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User Friendly Framework for Measuring Product and Process Novelty in the Early Stages of Product Development

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Abstract

This paper examines the innovation process in four Norwegian companies, all supplying the automotive industry with light weight structural components. Twelve representative product projects are categorized, together with people from product development in respective companies, according to product and process novelty. The main contribution from this study is twofold; first, a new framework and index for categorizing innovation across product and process newness is developed, second, putting empirical data into the framework demonstrates that product and process uniqueness does not seem to be dependent on amount of resources.

Keywords: Innovation; Risk; Product and Process development

1. Introduction

Firms are facing an ever increasing pace of globalization and changing reality, resulting in increased competition and more dynamic markets. These two factors are easy to observe in the automotive industry, a market which has been viewed as a globalization frontrunner for many years. First, the struggle to met growth strategies in mature markets has led to excessive capacity and thereby intensified competition. Second, rapidly changing customer requirements and regulative directives with regard to sustainable development and improved safety set the scene for how car manufacturers have to be adaptive in order to survive. A main strategy to meet these challenges has been to introduce new car models and derivatives for various markets.

Clark and Wheelwright [1] define product development as: "*The aim of any product or process development project is to take an idea from concept to reality by converging to a specific product that can meet a market need in an economical, manufacturable form*." The definition emphasizes that product development is a collective concern at the same time as the output from the process shall satisfy the customer, manufacturing, and the company in terms of return on investment. Clark and Wheelwright [1] also concluded that product development can create competitive advantage in at least three areas: market position, resource utilization, and organizational renewal. However, the ability to achieve and maintain these advantages is not a given; for instance Dougherty and Hardy [2] noted that many organizations have difficulty with sustained product development success or managing a number of product development efforts over time. Blum [3] categorized three different product development processes according to the perspectives market, resource, and evolution. He claimed that the market-based perspective emphasizes thorough planning and design, based on investigation of market opportunities, competitive moves, technical options, and product requirements, before concept freeze and subsequent execution in the form of product and process development. In such, planning and doing are separated, where doing, or product realization, is all about developing the product in accordance with specifications. Concurrent,

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integrative, and simultaneous product development are methods related to this resource-based perspective, where the idea of over-lapping phases is operationalized through the fact that product execution is initiated before final planning and concept specification. The evolutionary perspective derives from the shift from relatively stable market conditions to more uncertain ones. In a turbulent environment where the outcome is uncertain, a more iterative product development process may be needed. This process allows for adapting the concept design to new market and technological information during the development process, with frequent overlapping of planning and execution as a result. Learning and reconfiguration happens by several design-build-test iterations, learning a little more about the problem and alternative solutions each time before committing to a final design and detailed specifications. A concept which emphasizes both the resource-based and evolutionary-based perspective is the lean product development process. Here extensive planning and testing is conducted for several product concepts simultaneously, and final selection is based on evolving customer preferences and which concept or combination of concepts is most promising to satisfy these preferences.

However, classifications often have to be made with distinctive categories and labels, which may also be the case with Blum's grouping of product development processes in terms of their relation to the market, resource, and evolutionary perspectives. The classification provides a general overview, but the processes could as well be categorized according to, for instance, product complexity, company size or project scope, industry tradition etc. It can be argued that development projects accompanied with a high degree of uncertainty and a reliance on successful research results may follow an evolutionary process of learning bit by bit rather than follow a pure lean or resource-based process.

1.1. Product and process dynamic

Organizations can develop products and processes in different ways, where degree of innovation is categorized along a continuum from incremental to radical. Projects following a breakthrough path satisfy customer needs by fundamental changes of the existing technological base. Such changes may redefine the market in addition to causing disruptive changes within the organization. At the other extreme, projects can take an incremental path, leveraging existing technologies and resources to increase their match with market requirements. Over time such an approach may enforce considerable impact on both the market and the organization. However, history is full of linkages between incremental and radical innovations, often in a cyclical manner.

