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Investigating Organizational Knowledge Transformation Capabilities in Integrated Manufacturing and Product Development Companies

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Abstract

In today's fierce economic climate, many product manufacturing firms recognize that their knowledge process with regards to product realization becomes an increasingly important factor. However, it is challenging task for any company to better structure resources and practices, balancing between short term and strategic priorities associated with inter-intra knowledge transformation and organizational learning. We hypothesize that any successful improvement effort has to start with measurements of key characteristics associated with current practices, followed by a contextual implementation strategy scalable to the actual business environment. In this paper, we develop a maturity model for identifying gaps between current capabilities and those deemed necessary to improve knowledge processes. The overall objective is to identify differences between manufacturing companies as to how they assess capability gaps relating to knowledge in their operational context. The theoretical framework constitutes a hierarchical model consisting of four main characteristics and twelve practices. The model is integrated into an assessment framework that has been used in nine global knowledge-intensive manufacturing companies, all with significant R&D operations in Norway, using a continuous descriptive five-level maturity grid method. The results show that the degree to which product development practices are project or process driven, largely dictates where the companies identify to have major capability gaps. The developed framework has proven its capability as a practical assessment tool that can be used by other companies to identify capability gaps as a starting point for improving knowledge strategies in product development.

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Keywords: product development; knowledge; organizational learning; practices; assessment; capability gaps; continuous improvement.

1. Introduction

Product development (PD) is the collective activities, or system, that a company uses to convert its technology and ideas into a stream of products that meet the needs of customers and the strategic goals of the company. How can then a company improve its PD practices and capabilities to survive in today's hyper competitive market place? The body of knowledge in the literature constitutes a myriad of frameworks, models and methodologies, [1-3] aiming to represent the impact of various factors on PD performance, innovation outcome and new value. Since the main objective of PD is to make a 'recipe' of useful information that describes how to produce a new product with acceptable risk, [4] a vast part of prior art concerns knowledge and learning processes. However, little progress has yielded in arriving at unified strategies for implementation of theory in industrial practice. Therefore, there is a pressing need for more research that particularly addresses knowledge processes in the actual company context along with related continuous improvement efforts at PD team level.

In any company, knowledge is important both as a separate value stream and as a competitive factor. Those companies having systems, processes and culture for generating, capturing and standardizing knowledge for re-use have a competitive advantage over its competitors. In other words, capabilities for knowledge processes and organizational learning are said to be the only permanent competitive advantages as markets, technologies and competitors change over time.

The aim of any PD process is to create new value [5]. Consequently, the PD process will always involve some degree of learning, as stated in [6]: "*In a way all organizations are learning organizations. If they were not, they would not be able*

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to survive in a changing environment". There are still ongoing discussions in the learning theory related to the process of learning. According to [7], "*no theory or model of organizational learning is widely accepted*". Pawlowsky summarized learning in four phases from the literature [8]: identification, diffusion, integration and transformation.

In this paper, we study the maturity level of manufacturing companies in relation to different characteristics of knowledge processes at PD team level. Attempts are also made to identify similarities and differences between companies when it comes to knowledge practices and capabilities The long term goal is to gain insight into important factors for the development of contextual implementation strategies for improved knowledge processes in PD environments.

The reminder of the paper is organized as: Section 2 gives an introduction to learning theory and the development of a tool for assessment of knowledge transformation capabilities in PD. Section 3 presents the research method employed. Section 4 summarizes the main finings and gives a brief discussion, mainly on contextual factors revealed found in this study. Section 5 gives the conclusion.

2. Theory

2.1. The four phases of learning

Individuals are predominantly seen as the functional mechanisms for organizational learning by creating knowledge through experience. However, the value for the organization increases if individuals contribute to share, integrate and utilize their knowledge towards a larger meaning. From organizational knowledge theory Pawlowsky summarizes four distinctive phases of learning from individuals to organizations [8]:

- The *identification* of information relevant to learning;
- The exchange and *diffusion* of knowledge;
- The *integration* of knowledge into existing systems;
- The *transformation* of the new knowledge into action and the application of it to organizational routines.

