PMEX – A Performance Measurement Evaluation Matrix for the Development of Complex Products and Systems

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Abstract

A key aspect in a sustainable economy is to be able to do more with less by making better use of resources. Within the development of complex products and systems, a continuous need to improve performance exists, i.e., making better use of a company's resources. In this improvement process it is important to measure the performance of the product development process. Previous research mainly focuses on the design and implementation of new performance measurement systems, not on evaluating the measures currently used. The research question in this paper is how to evaluate a company's performance measurement systems from a manager's perspective. To answer this question, a performance measurement evaluation matrix (PMEX) is developed. The PMEX has the different phases of the Stage-Gate process as one dimension and important success factors in the development of complex products and systems as the other dimension. Furthermore, a multiple case study has been conducted as a first verification of the PMEX. The first results of the study indicate that the PMEX enables managers to overview what is and what is not measured. The PMEX can therefore function as a conceptual tool in the discussions for setting the scope of the performance measurement system.

I. Introduction

There is a consensus in that the market has never been more competitive than today. Technological advances, intensified global competition, changing customers and needs are some of the characteristics of the market of today [1], making the need for an effective and efficient product development (PD) process greater than ever. An important tool in the quest for a high performing PD process is the ability to measure performance. Measuring performance within a process is a classical research problem and also known as a complicated one. This paper studies performance measurement systems within the development of complex products and systems. A complex system e.g., a system comprised of interconnected simple parts, that together exhibit a high degree of complexity from which emerges higher order behaviour. Moreover, no single person understands the complete system. Often is the system long-lived and has been evolved over generations of engineers. In [2] complex products and systems are defined as high cost, high technology, engineering intensive, and business to business capital goods used to produce goods and services.

This paper takes a PD manager's perspective on performance measures in the development of complex products and systems, thereby emphasizing a holistic system view of the PD process. The research question in this paper is how to evaluate a performance measurement system from a PD manager perspective. There is a vast amount of research within the area of performance measurements available, mainly focusing on design and implementation of a new performance measurement system. However, the development of a new performance measurement system is related with high costs and a time consuming implementation process. Furthermore, there are few research studies with focus on evaluating the existing performance measures of the PD process. To address this issue a method for holistically evaluating performance measures within this context is proposed. PD managers often know they have a less than optimal performance measurement system but lack the ability to pinpoint what is good and what is not with the current system. Keeping measurements relevant to the changing business and organisational context is a problematic area, as "old" measurements are often not discarded and the new measurements are merely added to the confusion [3].

The outline of this paper is as follows: in Section II a brief presentation of the method and methodology used in presented research and continues in Section III with a short overview presenting previous research within PD and performance measurements. In Section IV a categorization of the PD process is proposed and the success factors identified in this research within the development of complex products and systems are presented. Moreover, Section IV then continues with a presentation of the proposed Performance Measurement Evaluation Matrix (PMEX).

Further, in Section V a first verification of the PMEX is performed. The verification begins with a mapping of the, in this research identified, success factors with the success factors within PD, identified in the literature. Two case studies continue the verification, where the PMEX is applied to two sets of performance measurement systems currently used by two Fortune 500 companies developing complex products and systems. The paper ends with conclusions and future research in Section VI.

II. Method and Methodology

To deal with the complexity of measuring PD performance, a systems theory combined with an actors' approach has been adopted, in accordance with the views of [4]. Increased complexity stresses the need for models that could be used by teams to develop a shared understanding [5]. 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 [6].

In presented research a method is proposed, to evaluate the performance measures within the PD process based on the PMEX. The success factors and the classification of them into a conceptual framework for performance in PD were done based on the results from interviews and a workshop where senior PD managers from seven different industrial companies developing complex products and systems participated. The participating companies are all international companies, based in Sweden. They all have extensive experience in developing complex products and systems within telecommunications, automotive, heavy vehicles, and automation. In the workshop the participants were asked for factors important for an effective and efficient PD process. The classification of success factors and the identification of gaps in existing literature gave rise to the PMEX. Moreover, the PMEX has been verified through two case studies with the aim of verifying how the PMEX can be used at a company developing complex products and systems within the area of industrial automation and heavy vehicles. The case companies are both divisions within two fortune 500 companies with a high R&D intensity in comparison to revenues. A total of 29 semi structured and open interviews were held at the two case companies to identify how they perceive performance and how it is measured at different levels of the organizations. These results were then incorporated into the PMEX. Furthermore, the authors professional work experience within complex PD was also used for reasoning during the development of the PMEX.

III. Related Work within Product Development and Performance Measurements

Turning an idea for an innovation into a successful product is by definition a unique experience and as such cannot be treated as a purely bureaucratic process. It must be treated as a project: a finite activity with its own objectives and resources, and above all its own leadership [1]. Measuring PD performance over time is complex due to inherent uncertainty [7]. The area of performance measurement has interested scholars with different functional backgrounds. A vast amount of research is available both within the area of performance measurements and within PD. Still, few studies analyze the PD processes from the performance measurement system perspective [8]. Nevertheless, the model proposed in [9] establishes the main guidelines for developing such an analysis. This model presents the PD process as a complex system consisting of two independent and parallel processes: the PD process itself and the evaluation process, i.e., the evaluation of the implemented performance measurement system.

The product development process

The term PD is often used without a proper definition. The research presented in this paper emphasizes a holistic view on PD by proposing the following definition:

"Product development is the set of activities beginning with the processes and tools used to perceive a market opportunity and ending in the production, sale, and delivery of a product fulfilling that market opportunity."

