

# What determines product ramp-up performance? : a review of characteristics based on a case study at Nokia Mobile Phones

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# **What determines product ramp-up performance?**

*A review of characteristics based on a case study at Nokia Mobile Phones*

Andreas Pufall<sup>1,2</sup>, Jan C. Fransoo<sup>2</sup>, A. G. (Ton) de Kok<sup>2</sup>

andreas.pufall@nokia.com; j.c.fransoo@tue.nl; a.g.d.kok@tue.nl

<sup>1</sup> Nokia GmbH  
Product Creation Center Ulm  
P.O. Box 2907  
D-89081 Ulm  
Germany

<sup>2</sup> Technische Universiteit Eindhoven  
Department of Technology Management  
P.O. Box 513  
NL-5600 MB Eindhoven  
Netherlands

## **Abstract**

We present a conceptual model to explore the essential characteristics that affect product ramp-up performance in the consumer electronics industry, specifically in the mobile phones sector. Our findings are based on data analysis within Nokia's mobile phones business group. Fast product ramp-ups are particularly critical for companies in which short product lifecycles prevail and in which development teams are required to work on new development projects than spending time with ramp-up support. Our model analyzes, extends and structures the results from other studies into five main characteristics: the product architecture, the product development process, the logistics system, the manufacturing capability and the external environment. We discuss the factors that describe and represent these five main characteristics on a quantitative basis and assess the impact of these characteristics on ramp-up performance with different measures in the model.

## **1 Introduction**

New product development is a challenge because several uncontrollable forces have emerged over the last decades putting companies that develop and launch new products in the high-technology sector under enormous pressure. Some of the most relevant forces are growing global competition, fragmented markets with sophisticated customers, technological changes and shrinking product life cycles (Gupta *et al.*, 1990; Clark and Fujimoto, 1991; Pisano, 1995; Mallick and Schroeder, 2005).

Competition on the global market has always been fierce as new players are continuously entering the market. In the 1990s, only a handful of mobile device suppliers existed. Nowadays, there are around 100 in China alone. Together with the decreasing brand preference this is becoming a major problem for the top ten mobile device suppliers in the world. In addition, these small players are often more reactive to market trends and very competitive in price.

Fragmented markets and sophisticated customers are the result of individualism and accumulated experience. This has sensitized customers to choose products for reasons that are not related to technical performance but to the fulfillment of their needs. As a result, companies have to leave the „one size fits all “strategy and provide products for different customer segments in diverse markets.

Technology changes might be the major driving force for high-technology companies. This evolves from the potential impact of new technologies on current business models. New internet services like VoIP (voice over internet protocol = phone calls via the internet), short range communication services like WLAN (wireless local area networks) or GPS (global positioning systems) can impact the value chain of telecommunication companies or enable other players to gain a stake in it.

Shrinking product lifecycles are another challenge for high-technology industries, because market windows and product lifecycles are decreasing in length, while technology investments are rising. Competitor products are also gaining importance. Companies must therefore shorten their development time (time to market) but also focus on the time it takes to reach full production volume (time to volume) in order to maintain high profitability. Early entrants to the market will enjoy higher profit margins and longer product life cycles, and can thus establish a dominant market position (Smith and Reinertsen, 1998). House and Price (1991) show that a product that is on budget, but introduced late to the market could miss one-third of the potential life cycle profit. Being on time but 50% overspent cuts the profit by only 4%.

With this background the economic success of manufacturing firms depends on their ability to identify the needs of customers and to quickly create products that will meet these needs and that can be produced at low cost (Ulrich and Eppinger, 1995). In spite of significant progress in new product development techniques such as concurrent engineering or design for manufacturing, the ramp-up phase remains a major challenge and provides a significant opportunity for gaining competitive advantage in high-technology firms. To be more precise about the terminology of product ramp-up, Wheelwright and Clark (1992) have created a useful and comprehensive definition: "In ramp-up the firm starts commercial production at a relatively low level of volume; as the organization develops confidence in its (and its suppliers) abilities to execute production consistently and marketing's abilities to sell the product, the volume increases. At the conclusion of the ramp-up phase, the production system has achieved its target levels of volume, cost and quality."

However, reality shows that the attained levels of volume, cost and quality are falling behind the planned targets. Studies carried out by Schuh *et al.* (2005) show that 47% of new product ramp-ups in the automobile industry were neither technically nor economically successful. In their studies on fast ramp-up, authors like Kuhn *et al.* (2002) state that not a single company claimed to have their production ramp-up under control. Research in the

global automobile industry by Clark and Fujimoto (1991) has shown that there are significant regional differences between the companies. Some companies achieve full-scale production six months later than others. This conflict between low capacity and high demand, that is putting a company under pressure from two sides, is referred to as the "nutcracker" effect (McIvor *et al.*, 1997).

The phenomena that make up the nutcracker effect were basically the trigger for this paper as the lack of understanding in this area seems to result from the fact that most of the current improvement activities are phase specific. They cover either product development or mass-production but ignore the link – the ramp-up phase. However, there are considerable business benefits if new product ramp-ups successfully overcome the nutcracker effect. In 2006, the mobile phones business unit of Nokia introduced 39 new products and it is likely that there will be even more product launches in 2007. If the velocity of change in an external business environment sets the pace for a firm's internal rate of new product introductions, it is called a fast clockspeed industry (Fine, 1998). Inspired by fruit flies, Fine (1998) developed an insightful interpretation of the ways product design, process technology and supply chains define the evolutionary course of a company. Fruit flies, as a result of their short lifecycle, must genetically respond to changes in their environment quickly or face extinction. As a consequence, companies like Nokia, operating in a fast clockspeed environment have to continuously assess industrial and technological dynamics in order to exploit current opportunities and anticipate future ones. Clockspeed in the area of product ramp-ups is therefore a precondition as it supports the opening up of current opportunities by dynamically positioning products or innovations in the market place. As a result this paper aims to understand the critical characteristics that are influencing (in a positive or negative way) the product ramp-up in order to manage them more effectively, to assess the risk level more thoroughly and to be able to make better decisions in the development phase of the product. Faster ramp-ups can also free up resources in the development or manufacturing area and allow them to support new projects or other value adding activities.