Identification: This first learning phase is about how relevant information is identified for the creation of new knowledge. This information can be derived from learning by doing, learning from customers, by copying, problem solving, opportunity taking, and by learning from mistakes [9]. Information which stimulates learning is often triggered by recognition of a crisis [7,10], which is based on the assumption that existing organizational routines must be unlearned in order to legitimize new information and knowledge [11]. Zhang et al. also pointed to critical incidents as triggers for learning, such as financial crisis, key staff exit, acquiring new customers, innovating new products, and mergers [12]. Dodgson recognized that organizational learning is triggered both by environmental change and by internal factors in an iterative manner [13]. Environmental changes that challenge the organization are often emphasized as the main trigger for learning and search for new information [14] but also the motivation to improve our way of working, seen as an internal factor, should be considered as an important criterion for information generation [15]. It is also important to note that just seeing a difference leads only to creation of information, while both seeing a difference and pointing it out may lead to creation of knowledge [6]. This is because information is viewed as an explicit representation of knowledge, not knowledge in itself.

Diffusion: Diffusion of knowledge is about exchange and distribution of knowledge from the individual to the collective level, or at the collective level itself. March and Olsen argued that individual behaviour is influenced by different patterns of interaction with other organizational members, emphasizing level of trust and integration as two important factors for effective information sharing [16]. In an atmosphere of trust, individuals will be more likely to perceive what other members of the organization or group perceive [17]. Hence, this assumption does not say anything about the common perception as intentional for the company. Schein pointed out that organizations are composed of sub-cultures often having different goals and languages [18], meaning that organizational learning will be impeded if these sub-cultures don't understand each other's terminology, metaphors or stories. Trust is also important in making information readable for others [19] Enabling translation is highly correlated with individuals' motivation to share their hard-won knowledge, something which is culturally conditioned rather than technology dependent (knowledge management systems).

Translation or transferability also concerns the ease of with which a type of knowledge can be transferred from one party to another. These knowledge types are often referred to as explicit and tacit, where the former is regarded as relatively easy to codify and transfer whereas the latter is more personal and difficult to articulate and codify [20]. Other obstacles to diffusion are formal structure, dysfunctional workflow and distance [19]. Hierarchical organizations with long vertical information chains are said to be counterproductive to information and knowledge flow [21].

Integration: The integration and modification phase describes how knowledge is kept, stored and secured within the organization, and how the existing knowledge base is altered, modified and renewed [19]. Thus, this phase poses fundamental questions about organizations' ability to unlearn or modify dominant mental models. It also raises questions about the incentives for experimental behaviour and if there is some sort of threshold for organizational learning. The latter points to the learning event itself, both the magnitude of a failure or a crisis leading to action and the organizational impact of such action measured in terms of both breadth and depth. The influence of history on the organization can be positive as well as negative [18], depending on the rate of technological change. Accumulated knowledge forms an organization's identity and can be a source of future competitiveness, but if that knowledge becomes obsolete it can lead to inertia since organizations tend to conserve what exists [22]. Accumulated knowledge can therefore slow learning processes, as stated in [23]; "*History becomes a constraint that prohibits seeing*". This dilemma implies that learning requires both change and stability in the relationship between the organization and its environment. Too much turbulence will make it difficult for the learning system to map and store anything [23], while a high degree of stability will offer few opportunities for learning. In both extremes, a formal knowledge management system will provide little help in acting as the organization's memory. This because a high rate of knowledge turnover will make knowledge less valuable to store, whereas in a stable environment the organization's behaviour is more routinized in which the knowledge is less valuable to store. March [24] has also described this dilemma, which he differentiated between exploitation and exploration.