In this research a PD project is to be considered successful if its products not only fulfils the needs and requirements of its customers, but also generates profits to its shareholders, and creates value to its stakeholder at large. Furthermore, the proposed definition of the PD process implies it spanning several different functions within a company, not just the R&D organization. In [10] a generic process is suggested for PD including: planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up. This generic PD process is depicted below in Fig. 1.

Fig. 1. The generic phases in the PD process involve planning, concept development, system-level design, detail design, test and refinement, and production ramp-up [10].

The process of PD within industry is diverse, both in the sense of novelty and type of products being developed. In this research, organizations developing complex products and systems are the unit of analysis. Complex products and systems are customised, high valued, capital goods, products, systems and networks, usually produced as one-off projects or in small batches [11]. Typical characteristics for this type of development projects; they are often executed by large organizations with a large network of contractors, subcontractors, suppliers and users [2]. A successful implementation is dependent on this network working well together.

The reputable Stage-Gate process [9], based on Booz, Allen and Hamilton's model (BAH), is both a conceptual and an operational model intended to move a new product from the idea stage through to market launch and beyond [8]. The generic Stage-Gate process [12], shown in Fig. 2, include stages and gates. There are strong similarities between the generic phases in the PD process and the stages in the Stage-Gate process. It is during the stages where the development work occurs; the project team completes activities to reduce business risks and advance the project to the next gate. The different stages are cross-functional and each activity is undertaken in parallel to accelerate speed [12]. Since each stage costs more than the preceding, an incremental commitment is achieved with each stage [13]. As uncertainties decrease, expenditures are allowed to rise and risk is managed. Gates are where the Go/Kill and prioritization decisions are made [12]. Mediocre projects may be culled out and resources could be allocated to the most promising projects of the portfolio. The focus during the gate decisions should be on three key issues: quality of execution, business rationale, and the quality of the action plan [13]. Often, different scorecards and criteria are used to evaluate a project's potential for future success.

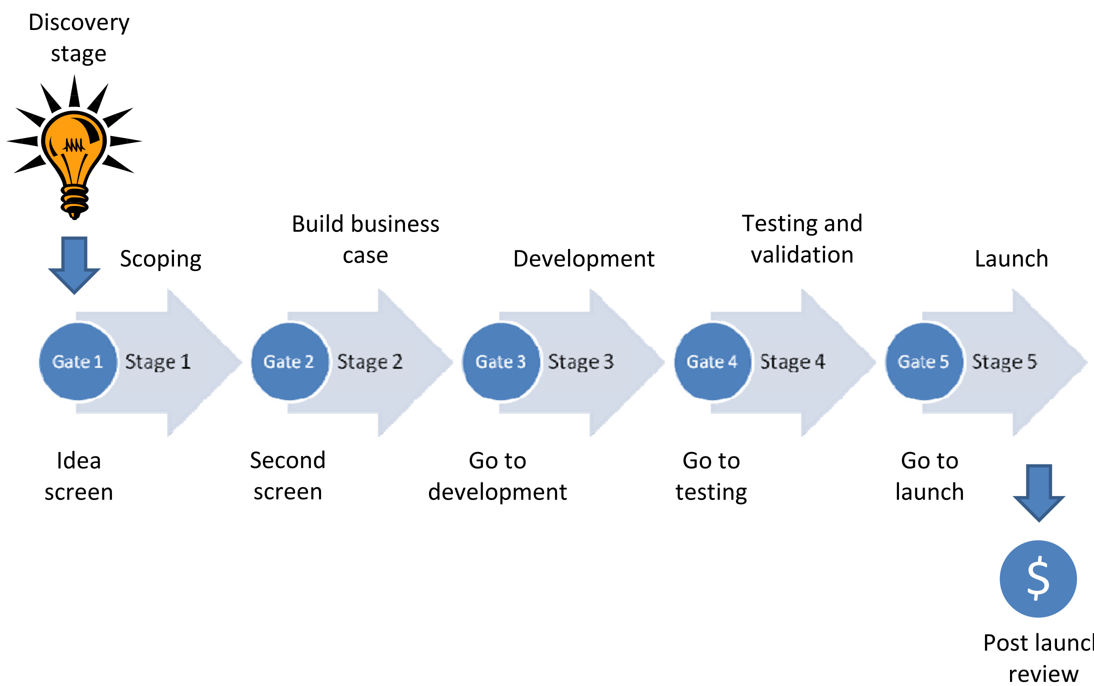

Fig. 2. The generic Stage-Gate process [12].

A study conducted by [14] shows that 60% of profit organizations are using a Stage-Gate or similar process for PD, whereas 39% indicated no formal development process in the PD at all. Further, results indicate that companies modifying their formal PD process improve efficiency while not significantly sacrificing product novelty [15]. Stage-Gate usage has also proven to be significantly related to PD process improvements and has indirectly but significantly been related to new product profitability [15]. Usually the Stage-Gate process involves four to eight stages and gates in a by the company modified process [8].

Performance measurement

The area of performance measurement has inspired numerous scholars. Researchers with functional backgrounds as varied as accounting, operations management, marketing, finance, economics, psychology, and sociology are all actively working in the field [16]. Performance measurement within PD belongs to the broader area of business performance measurement. There are several motives why it is important to measure performance. In [17] four different reasons for measuring performance are proposed: *check position, communicate position, confirm priorities*, and *compel progress*. This illustrates an important fact: measurements alone is not a direct value adding activity, value is achieved when the result of the performance measurement system is actively and adequately used by management.

