes the often abstract activities in PD more understandable. This is done by reasoning about input, goal, and resources, not just the output. This applies particularly to the product strategy and project management activities. Further, the definitions of effectiveness, efficiency, and uncertainty for each generic level are useful ways of analyzing performance, even if there is no tangible output created. This may be especially useful in the product strategy and in the project management activity.

In industry it is common for management to look for simple solutions to boost performance of the PD. Focus is often turned to the efficiency of the product activities in order to improve the overall PD performance. In this research it is suggested that performance in the PD process is achieved through three steps. The first step is to manage the uncertainty, since it is the knowledge of what needs to be created to fulfill the goal. Next step is to secure effectiveness, in order to create the right product. Once the first two steps are established, focus on efficiency, e.g., developing the product right, becomes important. Performance is attained when uncertainty, effectiveness and efficiency is managed in all of the generic levels of activities in the PDOPM.

There is extensive research available within each of the generic levels of activities in the PDOPM. However, instead of bringing them closer together in a system view of the complete PD process, a tendency to divide and separate them from each other exists. This may be the reason why the industry is still struggling to make use of all theories available. In this research it is suggested that the major issue is not the available knowledge in each of the generic levels of activities, but the ability to holistically manage the PD process. Only by adopting a holistic view, it is possible to identify the difficulties and limiting factors present in a company's PD process without sub-optimizing. By identifying and improving the weakest parts, the highest lever of overall performance, is achieved. Future research will focus on further verify and develop the model by case studies within the context of complex PD.

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