Transformation: The notion *"bounded rationality,"* coined by Simon [14], refers to the limitations of the human mind when it comes to formulating and solving complex problems. These limitations to prediction of a full range of possible actions and outcomes serve as an argument for a trial and error approach. Alchian [25] found that trial and error learning may be effective in an uncertain environment, saying that learning is partially influenced by chance. Reinertsen, who has described the "*Design Factory*" in relation to systems theory, said that events that are less probable contain more information than expected events [26]. Translating this information processing view to a learning approach indicates that degree of learning increases with degree of uncertainty. A small change in probability or risk generates information, and maximum information content occurs when there is a 50% failure rate. Weick [27] suggested a somewhat higher failure rate to create understanding by stating, "*There is a delicate trade-off between dangerous action which produces understanding and safe inaction which produces confusion.*" However, harvesting from the previous stages in the learning circle is demonstrated through the process of synthesizing information towards usable and valuable knowledge built into the actual product.

From these four stages of learning, a capability maturity tool for assessing knowledge practices in PD was developed.

2.2. Capability maturity method

In any continuous improvement effort, it is necessary to establish a methodology for assessing current capabilities, defining future goals and measure progress towards those goals [28]. Maturity models in various forms have been applied to assess different functional areas, including PD [29]. Its basic methodology includes describing in a few statements the typical behavior of an organization at a number of levels of maturity for selected characteristics of the process area assessed. The different levels provide the opportunity to codify what might be regarded as practice in accordance with a specific performance characteristic along with some transitional stages. Thus, the approach has many similarities with a questionnaire using a Likert scale [30] with response anchors. While the maturity grid approach describes practices at different levels of maturity, the Likert-scale approach describes only one practice and leaves it up to the respondent to interpolate without further guidance. The benefit of maturity grids is the descriptive text tied to a scale of each level of the performance characteristic. The drawback is that the descriptive text becomes increasingly difficult and complex as the number of levels increase.

There exists a number of different maturity models, all defining a number of dimensions or process areas at several discrete stages of maturity with a description of performance at the various levels. There exist several main types of maturity models. The first one is the traditional maturity grid method where all practices are scored to a different level ('continuous'), see e.g. [31,32]. The second one assumes that a cumulative number of process areas must be met at one level before advancing to the next maturity level ('staged'), [33] There is also a third category combining a questionnaire with definitions of maturity without a description of the activity ('hybrid'), used by [34] for seven areas with three PD practices

In our study, the maturity grid approach was chosen since it serves the dual purpose of providing a means for process improvement and management based on longitudinal process data, and being an interactive research survey tool for collection of cross-sectional data related to where different companies identify their performance gaps. Furthermore, according to [35], "*the typical maturity model used in PD tends to be structured according to existing notions of good practice, and generated using experience-based principles, and tested by qualitative approaches such as interview and beta testing, but with little quantitative or statistical analysis*". This was an important consideration because of the limited sample size, which was largely dictated by the time frame of the audits. The main inspiration for the format and structure of the assessment forms came from LEASAT due to its prowess and documented capabilities, [32]. However, the content was directed toward knowledge capabilities, rather than leanness at business level.

2.3. Structure of assessment tool

The four learning stages at team level are represented as capabilities and questions. Each of the capabilities is decomposed further into subsets of three characteristics. Each sub-characteristic gave situational descriptions of process, capability or behaviour at five different maturity levels, allowing the respondent to identify the actual practice. For each capability, the descriptive situations were tied to a maturity scale, where the auditee could identify the current situation and where to be in the future. To reduce complexity, statements for three different maturity levels were codified and linked to a Likert-scale (1,3 and 5). For each characteristic, the current and future ratings were obtained by averaging over the three capabilities.

The main purpose of this research is to identify capability *gaps* (**G**) between current and desired practices, rather than obtaining maturity levels (**C**). The domain was divided into four characteristics, with totally twelve capabilities developed to cover the entire knowledge practice domain, Table 1.

Table 1. Characteristics and capability covered in the assessment.