The most wide spread and cited performance measurement system is the Balanced Scorecard [18], introduced by Kaplan and Norton in 1992 [19]. The literature reveals that the Balanced Scorecard still prevails as the dominant performance measurement system [3]. Financial measures alone cannot adequately reflect factors such as quality, customer satisfaction, and employee motivation [20]. This was the reason behind the development of the Balanced Scorecard, to balance the financial perspective with the perspective of customers, learning and growth, and internal business processes. Successful implementations of the Balance Scorecard, however, are much less prevalent and translating the Balanced Scorecard into concrete action is still a problematic area. In [7] a framework to integrate the Balanced Scorecard in R&D management is presented. However, the Balanced Scorecard has not reached the same success within PD as it has within the more general business performance measurement system. Balanced measurements are designed to provide a balance by including measures of external success as well as internal performance, together with measures designed to give an early indication of future business performance as well as a record of what has been achieved in the past [21]. Leading indicators includes measures affecting the process, while lagging indicators measure the result of already performed processes. There are several other different classifications of performance measurements. Two common basic distinctions are *quantitative* and *qualitative measures*. For example computational methods clearly leads to a quantitative value e.g., time to market has been six months, whereas assessment methods usually result in a qualitative indication of the metric value e.g., time to market has been "good" or "unsatisfactory" [22]. Further, quantitative measures are often divided into financial and non-financial measures.

Research within performance measurements is often focused on the design and implementation of a performance measurement system. Still, little attention has been paid to the implementation of a complete performance measurement system covering the whole PD process [8]. There are several models and frameworks other than the Balanced Scorecard available but few of them have explicit focus on the PD process. A newly developed framework is the Performance Prism [23] that emphasizes a more holistic approach to the stakeholder perspective of performance measurements, compared to the Balance Scorecard. Moreover, few studies within performance measurement involve a holistic evaluation of the currently used performance measurement system. Merely half of the ten performance measurement systems, identified in [24], have some kind of evaluation of the current performance measurement system in their process of designing the new system.

Performance measurements are important as an aid to determine priorities, e.g., within different activities, and as means of providing direction to teams by highlighting how they are performing and where improvements would be most beneficial. However, the performance measurements must be kept in perspective; they must support the PD process and goal attainment [25] based on the business strategy. This implies the importance of continuously evaluating the performance measurement system. Process management theory suggests that one should not only implement the correct processes, one should also monitor how well the process is operating and, if necessary, intervene in a timely manner [26].

IV. The Performance Measurement Evaluation Matrix

In this paper a method for evaluation of a performance measurement system based on a Performance Measurement Evaluation Matrix (PMEX) is proposed. The PMEX provides PD managers with a tool to evaluate their currently used performance measurement system. Without a structured method, as the one proposed, it is difficult to assess what is measured and, maybe more important, assess what is not measured by the current performance measurement system. As described in Section III, PD is a dynamic and diverse task involving many different competencies and functions within a company. As a result, the process of PD differs between companies and domains of industries. This research focuses on evaluating the performance measures used by companies developing complex products and systems. Therefore, this research started with identifying important success factors within the development of complex products and systems. The first result of this research, a framework for performance in complex PD has been presented in a previous paper [27]. In the PD literature there are several studies identifying success factors but within the explicit area of developing complex products and systems such studies seems to be missing or their result have not reached a wide acceptance.

Conceptually, we have divided the PD process into three different categories based on our findings: *Planning*, *Implementation*, and *Marketing, sales and delivery* see Fig. 3. This categorization is in line with the definition of PD previously presented in Section III. The *Planning* activities typically involves decisions regarding what product to develop, especially the planning and concept development of the generic phases of the PD shown in Fig. 1. The *Implementation* activities are more operational in designing and constructing a product, typically involving system level design, detail design, test and refinement and the production ramp up, as shown in Fig 1. The final part *Marketing, sales and delivery* is important for the completeness of the PD process and in securing the overall success of the PD process. All the three parts of the PD process require unique specific competence and objectives if success is to be achieved. The PD process cannot be considered successful until the targeted customer needs are fulfilled and the new product generates profit. The reason for this categorization is to emphasize the different functions in a company needed in the PD process; it is not just a task involving R&D. Moreover, it is important to acknowledge the different competencies needed in the *Planning* compared to the *Implementation* activities of the PD process. In a performance perspective it is vital to differ between *Planning* and *Implementation*, since their objectives differ. *Marketing, sales and delivery* will not be further developed in this paper.

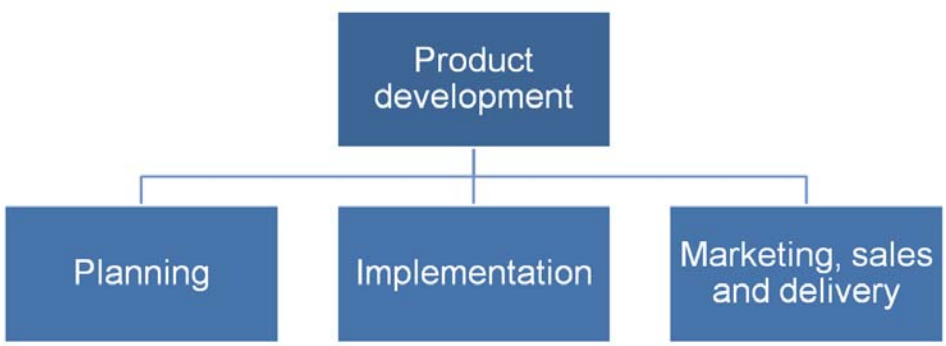

Fig. 3. PD can, for performance evaluation reasons, be divided into Planning, Implementation, and Marketing, sales and delivery of a product.