## **2 Literature review**

The purpose of this section is to establish the legitimacy of our study and to position the research problem within the existing body of knowledge. The review will compare and contrast the research problem with the existing theories structured by the industry environment, the research methodology and the lifecycle phase (product development, ramp-up, volume production).

Ramp-up management as the critical interface between new product development and volume production has been well described and analyzed in the literature (Clawson, 1985; Langowitz, 1987; Clark and Fujimoto, 1991; Pisano, 1995; Terwiesch *et al.*, 1998; Almgren, 2000; Kuhn *et al.*, 2002; van der Merwe, 2004; Schuh *et al.*, 2005). All of these papers have recognized the difficulties in exploring this subject for theory building or theory testing due to the multidimensional complexity of the subject. On the other hand, there are major cost- and time saving potentials that can be gained if the key elements of successful ramp-up management are understood. Although there are studies from several other industry sectors, the majority of research has been carried out in the automobile industry. Clark and Fujimoto (1991) were some of the first researchers who performed a global field study to understand and analyze new product development in the automobile industry. Their field research incorporated surveys and case studies within twenty companies in six countries around the world. Although the focus was on the effects of strategy, organization and management on product development their findings also revealed four essential factors that influence the product ramp-up:

- The manufacturing capability. Manufacturing capability is seen as the ability to make things rapidly and efficiently. A high manufacturing capability results in rapid prototype cycles, fast tool development times and effective ramp-up volume production. In addition, Clark and Fujimoto (1991) found indications for faster time to market, fewer engineering hours and higher quality as a result of outstanding manufacturing capability.
- The ramp-up curve. In principle there are three different choices called shut down, block introduction or step-by-step ramp-up. They differ in the way the old product is ramped down and the new product is ramped-up. The longer the transition period between the shutdown of the old model and the ramp-up of the new model is, the less steep and hence risky is the ramp-up. However, the transition phase is more complex because it requires a more sophisticated material handling and line scheduling.
- The operation pattern. The operation pattern is seen as the rate of production and mainly affects the ramp-up due to its impact on the line speed, the number of products in the line and the overall operation time per day.
- The work force policy. Depending on the ramp-up curve there are different policies to align the work force with the production rate. The firms can either try to keep a stable work force over time, layoff and call in's during changeovers or increase the work force temporarily during the transition phase. Clark and Fujimoto (1991) claim

that the rate of learning and hence performance tends to be higher if the working conditions and task assignments are stable.

Although the prime purpose of this study was to find the relevant factors that make up superior product development performance, Clark and Fujimoto (1991) present evidence that product development performance is closely linked with successful ramp-up management. This seems to explain why Japanese companies were more successful in timely product launches than their European or American counterparts during the 1980s. However, the findings are based on the prevailing concepts in the automobile industry during the 1980s and can't be generalized without considering the specific characteristics in other industries today. The mobile device industry for example is characterized by far shorter development times and life-cycles, different sales channels and different manufacturing/logistic concepts that are the result of the size, price and volume differences.

Another large study in the area of ramp-up management was carried out by Kuhn *et al.* (2002). The purpose was to perform a situation analysis in order to identify research demands that yield to quantum leaps in the area of ramp-up management. Kuhn's study more directly addressed the area of ramp-up management compared to the study by Clark and Fujimoto (1991) which was primarily focused on product development performance as a whole. Using on-site studies, workshops and public discussions in three business lines such as the automobile, electronics and engineering industry, Kuhn and his team identified the factors that affect ramp-up performance and classified them into six categories.

These categories are:

- Product development– the level of newness compared to existing products
- Production processes – the degree of process robustness, flexibility and newness
- Organization and personnel – the level of qualification and role clarity
- Logistics - seen as the generic term for the availability and quality of parts and subassemblies
- Networks and cooperation – characterized by the information flow and information transparency
- Methods and tools – project management and change management practices

Based on these factors, five action areas for further research have been defined. They incorporate the development of advanced methods to control the ramp-up complexity, robust manufacturing systems, change management procedures, improved cooperation models and holistic knowledge management. Comparable findings were documented by

Schuh *et al.* (2005) in their benchmarking project in the automobile industry. They refer to the concept of complexity management which is the result of the multitude and dynamics of interdependent objects and their interaction with different work functions. The objects are in line with the ones identified by Kuhn *et al.* (2002) and the work functions are classified by development, production, logistics and sourcing. However, neither of these two studies include a more detailed analysis of the complex interactions of the identified factors with regard to ramp-up performance. Their main ambition was to identify further improvement potentials disregarding the need to understand the underlying phenomena during the transition from the development phase to volume production within a certain industry. This gap is partly filled by Nyhuis and Winkler (2004). Based on the work by Kuhn *et al.* (2002), their target is to model the cause and effect relationships to simulate the impact of certain influencing variables on the target key parameters. Supplemental to these contributions is the work of Fleischer *et al.* (2003). They developed a simulation model that generates ramp-up curves as the result of the interaction between several elementary processes whose quality capability curves are known. However, there does not appear to be any paper that verifies the models with industrial data and the focus is limited to time dynamic parameters that have to be identified by explorative studies.

Similar results but with a more explorative character were found by Almgren (2000). He analyzed the pilot production and the manufacturing start up process at the Volvo Car Corporation in a longitudinal case study. He argues that the number and the frequency of disturbances during the start-up period overload the organization and result in a loss of production capacity or increased production load. He categorized the existing types of disturbances in terms of their sources, namely:

- Product concept – disturbance arising from the number of engineering changes
- Material flow – the quality, status and quantity of materials
- Production technology – capacity, availability and performance of equipment
- Work organization – the skill level, work performance and attendance

Priority wise, Almgren found that the most common type of disturbance in his study was the inability of the suppliers to deliver materials of the right status in the right quantity on time. There is a direct correspondence between Almgren's categories and the factors identified by Kuhn *et al.* (2002) except for some higher level concepts that exhibit the difference of the focus between the studies. In addition, Almgren identified also some moderating variables that positively affect the final verification process. Among those factors are the development of a temporary organization to support the ramp-up process and the principle of full speed. This principle states that production systems should always be run at full speed in order to



advance the rate of learning and to provide the right amount and quality of information for effective disturbance control.