Capabilities	Main question or issue	Characteristics
1. Knowledge value stream and identification	Which role has knowledge in terms of capturing new markets and growing the business?	1. Viewing NPD as knowledge process 2. Practices for sharing knowledge 3. System for knowledge capture and reuse
2. Knowledge owner-ship and diffusion	Is knowledge ownership defined, and is the knowledge capturing process systematically managed?	4. Defined knowledge owners 5. Standard knowledge in central base 6. Role of functional managers in PD
3. Cross-functional knowledge flow and integration	What are the practices for transferring knowledge between functional departments?	7. Business system for sharing cross-functional knowledge 8. Knowledge accessibility and retrieval 9. Viewing knowledge as a company asset

4. Set-Based Concurrent Engineering and transformation	To what extent is front loading and SBCE used in design and knowledge generation?	10. Test first, then design, using 'Darwinistic' approach 11. Requirements and concepts emerge by trade-offs and decisions 12. Knowl. capture from learning cycles for reuse

3. Method

3.1. Case study protocol

Our interactive study essentially followed the four main stages of a case study as proposed in [36]. The first phase included a literature review. Several methods were used, including keyword searches across databases and internet website searches to reach a broader variety of sources. The body of information was extended by backtracking the most relevant references. Also, active participation in research networks gave access to the most recent research, sometimes ongoing research, along with input through conversations with other researchers and experts.

The assessment tool along with the research questions and the specific needs of the case study were developed as a part of an ongoing research project. A PowerPoint presentation was developed for creating awareness and introducing the topic in the companies. The selected companies were all multinational knowledge-intensive manufacturing companies with significant R&D activities in Norway. The research team designed the research protocol.

The case study followed a staged implementation strategy, starting with a scoping event. This also served to educate the research team about the challenges that each company was facing as an important input to the assessment. A design outline for the case study report was established, using the format of an A3 or knowledge-brief [37].

3.2. Implementation and execution

After the initial awareness event, the date(s) for the audit was scheduled. One week prior to the audit, an introduction to the framework together with the assessment forms were mailed to the company contact person for further distribution. A typical assessment team was largely multi-disciplinary, consisting of a representative group of individuals (4−12 people) involved in PD projects. In total, 57 project team members from nine different companies provided their input through face-to-face conversations, discussions and dialogues while completing the assessment.

After reviewing the agenda and objectives for the assessment, the company representative(s) gave a briefing on the latest developments. The remaining of the event was entirely dedicated to completing the assessment. The structure of the form, audit process guidance, and the aim of focusing on capability maturity gaps ($\boldsymbol{G^k}$) rather than maturity levels ($\boldsymbol{C^k}$) were communicated. The assessment cycle included the surveyor giving a 30 minutes presentation on the underlying theory and the practices associated with knowledge and organizational learning in PD. This was followed by a 5-10 minutes question, answer and discussion session. Then, the capability maturity gaps were assessed for each of the twelve different capabilities on an individual basis. The research team then gathered and compiled the results, before presenting the individual scores to the audit team. If there were notable differences in the way individuals rated a specific capability, a discussion was facilitated to reach consensus before the team collectively re-scored each of the practices. As a general observation, individuals from the more support functions of the PD team, such as manufacturing, rated the capability gaps somewhat differently from people in e.g. design or engineering.

After completing the assessment, the research team analyzed, compiled and synthesized the results into a format to fit within an A3 report, serving as a part of the research protocol for our study. In seven of the nine companies, the assessment resulted in internal continuous improvement initiatives.

3.3 Company demographics

All nine companies in this study are multinational, with PD and manufacturing as central parts of their business strategy. In addition to a set of selection criteria, we demanded that the composition of the company sample covered a range of different business contexts. We chose to pair off companies operating with similar PD operational mode.

The case companies were from different industrial sectors. Only one company (I) operates in B2C and the remaining are truly B2B firms. The companies were identified to have different operational modes, including project-driven, balanced and process-driven, Fig. 1. The sample selection allows pairing off six companies along these two dimensions. The remaining three companies all entails some complementarity.