When a performance measurement system is to be evaluated, it is important to address *what* is measured and *when* it is measured. The motivation for a particular metric, the *why*, is also a central question in the process of evaluating a performance measurement system, especially since every measurement is inherent with a cost. To address *what* is measured, an analysis of success factors in the PD process within the seven participating companies has been performed. The result of this study was then categorized and the result is presented according to the PD Planning and Implementation sub-sections below.

Product development: Planning

The first part of the PD process, and unrelentingly the most important activities, is to decide why and what something needs to be developed. It is during the PD planning the upper boundary for overall success and profitability of the PD is set. The overall objective in the PD planning activities is to decide on customer needs and transform them into something that utilizes a company's resources the best possible way i.e., generate the best possible future cash flow. Two main questions emerged during this study as important, needing their answer during PD planning. The first questions are w*hat* to develop and *why*, the second set of questions are *how* and *when* to develop it, see Fig. 4. *What* and *why* are vital questions, since they set the boundaries for both the technical specification and the future cash flow. In a value creation perspective; once a company has decided *why* something needs to be developed and *what* product to develop, the future value of the PD investment is limited since the decision of technical solution and targeted market is made. Therefore, this is an important aspect of the PD process that needs to be managed accordingly in order to make the best possible use of a company's scarce resources.

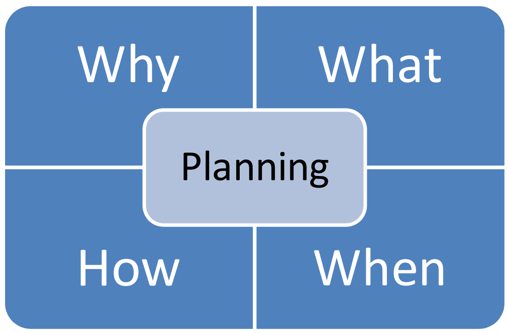

Fig. 4. Successful PD planning especially involves the following questions: *why*, *what*, *how*, and *when* to develop a product.

The *how* and *when* questions in the PD planning focus on utilizing a company's resources in the best possible way with efficient project execution as an important objective. A key success factor for *how* and *when* is not to start PD implementation activities if the key resources are not available. If a new PD project is initiated in an already fully utilized organization it will only slow the other projects down [23]. It is common for companies to initiate project after project without securing the key competence [3], in the quest for achieving higher performance. Further, technology planning that support and speed up the product implementation activities is a vital success factor [24]. The planning ends and the implementation starts when the firm decides to execute the PD project, i.e., implement the planned product. Table 1 illustrates the success factors that PD managers in our studies consider most important in the PD planning activities.

Table 1. Important success factors for performance in the PD planning [27].

Why & What		**How & When**	
Market Environment Analysis	Involves different aspects: technology, competitors, the customers' future business and processes, market knowledge etc.	**Technology Roadmap**	Develop the technology needed to support the product roadmaps.
Customer Needs and Wants	The ability to fully understand the customer needs and wants.	**Metrics**	Different metrics assisting the decision making.
Business Case	Clearly specify what this product will make profit of and why.	**Organization**	It shall have clear responsibility, mandate, culture, competence and roles to support the planning.
Product Roadmaps	A clear plan of how the product will evolve in the future.	**Ownership from Top Management**	It is important that the CEO understands how the PD process will generate future revenues and profit.
Risk Management	The ability to assess risks and work active with them.	**Planning Competence**	Understanding all the aspects: technical, market, economic, production, purchase etc. needs and address them.

Product development: Implementation

The PD implementation activities are all about project execution and to produce what was specified in the PD planning, as efficient and effective as possible. The ultimate success for the PD implementation is to deliver exactly what is specified within budget, on time, and with the specified quality. In the implementation activities there are several categorize of factors affecting the performance, shown in Fig. 5. The factors have been divided into four main categorize of success factors influencing the success of the product creation according to the analysis of the interviews and workshops: *management*, *process*, *technology*, and *people*.

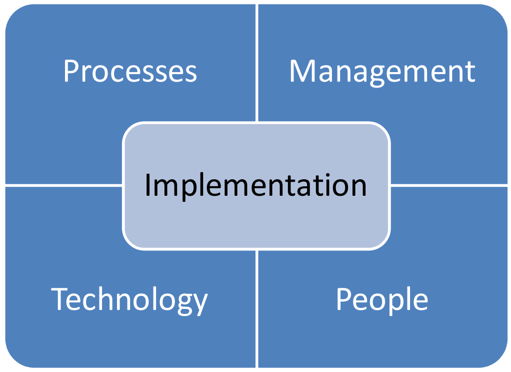

Fig. 5. Successful PD implementation especially involves: *processes*, *management*, *people*, and *technology*.