A study that is more focused on the consumer electronics industry was carried out by Terwiesch *et al.* (1999). The research objective was to gain a detailed understanding of the production ramp-up process in a hard disk drive company. Using a longitudinal case study approach, their finding revealed several organizational patterns that seem to shorten a products ramp-up period. First, a soft handover from pilot production to volume production gradually contributes to better performance. Second, clear organizational responsibilities together with a high commitment and cross functional interaction fostered a smoother transition. And finally, the introduction of product platforms allows companies to leverage previous ramp-up experience for the ramp-up of new products from the same platform. These findings support and enhance the existing concepts but due to the explorative nature of the study it does not provide a more detailed analysis of the relationship between product development and production ramp-up. The study only considers the last three months of the development phase thus neglecting the aspects of product conceptualization and development. Another study by Terwiesch and Bohn (1998) analyzed the effect of learning on ramp-up performance, described as capacity utilization and yield. The results of their simulation highlight the importance of learning during ramp-up in order to achieve fast time-to-volume compared with the still dominant paradigm of time-to-market. Not only the level of learning is important but also the sources of learning (normal experience, experiments, engineering time). Although the study has made strong simplifications of real world ramp-up situations it provides useful insights into the effects of "yield first" or "speed first" policies.

A complementary study on the relationships between the product development process and problems during the initial commercial manufacturing of a new project was carried out by Langowitz (1987). She developed and tested a conceptual framework to explore the impact of the development process, the product design and the manufacturing capability on the initial commercial manufacturing period. This study should be seen as supportive rather than conclusive for the existing frameworks as it was build on the interview data of 15 projects. Although the study was performed in the late 80's when the mobile device industry was still in its infancy and the business environment at that time was partly different from the one today the findings seem to be still valid. First, it is important how the development process is managed - meaning how clear definitions and milestone criteria are defined. Second, an atmosphere of high communication and cross-functional interaction leads to better results. And finally, particularly in highly technical ambitious projects emphasis should be placed on

manufacturability in the design. Manufacturability is also stressed by Pisano and Wheelwright (1995) who pursued a case study in the pharmaceutical industry. Their findings confirm the importance of process development at an early stage of the development cycle as a way to build a unique and sustainable competitive position. In addition, they found evidence that manufacturing process innovation results in faster and more productive product launches and even enhanced product functionalities.

Finally, there is a comprehensive study by van der Merwe (2004). He has developed a conceptual framework that extends the concept of learning as a driver of ramp-up performance with the concept of novelty, demonstrating that ramp-up performance is driven by two kinds of learning activities which are in response to five dimensions of novelty. Those novelty dimensions are product-, product mix-, process-, supplier- and personnel novelty. The study provides strong empirical support for the association between different levels of novelty and ramp-up performance. This framework provides a solid and tested high level conceptual model, but it does not provide a quantitative relationship between the novelty dimensions and ramp-up disturbances. In order to achieve the research aim, van der Merwe used a combination of different case study approaches. First, a preliminary framework was created on the results of six mini case studies. Second, two main case studies examining a new platform introduction and a new production line introduction were used develop the preliminary framework in further detail. Finally, the framework was stabilized by six additional case studies. Although this study determined the elements of novelty that impact the manufacturing ramp-up period, certain supplemental factors could not be included in the model. This is a result of the case study methodology van der Merwe used, because it prohibited him to get access to sensitive information like as cost or financial data.

As a conclusion of this literature study it can be said that previous studies agree about a similar set of influential characteristics that affect ramp-up although they examined different industries and used different research methodologies. The key elements are related to the product architecture, the manufacturing capability and the human resource setup. Further elements that seem to matter are the product development process, the material logistics, the cooperation model and the applied tools.

### **3 Conceptual model and propositions**

The purpose of this section is to define and quantify the identified characteristics into more detail and to elaborate the relationships between these characteristics so that a comprehensive conceptual model can be generated. First, we propose to regroup the seven

identified characteristics that are described in the literature into the following five main categories that provide the headers for the following sub-sections:

- the product architecture
- the manufacturing capability
- the product development process
- the logistics system
- the external environment

This grouping aligns the identified characteristics with observations and experience from the Nokia specific environment. Additionally, we believe that residual elements like the human resource setup or the usage of tools are either applicable to all of the characteristics or just sub-items of the main characteristics. The further structure of this section will be as follows: We begin with the product architecture and introduce measures for product complexity, newness and maturity. Afterwards we move on to the manufacturing capability characteristic which we separate into growth and steady state capabilities in order to define appropriate measures for it. The third characteristic that will be described and defined is the product development process. We expand this characteristic into process performance and product concept effectiveness in order to identify suitable measures. Next, we will characterize the logistic system. Our measures for this characteristic are based on the global structure of the Nokia logistic system and its interdependency to a logistic friendly product design. Finally, we will group the characteristics that are not related to any other group - specifically the volume plan and its forecast error - into the external environment category. Our aim is to select factors that can be captured quantitatively by using company internal information systems. This exhibits the strength and quantitative approach of this paper compared to other studies in this area.