This technological evolution can be characterized by periods of uncertainty followed by the emergence of a dominant design which is subject to optimization in form of continuous improvement [4]. Shifting to a state of continuous improvement often involves focus on processes improvement and innovation, adding features, and cost reduction rather than product innovation, and this goes on until a new product or product substitution starts a new cycle. Tidd et al. [5] recapitulate this cycle by ranking mode of innovation according to these four dimensions; first, changes in the products an organization offers, second, changes in the processes by which these products are produced, third, changes in the context where products are introduced, and fourth, changes in the underlying mental models which frame what organizations do.

Milling claims that the majority of the scientific literature focuses either on product innovation or on process innovation, neglecting the interaction and dependency between the two [6]. Companies have adopted evaluation criteria at decision gates to offer the decision makers sufficient knowledge of the alternative ideas and concepts, and to promote choices that would result in the best possible business benefit. But, the actual benefits of using the different criteria in the front end of innovation have rarely been studied [7].

Utterback [8] claimed that the main challenge is to develop the ability to innovate products, processes, and the organization, seeing them dependent of each other as a whole. The product-process life cycle theory of Utterback and Abernathy [9] provides a useful model helping to understand the pattern and mutual relationships between product and process innovation. They noticed that that the rate of product or process innovation depends on the present stage of the existing product´s life cycle. Following this concept Hayes and Wheelwright suggest a two-dimensional product and process matrix linking the two life cycles together and at the same time reflecting a company´s position in the interrelated product-process system [10]. This model provides substantial support in determining the direction and timing of innovation decisions in the light of a company´s manufacturing capabilities. A more comprehensive and conceptual framework was provided by Kotha and Orne [11], considering product line complexity and process structure complexity according to structure, strategy, technology and performance. Jacobs et al. found from their best-fitting model that product modularity directly and positively affects process modularity, manufacturing agility, and firm growth performance [12]. The models described above all represent integrative approaches illustrating the tight interconnections between product, process and strategy in manufacturing companies. They also provide support for decision-making concerning the specific type, the timing and the extent of innovation. Still, when new products tend to put a firm ahead of its competitors, investment in available process technology merely brings a firm up to standard. Process innovations have an internal focus, seek to develop new capabilities, competencies or routines and are primarily efficiency driven.

2. Research Methodology

A case study is one of several ways of doing social science and understanding complex social phenomena, used in many situations to contribute to our knowledge of groups, organizations and related phenomena within a real life context [13]. As Voss [14] has pointed out, case studies have become a very powerful research method, often dealing with growing magnitude of changes over lesser and lesser time. And therefore there are important to conduct such studies in accordance to established reliability and validity claims. Construct validity is making sure that we get the data that describe the phenomena we are investigating and that the data can be separated from other phenomena data [15]. Internal validity is making sure the causal relationship between certain conditions in the case [16]. And on the other hand the external validity claim is how much can be generalized beyond the case itself. Finally, reliability deals with how much of the findings in the case study can be repeated [16]. And it is generally believed that multiple cases have a higher external validity than single cases.

3. Case Companies

The four case companies are all suppliers of aluminium based products for the automotive industry. Their products are often preferred to steel versions due to low weight and high performance. Case A develops and produces wheel suspension systems, Case B crash management systems, Case C steering columns, and Case D wheel rims. Similarities between the cases are elements like intertwined history, customer base, future visions, business environment, business to business logic, requirements and standards, R&D topics (forming of aluminium), whereas the main differences are organizational structure, size, business culture and openness to change.

4. Risk assessment approach

The risk assessment framework is motivated by Utterback's [8] product and process focus, discussed in the introduction, in combination with the Booz-Allen & Hamilton matrix which introduces the scales along the dimensions product and process newness. Booz-Allen & Hamilton [16] provided a product classification based on the two dimensions "new to the company" and "new to the market." The first one roughly refers to products the company has never made or sold before, but may be offered by competitors, and the latter points to products that are the first of their kind. Their matrix model is shown in Figure 1, with six distinct product categories, described below, ranging from cost reduction programs to new to the world products.