The PD implementation activities of the PD process could be looked upon as a manufacturing process, since the best possible outcome is to deliver exactly what was decided in the PD planning. However, for this to be reality it is essential that the technology supports the project with pre-development and re-use. Furthermore, it is important to have a properly planned project e.g., a front loaded project in order to achieve an efficient and predictable implementation process. It is also vital for the PD implementation to involve people in the project with an understanding of what is needed from them. The ultimate success during the PD implementation is all about time to market with sufficient quality. In order for management to make use of the resources in the most beneficial way, it is important that the project members find their assignments: professionally challenging, leading to accomplishments, recognition, and professional growth [12]. A study presented in [5] reveals that most of the new products, from automobiles to washing machines, are over engineered as a result of not communicating and managing the customer needs properly. In the implementation phase it is important for management to continuously update and communicate organizational goals and project objectives. Management also needs to illustrate the relationship and contribution of individual activities to the overall PD process and business case [12]. Table 2 and 3 illustrate the result from workshop and interviews with respect to success factors in the product implementation activities.

Table 2. Important success factors for performance in the PD implementation [27].

Processes		**People**	
Process Quality	The maturity of the processes	**Feedback**	Feedback to the people involved in the project to further develop their competence.
Clear Development Process	That everyone in the organization understands and are able to follow	**Culture / Attitude**	In the global world of today it is important to have every one work together as a team.
Tools	Updated tools that support the PD work the best way possible.	**Organization**	Important that the organization evolves with the changes that occur in the firm and thereby support projects the best way possible.
Industrial Structure	Meaning that the right support systems are in place and can be used by the projects.	**Resources**	Important to have motivated and the right amount of resources available for the project.
Clear Metrics	The use of metrics will improve the under-standing the performance of the process.	**Competence**	Involves securing a diverse and excellent competence in the company
Requirement Management	A structured way of handling requirements.	**Incentives**	Could be in the form of bonuses and other carrots.

Table 3. Important success factors for performance in the PD implementation [27].

Management		Technology	
Professional Project Implementation	Important with skilled project leaders the enables effective project execution.	**Technical Platform / Architecture**	Makes it possible to share technology and thereby cost between projects /applications
Multi Project / Portfolio management	The company must be able to handle multiple projects and maintain effective project execution.	**Predevelopment of Technology**	Shall support the implementation to improve time to market and quality
Risk Management	All risks must be identified and assessed.		
Handle Dependencies	Dependencies could involve business, resources, technical issues and project.		
Global and Local Development	Find the right setting for what should be developed where.		
Clear Objectives / Requirements	Management must be clear of what is expected from the people involved in the project.		
Supplier / Partners	The ability to handle suppliers and partners during the development.		

The Performance Measurement Evaluation Matrix

To be able to evaluate performance measurements within the PD process, not only why and what is measured are important, but also when they are measured is an essential question. In this research the previously presented Stage-Gate process is proposed to address the *when* to measure *what*. Since the Stage-Gate process represents the different phases of a PD project it is convenient to have it representing the timeline of the sampled measures. The PMEX, shown in Fig. 6 below, has the different phases of the PD process as one dimension of the matrix and the categorization of important successes factors for developing complex products and systems, as identified in this study, as the other dimension.

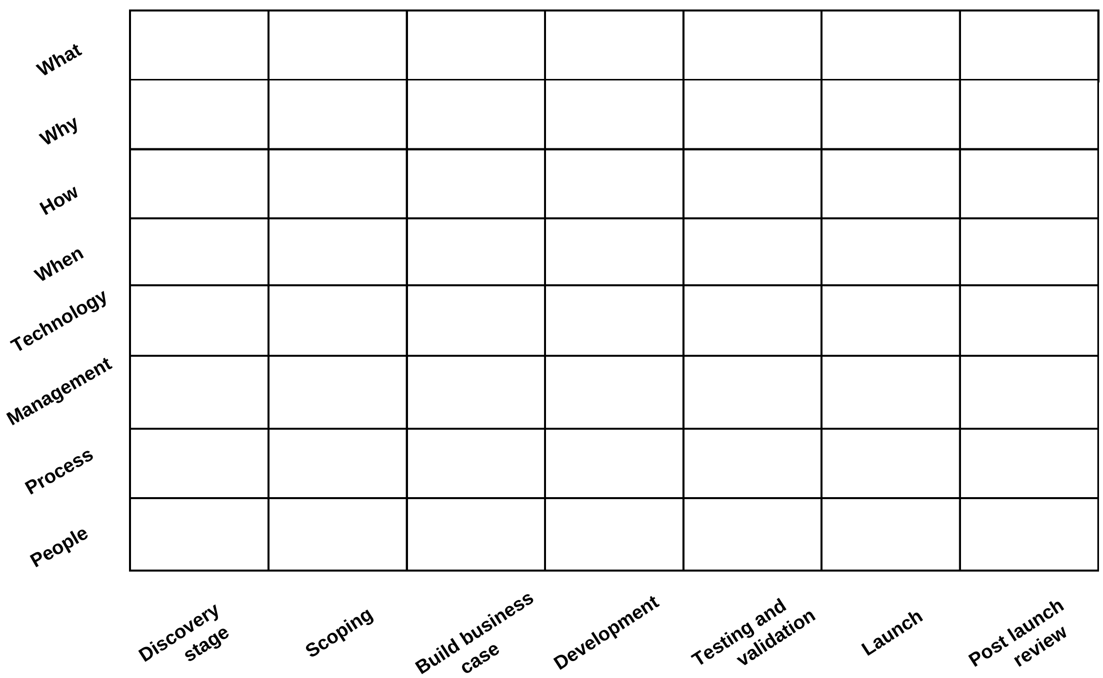

Fig. 6. Illustrates the PMEX including the Stage-Gate process and the categorization of success factors important for performance in PD.