The companies operate in various industrial sectors, including oil & subsea, automotive, consumer goods and defence & aerospace. The common denominator is their development of advanced products with relatively high value-added. Their long history of operation is related to a long-lasting strategic focus on competence and technology due to the high costs of industrial workers in Norway. The company size ranges from just above 100 to 4,700 employees working in the Norwegian operation(s) only. Lead time is for the most relatively high compared to many other product manufacturing companies—up to 10 years for the most advanced products within defence and aerospace.

4. Results and Discussion

4.1 Current state

Table 2 lists the overall results of the assessment of current characteristics and gaps. Note that in order to arrive at a single company score in each category, Company E decided to round off the average of the individual ratings to the nearest integer. Companies B, F and I rounded off to the nearest multiple of 0.5 and the remaining rounded off to the nearest multiple of 0.1.

When the data is analysed at company level, it is very clear that the sample size is limited from a statistical point of view. However, the assessments were made by input from up to twelve people from each company, altogether 57 surveyees, and the research methodology included face-to-face interactions and discussions before arriving at a collective score. Hence, the values in the table may be more robust than the sample size might indicate at first glance. Note that the current ratings ($\boldsymbol{C^k}$) are not suitable for identifying the characteristics where a company's knowledge practices are more or less mature than those of other companies. The reason for this is that the situational descriptions in the assessment sheet were tied to ordinal scales, which generally fail to capture information that will be present in other scales due to unintended differences between the levels of the various ordinal scales. Therefore, the important rationale, which can be extracted from interpretations of current maturity levels, is comparing capability maturity levels *between* different companies on a characteristic or practice basis.

The collective average score of the sample was 2.6, taken across all companies, ($\widehat{\boldsymbol{C}}$). This is significantly below the neutral point of the ordinal scale used (3.0). Considerable variations are observed between each company and between the three capabilities (Table 1) that belong to the same characteristics within a single company.

Table 2. Current maturity scores (C) and gaps (G) for companies A-I.

	A	B	C	D	E	F	G	H	I	$\hat{S}^k_{avg}$
C^1	2.6	2.0	3.1	2.7	3.0	3.0	2.8	2.5	2.5	2.7
C^2	2.4	2.0	3.0	2.9	2.0	3.0	3.0	2.8	2.0	2.6
C^3	2.8	2.0	3.0	2.4	1.0	2.0	2.8	2.7	2.0	2.3
C^4	2.6	3.0	2.8	2.4	2.0	3.0	3.3	3.5	3.5	2.9
$\widehat{\boldsymbol{C}}$	2.6	2.3	3.0	2.6	2.0	2.8	2.9	2.9	2.5	2.6
G^1	1.4	3.0	1.5	2.3	2.0	2.0	2.3	2.0	2.0	2.1
G^2	2.0	2.0	1.4	2.1	2.0	2.0	1.8	1.7	2.0	1.9
G^3	1.7	1.0	1.5	2.6	4.0	3.0	1.8	1.8	2.5	2.2
G^4	1.0	1.0	1.5	2.5	2.0	2.0	1.3	1.2	1.0	1.5
$\widehat{\boldsymbol{G}}$	1.5	1.8	1.5	2.4	2.5	2.3	1.8	1.7	1.9	1.9

4.2 Capability Maturity Gaps

Table 2 lists the associated knowledge capability maturity gaps identified when using the assessment framework as an interactive research tool. Here, the maturity gaps ($\boldsymbol{G^k}$) have a somewhat broader applicability than the maturity levels ($\boldsymbol{C^k}$) listed above since the former represents a variation from a given reference. Therefore, these would be less sensitive to any potential bias between the scale levels of the individual characteristics. The knowledge capabilities depict a relatively high maturity gap. The two characteristics with the larger contribution to the identified gaps are G^1 (*Knowledge value stream*) and G^3 (*Cross-functional knowledge flow*), which provide average gaps across the different companies of 2.05 and 2.21, respectively. It is noteworthy that even the characteristic with the lower average gap, G^4 =1.49, *The use of Set-Based Concurrent Engineering methodology*, has a higher gap than the average gap across all components and companies ($\widehat{\boldsymbol{G}} = 1.9$). Overall, the results indicate that many of the manufacturing companies in the sample have a clear need to strengthen their practices as to how they operationally and strategically deal with knowledge transformation and retrieval processes.