	Low	**Newness to the market**	High
High	New to the company		New to the world
Newness to the firm	Product improvement	Add to existing lines	
Low	Cost reduction	Re-positioning	

Fig. 1. Product innovation typology

These six categories are reduced to respectively four and three categories for the product and process dimensions. The reasoning behind this simplification is twofold; first, the nature, horizon and customer power in supplier and customer contracts in the automotive industry leaves out the alternative of cost reduction, and second, product characteristics, knowledge, and production equipment are so specialized towards automotive that repositioning seems difficult.

To develop a useful index the product dimension is divided into minor changes, improved performance, new to the company and new to the world, where the criteria is product functionality. The process dimension excludes the category minor changes because the case companies believe process development is initiated at a higher level.

1. Cost reduction means that firms can search for ways to cut costs and then pass the savings on to customers through lower prices.
2. Repositioning can be explained by retargeting already existing products to new market segments or different applications.
3. New and improved products, also called next generation products, are modifications of existing products in terms of improved performance and/or added functionality.
4. Additions to existing product lines include products which are considered both new to the company and new to the market.
5. New to the company refers to adding new technology to the firm's product portfolio, but not necessarily technology that is new to the world.
6. New to the world products generally either revolutionize existing product categories or define new markets.

5. Results

Development process; All case companies claim to follow a linear product development process with stages and gates, which embodies required quality assurance standards. Extensive market communication has traditionally kept track of planned car models by OEMs; so much work has been conducted up-front in the pre-qualifying process in order to get a head start. A pre-qualifying process implies several bidding rounds from invited suppliers, where concepts materialize more and more for each round for those offering close to acceptable price, performance, functionality, and quality. If the supplier is chosen for the next round, and accepts it, a cross-functional team is appointed to further develop the concept, together with the customer, and make the first prototypes. Based on this work the client nominates sub-contractors, usually one or two, to offer a final concept with an acceptable price. The contract is often confirmed by a tool order from the customer. Tool investment and ownership is important for the customer in two ways; it gives a warranty against non-compliance by their suppliers and assures that the supplier can afford to initiate the tooling process, which often incurs considerable costs and lead times. The product project team then signs a team feasibility commitment in order to guarantee agreed upon terms and requirements stated in the customer contract.

Product and process complexity; Categorizing products according to degree of specifications set by an OEM is important in order to understand the supplier's role and responsibility. The products with the highest degree of specifications are typical off-the-shelf components, found in a catalog, shared by several OEMs. On the next level the OEM itself conducts in-house engineering and detailed drawings and then outsources production to the lowest bidder, which becomes responsible for process engineering and manufacturing. The third category may be divided into gray-box and black-box integration. The former is defined by a situation in which the supplier works alongside the customer's engineers to develop the product, and the latter refers to a situation in which suppliers are given responsibility for development of the product, process, and manufacturing. In all four cases requirements and guidelines for functionality, main shape, quality, and interfaces are set by the OEM, together with price and delivery terms. The approach chosen by the OEMs depends on how much risk they are willing to take. The main reasons for outsourcing engineering capability are to spread risk and to get access to specific competence. In contrast to black-box components, for instance, off-the-shelf parts will not differentiate the finished product very much from those by the competitors. However, an extensive black-box approach may lead to decreasing ownership and in-house knowledge by OEMs. External product development may lead to concept leakage to competitors as well [17]. As seen in the case companies, by degree of involvement and frequency of communication between them and the customer, it is reasonable to conclude that their relationship, based on the above definitions, produces grey-box rather than black-box products. An interesting feature with the grey-box strategy, found by Koufteros et al. [18], is that it has statistically significant positive effects towards product innovation while the effects of black-box integration are negligible.