The success factor categorization included in the PMEX represents what is important to manage in order to enable a high performing PD process. It may be tempting to design a performance measurement system that covers every square of the PMEX. This is not the intent of the PMEX and even if it is achieved, it probably would be difficult to make use of all the information. Instead, the PMEX should be viewed as a conceptual tool for PD managers to discuss the performance measurement system, in the sense of what needs to be measured, why it should be measured, and when it should be measured. In Section V, an initial verification of the PMEX is performed.

V. Verification of the PMEX

An initial verification of the PMEX is performed in this paper, involving two steps. The first step includes a brief presentation of critical success factors from the literature. These success factors are mapped against the success factors identified in this research. The second step of the verification includes a multiple case study within two companies developing complex products and systems. From the multiple case studies, the two organizations' different performance measures were identified and mapped into to the PMEX.

Critical success factors in product development in the literature

The research literature and industry best practices report a vast number of success factors that contribute to successful PD [28]. The thought of having a limited amount of factors that directly affect the outcome and underlie excellent performance of the PD process is appealing for every manager. As a result there is a vast amount of research available within the area of success factors within PD [29]. Normally, success factors are identified either at the business unit level or at the product level. By comparing a successful business unit or product with a less successful, success factors are identified.

In [28] a distinct set of success factors for PD that are statistically accurate predictors of the specific project outcomes of profit, market share, customer satisfaction, organizational effectiveness, and product quality. Moreover, the following categories are identified: *Leadership, Organizational culture, human resources, information, Product strategy, Project execution, Project execution, product delivery, and results*, Leadership involves key characteristics of the project leader, the power delegated, and whether there is clear strategic direction for the project. The organizational culture, engages the extent to which management has taken advantage of the established values of the people to improve project outcomes. Human resources, involves management's actions to improve the skills and the work environment. Information is concerned with the treatment of information as a valuable asset, their quality, and whether it is systematically collected, shared, analyzed. Product strategy includes the product planning processes and the extent to which they promote readiness for PD and product delivery. Project execution involves the key issues of the PD process. Product delivery consider to what extent manufacturing, sales, service and support are considered; or whether the product is just "tossed over the wall". Results evaluate the project from multiple dimensions such as: financial and market, customer satisfaction and loyalty, organizational effectiveness, product results, and benchmarking.

In a thorough review of critical success factors in [29] the following categorization, as previously developed in [30], was adopted: *customer integration, organization, culture, role and commitment of senior management* and *strategy*. In [31] another review drawing on a wide body of the product innovation literature, the following seven categories is identified as important in the product innovation process: *inputs management*, *knowledge management*, *innovation strategy*, *organizational culture and structure*, *portfolio management*, *project management*, and *commercialization*. Further, [32] argue for the following success factors in PD: *market knowledge*, *clear product definition*, *product advantage*, *project organization*, *top management support*, *risk assessment*, *proficiency in execution*, and *project resources*. *Product advantage* involves product superiority in the eyes of the customer e.g., delivering unique benefits to the user and high performance-to-cost ratio. *Market knowledge* i.e., customer and user needs assessment and understanding is critical. A *clear product definition* by defining target markets, clear concept definition and benefits to be delivered before the development begins. Holistic *risk assessment* including market-based, technological, manufacturing and design sources must be built into the business and feasibility studies. The use of cross-functional, multidisciplinary teams carrying responsibilities is important within the *Project organization* from beginning to the end. *Project resources* including financial, human skills, and material resources; the firm must possess the right skills to manage and develop the new product. *Proficiency in execution* includes all the activities of the PD process. *Top management support* is important through the complete PD process from concept to launch. Table 4 below, illustrates how the in this research identified categorization of success factors, presented in table 1-3, maps to the success factors identified in the literature presented above.

Table 4. Illustrates how the in this research identified categorize of success factors maps to the success factors identified in the literature.

	Tang [28]	Ernst [29] / Cooper [30]	Adams [31]	Bessant [32]
What	Product strategy	Customer integration, Strategy	Portfolio management Innovation strategy Commercialization	Market knowledge Clear product definition, Product advantage
Why	Product strategy	Strategy	Portfolio management Innovation strategy Commercialization	Market knowledge, Product advantage Clear product definition
How	Product strategy	Strategy		Market knowledge Clear product definition
When	Product strategy	Strategy	Portfolio management Commercialization	Market knowledge
Technology				
Management	Leadership, Organizational culture, Information, Human resources	Organization, Role and commitment of senior management Culture	Innovation strategy Knowledge management Project management Organizational structure	Project organization, Top management support
Process	Project execution, Information, Product delivery Results	PD process	Input management Knowledge management Project management	Risk assessment, Proficiency in execution
People	Information	Organization, Culture	Organizational culture Input management	Project resources, Proficiency in execution