### ***3.1 The product architecture***

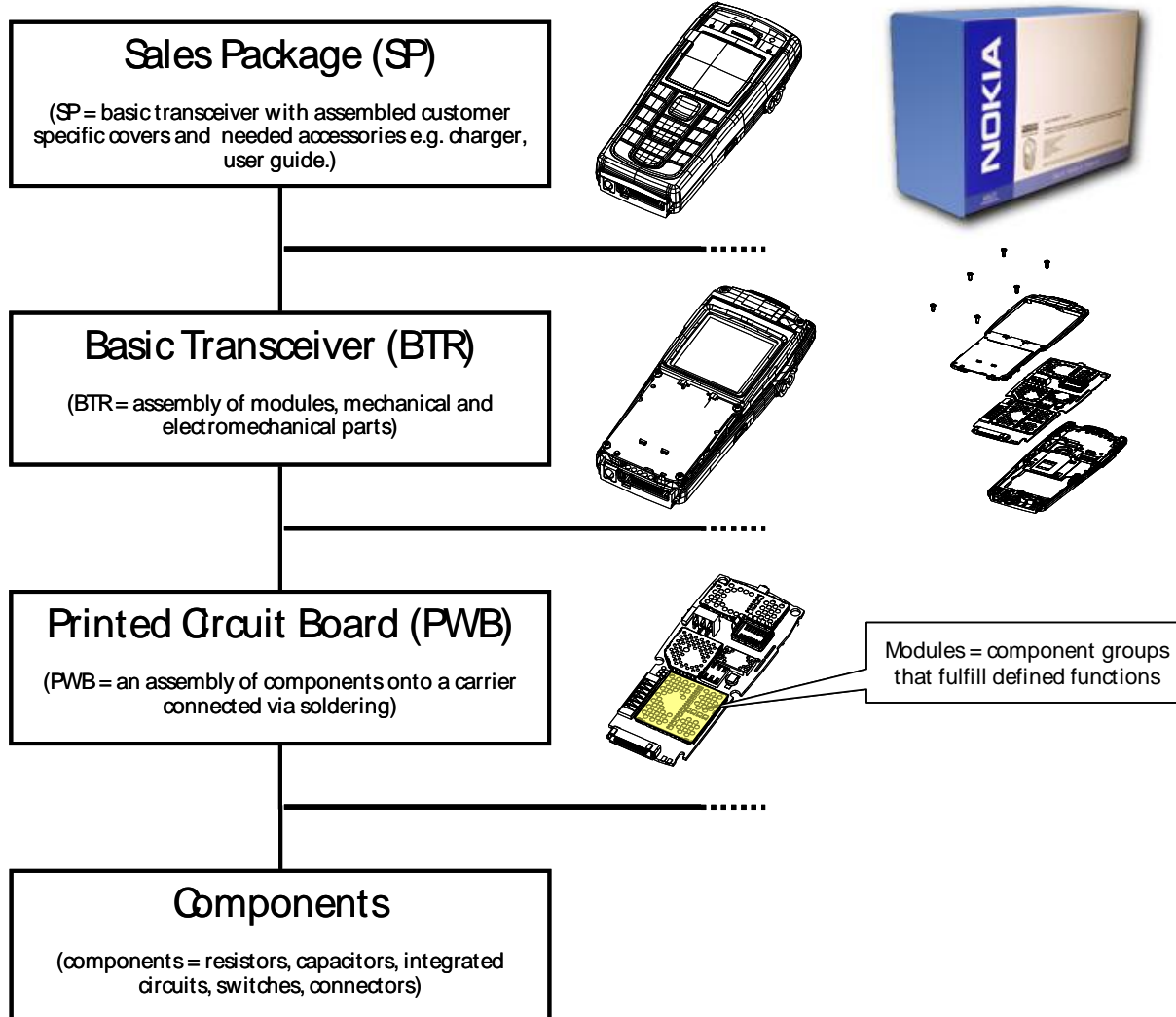
The product architecture comprises all the functional and physical items that are needed to fulfill the customer requirements. In more detail, the product architecture is the arrangement of the functional elements of a product into physical blocks (Ulrich and Eppinger, 1995) or, as defined by the PDMA (2006) the way in which the functional elements are assigned to the physical chunks of a product and the way in which these physical chunks interact to perform the overall function of the product. The product architecture normally starts to emerge during the concept creation phase. It becomes more sophisticated during the development phase by choosing key design variables, components, technologies and suppliers. The literature suggests many elements, characteristics, dimensions and factors to describe and define product architecture in exact terms. As most of the authors use similar dimensions we

propose to group the product architecture characteristics into complexity and newness (Novak and Eppinger, 2001; Kaski, 2002; Tatikonda and Stock, 2003; Swink, 1999; Nyhuis and Winkler, 2004; Ehrlenspiel, 1995).

Complexity can be defined with an information-based definition (considering the property of a system depending on the description of the system by an observer) or with a structural-based definition that describes complexity as a property of the object (Rodriguez-Toro, 2004). The structural-based definition is less subjective and easier to measure, therefore we will use it with the following elements:

- the number of product components
- the extend of interaction and interdependence between these components

Before these characteristics can be applied to the Nokia specific environment, a short digression into the architectural structure of a standard mobile device sales package is needed. Although the architecture described here is based on Nokia devices it is quite similar across the entire industry. The architectural structure consists of four hierarchical levels as presented in Figure 1. Components like resistors, capacitors, transistors, integrated circuits, connectors and switches are at the lowest level. The printed circuit boards stands at the next higher level in the hierarchy. Printed circuit boards contain all the components that are necessary for the electrical functionality of the phone. A typical printed circuit board consists of up to 500 components distributed both to the top and bottom side. Certain component groups that fulfill specific and clearly defined functions are called modules. Examples are the digital block, the analogue block or the radio frequency block of a phone. The basic transceiver (BTR) stands at the next higher level in the architecture. In addition to one or sometimes more printed circuit boards a basic transceiver contains all the mechanical and electro-mechanical components that make up a complete device but without the customer specific covers and keypads. Finally, at the highest level of the architecture stands the complete sales pack including the fully assembled and customized device, a battery, a charger and other customer specific material.



**Figure 1: The hierarchical structure of a Nokia mobile device sales package**

As this type of hierarchy is present in all Nokia mobile device sales packs, we propose to apply the two categories of complexity that were defined earlier in the following way. First, complexity is driven by the number of components. This was empirically derived and is well described in the literature about design for manufacturing (DFM) (Boothroyd and Dewhurst, 1987). Products with a low component count require fewer components to be manufactured, sourced and assembled and have fewer parts that can fail in manufacturing. Second, we include the material cost as a measure because the component count alone is not inclusive enough. Two product designs can be equal in component count and still differ in complexity as the following example shows. Memories (high capacity vs. low capacity), displays (high resolution vs. low resolution) or connectors (high pin count vs. low pin count) are parts that count as one on this level of aggregation but they reveal different complexities on product level. Such components often require the application of more sophisticated manufacturing technologies (e.g. memories), materials (e.g. LCDs) or integration testing concepts which is

subsequently reflected in price. This leads to the additional measure of the bill of materials cost next to component count as a representation of product complexity.

The definition about the extent of interactions between these components is more difficult. A mobile device can contain up to 1000 parts which results in an enormous number of interactions. Therefore a more pragmatic definition must be used. Based on own experience we suggest to measure the number of electrical interfaces on the basic transceiver level that are not soldered. Experience has shown that all electrical components or modules that are connected via spring contacts, hand soldered wires, connectors or bondings are exposed to higher failure rates, especially during ramp-up when the knowledge about these interfaces is still low. We count every connection between two components or modules as one even if there are more electrical connections involved. This avoids bias towards high pin count connectors. These connectors consist of hundreds of electrical connections which in most cases do not fail separately but rather as a whole. In comparison, solder connections between the components of a module seem to be much more robust and failure rates tend to depend mainly on component pin count<sup>1</sup>.