Having placed the case companies into the grey-box classification, the next step is to look at how innovative they are within this segment. The innovation process has a somewhat broader scope than the relatively structured product development process. If outputs from these CAD-models and FEA simulations are in accordance with requirements, then process simulations can be done to verify material flow in order to give feedback to preceding processes and input to tooling and requirements for equipment. This sequence is logical, but can be manipulated by the degree of overlapping activities, product and process integration, and the number of concepts evaluated simultaneously. Trott [20] illustrated degree of innovation as a result of theoretical conception, technical invention, and commercial exploitation, implicitly stating that that innovation is concerned with the theoretical, practical, and commercial applications of ideas or inventions. Thus innovation is separated from invention, where the latter is narrowed down to describe the process of converting intellectual thoughts into new artifacts. It can be added that innovation is perceived as an ongoing process and application of knowledge, not a single event [19,20].

Categorization; A selection of 12 representative product projects from the case companies, three from A, four from B, two from C, and three from D, were chosen as input data to test the risk assessment framework. Key personnel in these companies were asked to review product and process novelty by ranging these two dimensions according to newness - on a scale from minor changes to improved performance, new to the company, and new to the world. Each scale representation for the product dimension is weighted successively from 1-4, and from 1-3 for the process dimension. To create an index for each dimension, the numbers of processes/product functions perceived to fit within each category are multiplied by its weight, and then summed over the scale before being divided by the total number of processes/product functions. The number of value creating processes and main product functions are respectively derived from process charts and specifications. An example is illustrated in Table 1 where process and product indexes are calculated for a case 4 project. The equation for calculating the product and process risk index is as follows: Risk Index (process) = ((1×Improved performance) + (2×new to the company) + (3×new to the world)) / (number of processes). The exercise of calculating indexes was done for each project, in addition to recall number of project hours, internal and external, spent on research and development.

Table 1. Risk index example from case 4

		Weight	Process	Product
Number of processes / functions			22	4
Category	Minor change	*1*	NA	3
	Improved performance	*2 (1)*	14	0
	New to the company	*3 (2)*	7	0
	New to the world	*4 (3)*	1	1
Risk index			1.41	1.75
R&D hours spent: 11500				

The results are shown as a bubble chart in Figure 2, where the vertical axis represents the process dimension and the horizontal axis the product dimension. The third dimension, number of project hours, is indicated by bubble size and explicitly labeled. The projects representing the least and the most unique project, respectively the lower left corner and upper right corner in Figure 2, are both from case company four. To verify the model a brief explanation of these extremes may be required. Case four develops and produces aluminum wheels for the premium market, mainly for Volvo and Audi. Their traditional low pressure casting (LPC) processes became more and more subject to competition from low-cost countries, so they realized that to remain in the industry a complete new concept had to be developed.

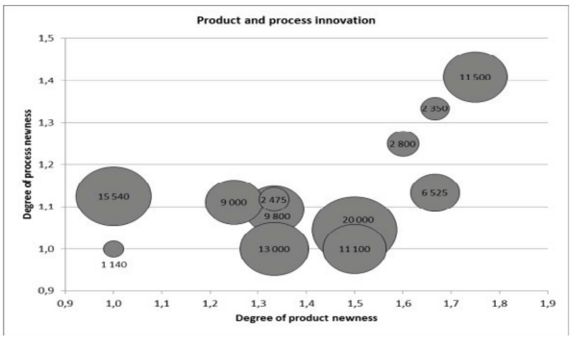

Fig. 2. Product and process risk compared for twelve projects

Hence, they came up with the now patented hybrid wheel, made out of the two pieces of the rim and disc instead of slipping it as one part out of the casting dies. This approach combines the properties of wrought and cast aluminum alloys, allowing designs with both thinner wheel rims and discs.