It is difficult to directly compare success factors from the literature with the ones identified in this research because they are defined with different levels of abstractions. One example of this difficulty is strategy, identified in [29] and in [30] as an important success factor, that is mapped into the *why*, *what*, *how*, and *when* categorizes. In this initial verification of the success factors identified in this study, the main objective is not to highlight the detailed variations instead the major differences are important. With this in mind a first analysis of the mapping in Table 4 shows that the technology category is not directly addressed by any of the other studies found in the literature. This is an interesting finding that might be explained by the other previous studies focusing on a wider set of companies and products while this research explicitly focus on the development of complex products and systems. In the context of developing complex products and systems, technology is per definition an important aspect of PD performance. The technology aspect involves, for instance, platforms or product-line architectures that are used across a set of related products making it possible to share and re-use technology and thereby sharing cost between products and applications. Pre-development of technology supporting the PD implementation is another factor will have effect on time to market and quality of the developed product. Moreover, the technological infrastructure, e.g., a systems' architecture can have both positive and negative affect on the PD performance. The architecture may exhibit different levels of inner-quality attributes such as evolvability, flexibility, testability which have effect on the performance when evolving a long-lived system. In [33] a thoroughly conducted study within the disk drive industry highlights the importance of this issue. Both the rate of a technology's performance improvement and the rate at which the technology is adopted in the marketplace, has repeatedly shown to conform to a s-shaped curve [34]. The ability to assess when, the currently used technology reaches the end of such an s-curve, and hence is in need for e.g., improving inner-qualities in the architecture, would clearly be beneficial especially for the efficiency aspect of PD performance.

The *how* and *when* questions in the PD planning are less emphasized compared to questions of *what* and *why* in Table 4. The aspect *when* is important since it is a common phenomenon to overload the PD portfolio in the search for higher efficiency. However, such an overload often results in an increased PD project lead time. In a PD manager perspective the success of the overall portfolio is of more importance than the performance of an individual PD project. Studies focusing on the success of an individual PD projects is likely to miss out on the importance of the *when* perspective of the PD portfolio performance. In the PD implementation it is *management* that is by all the studies highlighted as the most important success factors.

Two case studies within the development of complex products and systems

To be able to verify the PMEX, two case studies were conducted within the automation domain, and the heavy vehicle domain. The first result from these case studies was to extend the PMEX to also include time, cost and quality. Not because they are success factors of the PD process, but because of many measures involves time, cost and quality. It is interesting that time, cost and quality was never mentioned in the workshop when the success factors where elicited and analysed by the senior managers in our study. The proposed PMEX, with an indication of what is measured by the two case companies, is shown in Fig. 7. The gathered performance measures within the two case companies were successfully structured into the modified PMEX. The stars represent the metrics used by the automation case company and the circles represent the measures of heavy vehicle case company. It was decided to map the measures into the matrix in order to emphasize the presentation and usage of the PMEX as an evaluation method, rather than focusing on the specific metrics used by these two case companies.

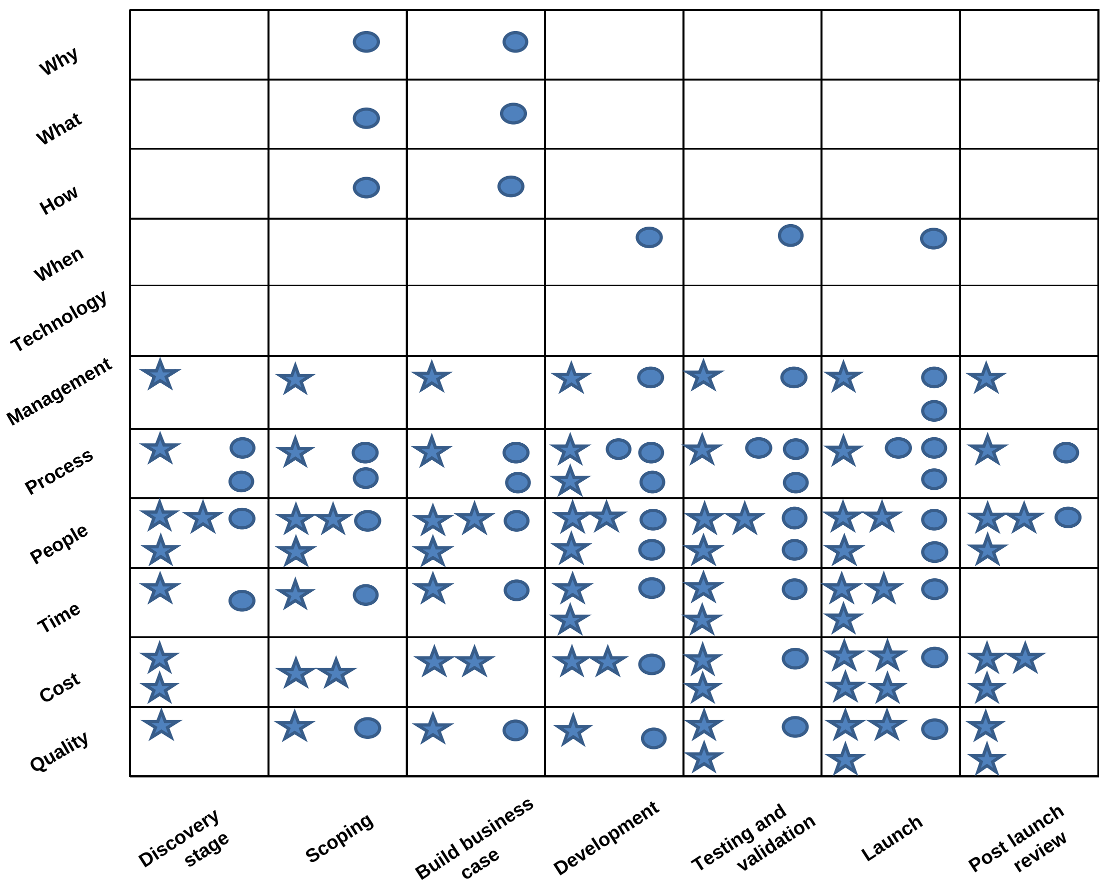

Fig. 7. The PMEX illustrates what and when there are measurements present in the PD process for the two companies. The star represents case company 1 and the circle represents case company 2. Stars and circles were chosen instead of the real measurements in order to keep the focus on the PMEX and not on the measurements.