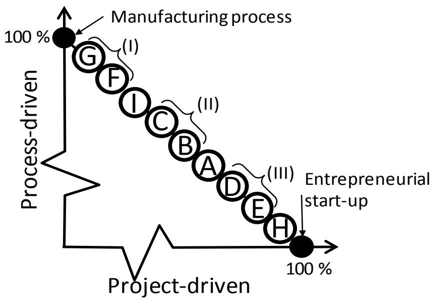

Fig 1. PD operations of the case companies decomposed into two dimensions.

4.3 Discussion

Product development as a 'territory' consists of two widely different landscapes that would require different strategies for optimal performance: (a) the process-driven one, and (b) the project-driven one—where values are newness, variability and uniqueness with work mainly being cross-functional. In Fig. 1 an attempt has been made to relatively position the different companies in this study, depending on how they relate to these two dimensions. The assessment included, among others, questions related to how knowledge is transferred and retrieved. Also, two fundamental questions related to the embedding of knowledge into the company culture are: How does the company regard the value of knowledge in its operational practice? Which strategic role has the company's collective knowledge in capturing new markets and growing the business, if any? In any sustainable company, PD should be seen as a continuous learning process where the basis is knowledge generation with the product emerging as the natural result [38]. Knowledge is regularly created, captured, synthesized and stored with the overall purpose of being used for problem-solving and future products. The process for transforming and sharing knowledge is standardized. One central issue in this regard is the integration of the production value stream and the knowledge value streams ([28],[39],[40]) to ensure that new knowledge results in organizational learning and risk mitigation to an acceptable level.

The assessment results showed that large maturity gaps were associated with knowledge transformation practices for most of the companies. Even the minimum average maturity gap for knowledge ($\widehat{\boldsymbol{G}} = 1.53$ for Company A) was rather significant. The sample companies demonstrated that they have a relatively large maturity gap to bridge within the practice of integrating the two value streams ($G^1 = 2.05$). Another central issue is *Defining ownership to knowledge, organizing and managing knowledge within the company*—including responsibilities for knowledge system maintenance, standards and development of people's skills, along with continuous improvement and maintenance. This is essential in establishing and orchestrating an effective PD system. Here each functional area should assign a knowledge owner with clear ownership and responsibility to knowledge relevant to that specific area. Knowledge owners have to be trained to create and capture knowledge, validate, generalize and organize knowledge for reuse, and build and maintain best-practice standards. In PD project teams, there must be a clear definition of the roles of the project manager and the various knowledge owners. For this characteristic, this study showed an average gap across the companies of $G^2 = 1.88$, which is significant on a 1-5 scale.

Knowledge should be viewed as a common asset that benefits the whole organization and having a central role in the customer value creation process. PD is essentially a multi-functional, collaborative discipline, whose successful outcome is strongly related to the communication practices used to transfer knowledge between team members and functional departments. Therefore, a structured system aimed at sharing information and knowledge between departments and business areas should be utilized across the entire organization. *Cross functional knowledge flow* was the characteristic with the larger average gap found in our study ($G^3 = 2.21$), which is very significant considering the 1-5 Likert scale used.

The last characteristic assessed within knowledge transformation is to which extent *Front loading and Set-Based Concurrent Engineering* is used in product engineering and knowledge generation processes. This characteristic is the one that the Norwegian-based R&D organizations assessed in our study seemed to have most compliance between their current and desired practices, with a gap $G^4 = 1.49$ across all the companies. This finding is somewhat in contrast [41] based on her study of product development practices in mostly US firms.

5. Conclusion

This study presents a tool for assessing knowledge practices in product manufacturing companies. The results show that the vast majority of the case companies demonstrates significant capability maturity gaps within knowledge transformation and retrieval in their PD operations. Further work includes studying implementation of improvement efforts.

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