The second main factor of the product architecture - newness - should be seen as the degree of prior experience with the functional elements of the product or its technology. Within the literature on management, newness is sometimes also characterized as the magnitude of technological change (Barnett and Clark, 1996), the percentage of change in the new product relative to its predecessor product (Griffin, 1997), or the organization's experience with the given technology (Abernathy and Clark, 1985). When a new product involves new functional elements or technologies there are new sets of interactions between the components that are not yet well understood. The process of identifying and understanding these new interactions adds uncertainty, risk and effort to the development team, possibly resulting in difficulties before and during the ramp-up. This is supported by Abernathy and Clark (1985) who confirm that newer technologies require new knowledge, skills, organizational procedures, capital equipment and organizational relationships with vendors. Yoon and Lilien (1995) even claim that newness is one of the most important factors affecting success or failure of a new product. There are many intermediate forms between the extreme incremental and radical categories of newness. Different levels of both forms are commonly found in Nokia projects, therefore we need to measure newness on

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<sup>1</sup> This is a simplified statement, for a more detailed view refer to Shina (2002).

three dimensions (refer to Table 1): functional module newness, technology newness and software newness.

- Functional module newness: functional modules are an aggregation of components, software, interfaces and test-sequences that constitute a product-function. Examples are displays, audio components, radio frequency modules or hinge/slide mechanisms. These modules differ from pure components because they are fulfilling complete sub functions in a mobile device. To account for the degree of newness of each functional module we calculate the relative value of the module per basic transceiver. This normalization is necessary in order to compare the measure between different products and to quantify the degree of newness per product. Simple low-cost modules often only require small changes in the hardware layout, the software or the test procedure – which in turn only presents a low risk for ramp-up performance compared to highly complex modules that require high integration efforts.
- Technology newness: technology refers to the methods and means to produce components and parts. Examples for new technologies are unique plastic or metal coverings, special joining methods like gluing or thermo-bonding or the use of advanced customization technologies like laser engraving. All these technologies might affect the final verification process of the product or have an impact on the supply side, forcing suppliers to deliver products with these new technologies.
- Software newness: in addition to hardware and technology newness we also need to cover the dimension of software newness. This can be done by counting the number of critical software features. Due to the fact that every new feature needs to be specified, implemented, tested and corrected, it adds a tremendous schedule risk to some of the development projects. Non solved software bugs as a result of new and complex features are often the reason for delayed ramp-ups. This is especially critical if material and production lines are reserved but not in use because production testing and product delivery is dependent on approved software releases. Critical software features are always counted and assessed by the software project managers during the specification phase to estimate the testing effort- and risk.

The impact of complexity and newness on ramp-up performance is also affected by the way the project team manages the uncertainty. In order to quantify this effect we need to add a third characteristic – the level of maturity. In this context, maturity is the level of product completeness compared to the frozen product specification. A more mature product requires less engineering changes, less debugging / rework and less coordination efforts resulting in less uncertainty during ramp-up. Based on these facts, we propose to describe product

maturity according to the characteristic in Table 1. Data sources for this measure are trial run results that are performed at a special location called “pre-production line” which is *outside* the actual target factory. Two to four trial runs of this type are typically performed in order to develop the product and the underlying processes. This measure provides us with a good estimate for product maturity because the complete production setup including the workforce follows the same procedures irrespective of the product under production. After the product and the processes have achieved a certain level of maturity on this “pre-production line”, one or two additional trial runs are performed – this time however, on the final mass-production line which is temporarily converted for this purpose. The purpose of these trial runs is to simulate the mass-production environment including the fine tuning of the manufacturing processes, the operator training and the verification of locally produced material. However, this measure will be used to estimate the factory readiness and is described in the chapter about manufacturing capability (steady state capability). Our proposition is based on the assumption that products with a high maturity, reflected in an already high yield level before the mass-production simulation, have higher yield levels during ramp-up and require less problem solving activities. This is reflected in an overall better ramp-up performance.

**Table 1: Product complexity- , newness- and maturity measures**

Name	Description	Data type
PC <sub>1.1</sub> PC <sub>1.2</sub>	The component count on module level and basic transceiver level (including cover parts and keypad)	Metric, discrete
PC <sub>2.1</sub> PC <sub>2.2</sub>	The bill of materials cost of the printed circuit board and the basic transceiver (including cover parts and keypad) [EUR]	Metric, discrete
PC <sub>3</sub>	The number of electrical interfaces on the basic transceiver level that are NOT soldered (e.g. spring contacts, hand soldered wires, connectors, bondings etc.)	Metric, discrete
PC <sub>4</sub>	The material cost of new functional modules [EUR] that are not yet familiar to the development site  $\text{module newness} = \frac{\text{material cost of new functional modules}}{\text{total BTRmaterial cost}}$	Metric, continuous
PC <sub>5</sub>	The number of new and unfamiliar technologies per product (new and unfamiliar for the development site)	Metric, discrete



PC <sub>6</sub>	The number of critical SW features	Metric, discrete
PC <sub>7</sub>	The difference between the target yield and actual yield during the last pre-production trial run (outside the final mass production line)  $\text{product maturity} = \frac{\text{final pre - production trial yield level}}{\text{target yield level}}$	Metric, continuous

Finally, based on the elements of product complexity, newness and maturity we expect the following:

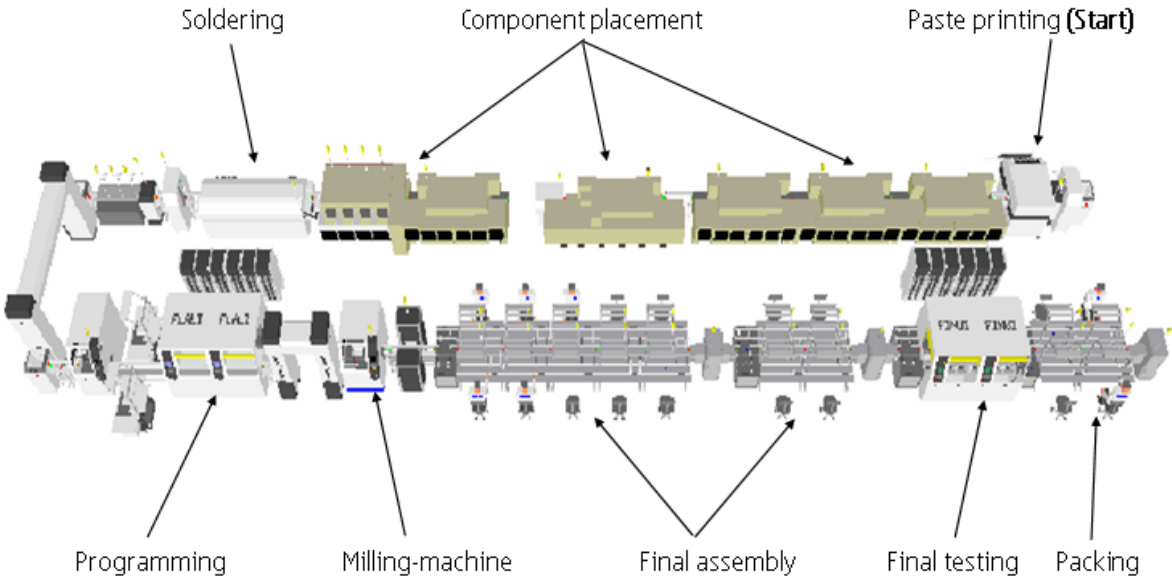
*Proposition 1a: Lower levels of product complexity and newness are associated with better ramp-up performance.*

*Proposition 1b: Higher levels of maturity are associated with better ramp-up performance.*

**3.2 The manufacturing capability**

Manufacturing capabilities span a wide range of attributes, so first we need to introduce the underlying manufacturing process for a mobile device in order to group the relevant attributes and their measures in a comprehensive but also specific way. Figure 2 shows a simplified picture of a standard manufacturing line. The starting point is on the upper-right side with the surface-mount technology part (SMT). Surface-mount technology encompasses the placement, attachment and soldering of electronic components directly onto a bare printed circuit board. After processing a printed circuit board, the programming phase adds test software to the board to perform a basic functional test and to align the radio frequency part. This is necessary because the radio frequency requirements for a mobile device are tight and the hardware capabilities are rather low due to the inherent tolerances of the used components. Before the boards can be assembled into mechanical elements they have to be separated from the auxiliary-flaps in a milling-machine. The subsequent and most manual step is the final assembly phase. In this phase the printed circuit boards and other electromechanical components are assembled into the mechanical covers. In order to avoid shipments of non-conforming units and to control the assembly process, a final test has to be performed. Finally, the ready-made basic transceivers are packed and shipped to the customization centers where the customer specific configuration takes place. This involves very simple activities like the assembly of customer specific covers and the packaging into

the final country/customer specific sales package. An essential part of all Nokia manufacturing lines is their standardization. This means that most of the equipment, the consumables, the line control software, the generic layout and the process parameters are standardized and do not grant a large degree of freedom to the factories. Applied to the conceptual model, this fact will shift away the focus from the manufacturing capability towards the other areas as they are less restricted.



**Figure 2: A highly simplified manufacturing line for a Nokia mobile device**

Manufacturing capability can be seen as the ability to make things rapidly and efficiently. This was initially found by Clark and Fujimoto (1991). In regard to new products, other authors like Langowitz (1987) describe the manufacturing capability to be defined by two major components: a physical resource capability and an organizational capability. The resource component is embodied in the factory’s resource endowment. It consists of those resources that are directly related to fabricating the new product and of those resources that are directly related to the movement of the new product through the factory. The organizational component of the manufacturing capability in regard to new products is inherent in the factory’s situational response system. Namely, in the ability and means of a factory to monitor its activities, identify issues that need special attention, evaluate these problems, and respond to them. Swink and Hegarty (1998) have expanded the concept of manufacturing capabilities into seven elements that can be grouped into two areas. First, into *steady state capabilities* that are indicated by superior manufacturing outcomes and specified by their level of accuracy, control, agility and responsiveness. Second, into *growth capabilities* that are indicated by the development of new steady state capabilities. Their

components include improvement, innovation and integration. Based on this characterization we propose to group the Nokia specific manufacturing capabilities into *growth capabilities* and *steady state capabilities*.

*Growth capabilities* are very much characterized by the ability to incorporate new products or processes into the operation or by how well the performance can be improved by the existing resources. Not a direct measure but an indicator of this is the number of ramp-ups of new products that a factory has performed over the last six months. If there have been many ramp-ups we expect the manufacturing site to own a high level of motivation, introduction flexibility and knowledge compared to a site with fewer number of ramp-ups. These assumptions are in line with the work of Hatch and Mowery (1998) that improvement of manufacturing performance through learning is not an exogenous result of output expansion but primarily influenced by the systematic allocation of engineering labor to problem solving activities.

New manufacturing processes could be the reason for yield and output losses as the initial process understanding is often low and process control is insufficient. Nyhuis and Winkler (2004) argue that most of the arising problems during ramp-up are the result of immature production lines. A typical example that illustrates this fact was the introduction of lead free soldering. Lead free soldering required the factories to implement a new process with tighter process parameters. Unfortunately this resulted in yield- and output drops because the new process was not as stable and mature during the ramp-up as the previous one. We measure production line maturity as the extend to which new processes are introduced into an existing line as this seems to be the most pragmatic measure for it.

A *steady state* capability variable is the ability to direct and regulate operating processes. We believe that a factory inhibits a higher level of knowledge about the current process capability limits and sources of variation if less changeovers and new setup activities have to be introduced to a manufacturing line. To measure this phenomenon we add production line commonality to the conceptual model. High commonality factors expressed as the relative value of new product specific equipment require less modification activities at the production line. In these cases verified and smoothly running mass-production lines can be fast and easily converted, allowing smooth ramp-ups with little disturbances by the manufacturing line itself.

Maturity was already considered in the last chapter but focused on the product architecture. The measure applied in this section is intended to reflect the manufacturing maturity as a result of executed trial runs. The major influential variable for such a trial run (compared to

the last trial run on the pre-production line) is the usage of the final mass-production line and their operators. We believe that this offers us a good representation of the manufacturing line maturity at that point in time.