It should be noted that a star or a circle is not equaled to a unique measure. It could be that the same measure is used in multiple squares of the PMEX. An example of this is the circle in the why, what, and how measured during the discovery and build business case is the same measure. It is a measure of how the prescriptive process of early stages in the PD process is followed. When there are multiple entries of stars or circles it represents multiple measures applied to the same area. A further result of the analysis is that the two case companies seem to measure what is easy to measure and not what managers emphasize to be important. If the measure of fulfillment of the early stages of the PD process is disregarded, there are hardly no measures at all within the planning activities (why, what, how and when) or the technology aspects of the PD process. This may be negative in the important effectiveness perspective of the PD process. It may be the result of companies focusing on the efficiency and not the effectiveness of PD. Another interesting finding is that none of the two case companies measure the aspects related to technology. In spite the potential big influence it may have on particularly PD efficiency. Since both the studied companies are successful, and have an interest in increasing their PD performance, it could be that this information is managed as tacit knowledge. Tacit knowledge is defined in [35] as knowledge that cannot be articulated or verbalized; it is a knowledge that resides in an intuitive realm. Since the subject of tacit knowledge transfer, content and process, is poorly understood [35] it may be a substantial risk to treat the technology and planning aspects of the PD process this way. If that is the case it may be difficult to manage the planning phase as a process and thereby enable continues improvements.

Experiences from the first verification of the PMEX

The first indications from the verification of the PMEX show promising results. The PMEX has so far only been tested at the two case companies. However, within these companies the PMEX has been received as a novel way of evaluating the current performance measurement system. In both the studied cases the PMEX clearly illustrate what is and what is not measured. The problem still remains; how to design performance measures that addresses this issue. However, with the use of the PMEX this phenomenon is clearly shown; there are important aspects missing in the current performance measurement system of the PD process. The main idea of the PMEX is to holistically evaluate the performance measurement system and use it as a conceptual tool when performance measures are discussed. Moreover, both case companies have a clear potential to further develop their performance measurement system since the success factors identified by the participating companies are almost disregarded, especially the planning activities. Furthermore, the findings that technology is not explicitly perceived as an important success factor in the PD literature and at the same time disregarded by the performance measurement system are both interesting findings. Especially since the majority of the PD within companies developing complex products and systems are incremental development of long living systems rather than development of completely new products. Often, are product-line architectures or platforms used and shared between products. It is our experience that the important inner quality of such architectures decreases over time if quality is not actively managed by the R&D organization and PD management. Reasons for this are, for instance, poor communication of important architectural decisions and constructs leading to architectural falling apart when new features are implemented in ways that violates the rules set by architecture, the introduction of new features that do not fit the current architecture, changes in business context that is not supported by the current architecture, turn-over of engineers resulting in the loss of knowledge. For a company developing complex products and systems it is therefore a clear competitive advantage to have the technology evolving in line with the business context and thereby support an efficient and effective implementation of new features and applications.

VI. Conclusions and Future Research

In this paper, a method for how a company's performance measurement system can be evaluated from a product development (PD) manager's perspective has been suggested. The first conclusion of presented research is that previous literature within both PD and performance measurement is vast. Despite this fact, there is a lack of research focusing on evaluating the performance measures used within the development of complex products and systems. The research of evaluating the performance measurement system is scarce or even missing, especially within this context. A second result from presented research is the Performance Measurement Evaluation Matrix (PMEX), a conceptual tool to holistically evaluate the performance measurement system used by companies developing complex products and systems. The PMEX has the success factors within the development of complex products and systems as one dimension and the phases of the Stage-Gate process, representing the timeline, as the other dimension. One benefit of the PMEX is the possibility, for a PD manager, to holistically evaluate what is measured and maybe more importantly, what is not measured within the PD process. The PMEX may also be used as a conceptual tool to reason about the performance measurement system, making it possible to initiate discussions of what is measured and why, and also when it is measured. Furthermore, the PMEX also illustrates what is not measured and can therefore be used when changes or new metrics are to be added, in order to ensure a performance measurement system that measures what is important in a company's perspective in the quest for a more successful PD.

A third conclusion based on the result of using the PMEX, is that the technology aspect of the PD process is not measured by any of the two case companies. This is especially interesting since both companies acknowledge the importance of technology as a success factor. Moreover, a literature study of different success factors within PD also disregards the technology aspect of PD performance. This is remarkable since there seems to be a gap both within the literature and within the current performance measurement system of the two case companies. Further research is needed, focusing on possible success factors and measures that can be used to address the technology aspects within the development of complex products and systems. An overall conclusion from the case studies is that there seems to be a mentality to measure something because it is possible to measure, rather than because it is important to measure. This would explain why there are few metrics measuring the planning and the technology aspects of the PMEX. Research is ongoing to formally verify the PMEX through five more case studies. The technology aspect together with its affect on the overall PD performance from a PD manager's perspective and possible ways of designing measures of technology's effect on efficiency and effectiveness will be further investigated.

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