This concept adds design freedom for the visible part of the wheel, and it provides the automaker with more options due to the considerable weight saving. The latter serves as the reason behind the new-to-the-world product score on product functionality. For the process dimension the same score is given to the friction steer welding process (FSW) which is conducted without backing. Also seven new-to-the-company processes contribute to the superior process risk index over the other projects, where for instance roll-forming, butt welding, and several spin-forming and calibration processes were introduced to the process chart at case four. Based on its product and process novelty it is not surprising that this project locates itself in the upper right corner. However, novelty does not necessarily mean innovation. Successful industrialization of the hybrid wheel seems long and cumbersome. On the other end a product development project for a basic traditional wheel represents little uniqueness with regard to the product and its processes. For this particular project the design was given by the customer, leaving case four with the responsibility for verifying material flow in the casting process, sourcing tools, testing tools and equipment, and producing the required quantity.

In between the above described extremes there are projects ranging from large industrialization projects with many processes to carry-overs from existing product lines. Two products from case company three which rate relatively high on both product and process newness earn their position due to new methods for feed-forward cold forging processes of internal splines in components for steering columns. A case one product adds functionality to rear control arms by extreme deformation of extruded profiles, whereas a front control arm carry-over project increases its process newness index by introducing an adaptive and more robust assembly process. Case two has also focused on assembly processes, where for instance two GM projects are represented by new-to-the-company processes and improved functionality for the customer. The first project developed a new method for assembly of bumper beams and crash boxes and the second pioneered an easier way to attach crash management systems to car-frames. In general, the improvement focus in this selection of projects is on weight reduction and robust assembly processes.

It is interesting to note that product and process uniqueness does not seem to be dependent on amount of resources. As seen in Figure 2, it is difficult to recognize any pattern between number of project hours and newness. Some companies can develop relatively innovative products with a small number of resources if existing machines and equipment can be used and few sub-components and manufacturing processes are needed. Other, and less innovative, products may require many sub-components and 15-30 value creating processes;

hence, more resources are called upon. Also the number of change orders, which often depends on the number of interfaces the product has with other parts, may influence product development iterations and resource usage. Thus, interpretation of project hours along with the two other dimensions requires more explanation factors.

The project period for the 12 projects referred to above ranges from 10-53 months, while the average is about 26 months. Project hours needed also varies considerably and shows insignificant correlation with project period; however, the average is close to 8800 hours. The number of people involved in these projects amounts to about 10 in average, counting both internal and external contributors. This number is relatively significant, indicating that the same number of skills and functions are necessary independent of project size, scope, and newness.

Verification; Data was collected through interviews and search in internal company data bases. In total 27 informal interviews were conducted, using an Informal semi structured interview approach. This is an interview category that best can be described as face to face communication following a set of guidelines. Interviewees were picked based on how central they were in the selected projects. In addition all internal and external documents in the cases were made available to the research team. This means access to databases and systems consisting of project documentation, financial numbers, forecasts, QA systems (quality assurance), production planning etc. But we believe this approach satisfied the construct validity claim since interviewees could talk freely inside a frame and information from them could be check against formal systems. And it also secured the internal validity.

6. Conclusion

Companies today need to improve the success rate in order to sustain competitiveness and growth. This involves a well balanced portfolio of carry-over products in the low risk zone and breakthroughs in the other end, as well as knowledge about both product and process risk involved. Four Norwegian case companies which deliver value to their automotive customers by niche products in aluminum have tested the risk assessment framework developed in this study. The companies report that the framework is intuitive and easy to use and data to calculate the index is easily retrieved from existing data bases – making it a useful tool for calculating project risk in early product development stages. It is, of course, tempting to add factors and dimensions to this analysis. But, our belief is that this framework provides appropriate usefulness for the case companies at an early stage of product and process development. Adding complexity calls for more information and use of resources - something that can be done later on when companies for certain know that they are chosen as the preferred development partner.

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