**Table 2: Growth- and steady state manufacturing capabilities**

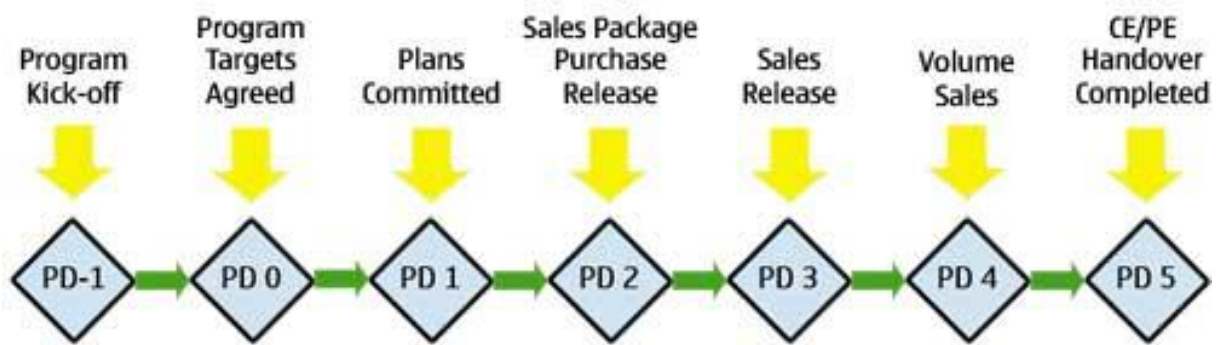
Name	Description	Data type
<i>Growth capabilities</i>		
MC <sub>1</sub>	The number of new product ramp-ups during the last 6 months	Metric, discrete
MC <sub>2</sub>	The number of new manufacturing processes (which are new to the factory) that have to be introduced	Metric, discrete
<i>Steady state capabilities</i>		
MC <sub>3</sub>	Line commonality as a measure for mix flexibility between an existing and a new line configuration as expressed below:  $\text{prod.line commonality} = \frac{\text{value of new prod.specific\textcircled{e}quipment}}{\text{total value of prod.specific\textcircled{e}quipment}}$	Metric, continuous
MC <sub>4</sub>	The yield level during the last trial run (performed on the final mass production line)	Metric, continuous

There are other measures within these categories but as already explained, most of the parameters are standardized and do not significantly differ within the Nokia specific environment. According to the presented factors we suggest the following proposition.

*Proposition 2: Higher levels of growth capabilities and steady state manufacturing capabilities are associated with higher ramp-up performance.*

**3.3 The product development process**

For every new product, Nokia uses a phase driven development process that divides the whole project lifecycle into smaller phases with clearly defined deliverables (Figure 3). In this research context, the key milestone is PD3. Production starts at this point in time and the first sales packages are shipped out to the customers. Later, when production has reached the planned target capacity and the suppliers have given their commitment to the planned volumes, PD4 is granted. PD4 marks the sales volume commitment and defines the point in time at which the ramp-up is finished. After this point, volume production is achieved and only maintenance and ramp-down activities are performed.



**Figure 3: The Nokia development process of a mobile device**

The phase between PD2 and PD3 is mainly dedicated to the process development and the fine tuning of the product. During this phase intense manufacturing trials and supplier verification runs are executed. However, product design has to be completed at PD2, so that components and mechanic molding tools can be purchased. This step is required at a minimum of twelve weeks before PD3 because the lead times for certain components are long. The actual development phase is reduced to the phase between PD1 and PD2. The time after PD2 can only be used for fine tuning activities that do not require major hardware changes such as the elimination of software bugs. A fine balance between needed improvements and potential ramp-up delays is mandatory, because type approval and molding tool production is started and can not be interrupted without severe consequences. The time between PD0 and PD1 is mainly used to create the project plans and to freeze the product specification whereas the time before PD0 is used to define the project scope and to collect the project team.

The theoretical base on product development proficiency has increased during the last years as this process has been acknowledged to be important for competitive advantage (Clark & Fujimoto, 1991; Zirger and Maidique, 1990; Brown and Eisenhard, 1995; Sobek *et al.*, 1998). Although there is a vast amount of literature about product development, Brown and Eisenhard (1995) have organized the different research streams along three factors that contribute to product-development success:

- *Process performance*
- *Product concept effectiveness*
- *Market situation*

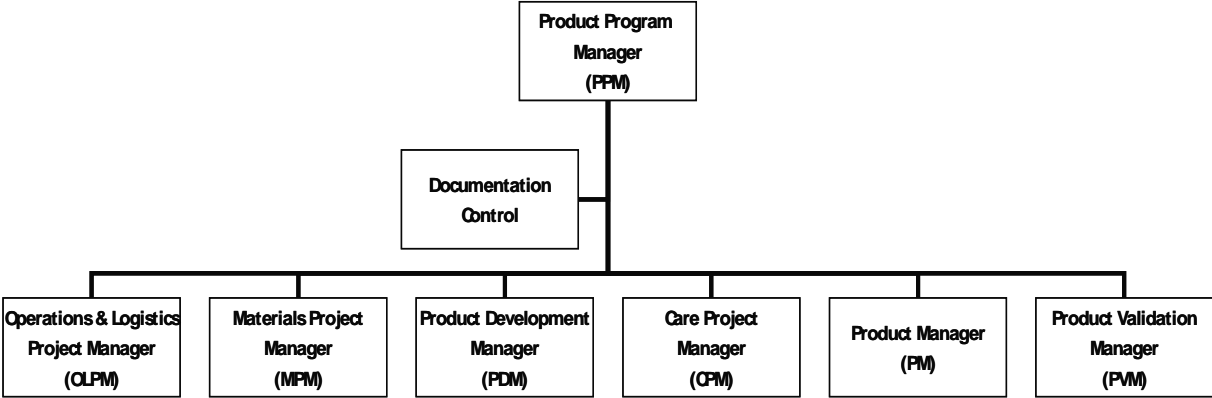
This arrangement will provide the structure for the further analysis. The first factor, *process performance* is about speed and productivity. It is driven by team composition, supplier involvement, team organization, team group processes and project leader skills. Most of the

upstream activities in Nokia take place around supplier selection, location, involvement and capability. This is based on the fact that a mobile device is so complex that no single company alone is likely to master all of the relevant technologies on a competitive level. Involving sub-suppliers at an early stage can for example have advantages such as shorter lead times, lower costs, higher quality, shared costs and earlier availability of prototypes (Fagerström and Jackson, 2002). However, the supplier interaction is strictly specified by the development process and it can also result in drawbacks if uncertain product specifications create an unstable product development process. This led to the decision to focus on the speed variables in the process performance area. We measure development time as a result of our assumption that shorter development times provide project teams with less time for improvement and verification activities. This can result in lower product maturity and hence worse ramp-up performance. A similar result is expected for the time between supplier mass production simulation and ramp-up start. Supplier mass production simulation means that all mechanics suppliers perform a one week full production run to proof their mass-production capability - volume and quality wise. The earlier this can be started the more time is available to fine tune the molding tools, the metal stamping lines and the decoration processes. However, this rule can be falsified if there is a negative impact through late engineering changes because that would collide with the supplier mass production simulation as a result of their earlier start.

The impact of the team composition and cross functional integration on the success of development projects is already well described in existing literature (Sobek *et al.*, 1998; Langowitz, 1987; Almgren, 2000; Terwiesch *et al.* 1999; Tabrizi and Walleigh, 1997). Most product development teams are formed at the beginning of the project. They typically include representatives from all areas as shown in Figure 4. Although the overall structure and the working mode of the teams is similar between the projects there are many differences in team behavior that can have a significant impact on the overall team performance. Voigt and Thiell (2005) point out that an efficient ramp-up team has to be composed cross functionally, including people with just the right competences and experience levels. Additionally, it is crucial for the accomplishment of a successful ramp-up to keep the general work level in balance. An increased work level due to ramp-up activities might otherwise compromise the motivation of the teams. We therefore hypothesize in our model that teams with enough experience and a moderate workload will perform most efficiently. A moderate workload allows team members to support each other and leaves them enough time for communication within the team. Compared to overstrained colleagues, they are also more likely to stay motivated. Results from several research papers (refer to

Brown and Eisenhardt, 1995) indicate that effective group processes - particularly those related to communication - increase information and thus are essential for highly effective development processes. On the other hand, moderate experience reduces the individual level of uncertainty in new projects, contributes to a certain level of trust and keeps team members more flexible than their highly experienced counterparts. Van der Merwe (2004) supports this view, stating that a venture is more likely to be successful if the team members are experienced with new product development projects. Experimental tactics seem to be more effective than established and mature strategies, especially in highly uncertain projects with short iteration cycles (Brown and Eisenhardt, 1995). We defined two measures for team composition (refer to Table 3) as a result of the previous discussion, the work experience that these factors differ significantly between Nokia projects and because of the reliability of the data.

Although other research like the work of Fleischer and Liker (1992) points to the importance of team integration and manufacturing involvement on product development, these factors are not explicitly recorded here due to the assumption that these factors do not significantly differ between the projects. This assumption is based on the obligatory and formal application of the development process guidelines, the usage of uniform tools and the homogeneous organizational structure as shown in Figure 4. This structure fosters functional diversity of project teams so that project team members understand the development process from a variety of perspectives.



**Figure 4: The organizational structure of a typical product development team**

The second factor, *product concept effectiveness*, is affected by the customer involvement and the senior management support but plays only a secondary role in this conceptual model because these factors do not differ much between the projects. The third factor, *market situation*, consists of elements that are judged by the external environment characteristic, consisting of the market size, market growth and the level of competition.

**Table 3: Product development process performance- and team composition measures**

Name	Description	Data type
PDP <sub>1</sub>	The number of days between the PD0 (project start) and PD3 (ramp-up start) milestones	Metric, discrete
PDP <sub>2</sub>	The time between the start of the supplier mass production simulation and PD3 (ramp-up start)	Metric, discrete
PDP <sub>3.1</sub> PDP <sub>3.2</sub>	The experience level of the project management team expressed as the average number of finalized projects per team and the range between the least and most experienced team member	Metric, discrete
PDP <sub>4</sub>	The workload of the project management team expressed as the average number of projects in which the team is involved simultaneously	Metric, discrete

Based on the mentioned factors we expect the following:

*Proposition 4: Higher levels of product development process performance are associated with higher ramp-up performance.*

### **3.4 The logistics system**

Logistics is concerned with planning and controlling material flows and related information in organizations. Simply speaking, the mission of logistics is to get the right materials to the right place at the right time, while optimizing a given performance measure and satisfying a given set of constraints. Ghiani *et al.* (2004) formalize such systems into a set of *facilities* linked by *transportation services*. Facilities are sites where materials are processed. They include manufacturing and assembly facilities, warehouses; distribution centers (DCs) and more. Transportation services move materials between facilities using vehicles and equipment such as trucks, planes, trains etc.. The influence of these elements on effective new product development and launch is widely recognized. Problems during the early phase of any ramp-up are often caused by unavailability or insufficient quality of parts, and the fact that the processes during ramp-up deviate from the processes at volume production (Pfohl and Gareis, 2000; Baumgarten and Risse, 2001). One of the key differences during Nokia ramp-ups compared to volume production is the way how material supply and manufacturing operations are managed. They are fully push driven, based on the materials and



manufacturing capability estimations of the product development team. Therefore, inventory buffer and sales commitments are largely under the control of this team. This is in contrast with volume production where all demand management, scheduling and forecasting activities are handled via MRP systems. For the further structuring of the relevant characteristics of a logistics system we use the terms *facilities* and *design for logistics*. Transportation services do not play an important role in our model. The type of transportation is standardized to truck for domestic and air freight for international transportation for all projects except some ultra low cost or premium products which are not part of this study.

This first measure refers to facilities as it reflects the composition of the global logistics network. If more factories are needed, the supply network and the ramp-up management tend to be more difficult and more sophisticated. The number of supply networks is closely linked to the number of factories but due to the dependency on the global supply strategy, separate measures are needed. This highlights the fact that a major part of the value chain is not vertically integrated, extending the ramp-up to the supplier network.

Products seem to have a better ramp-up performance if they are logistical-friendly (Baumgarten and Risse, 2001). Of particular importance during changing market conditions (e.g. during ramp-ups) is the concept of agility (Lee, 2004). Agility is defined as the quick response to short-term changes in demand or supply and decisively influenced by form postponement. Form postponement reduces the risk to manufacture an incorrect product mix as the customization is delayed until specific customer orders are received. It reduces the need to stock inventory of component-, module- or basic transceiver variants and therefore lowers the risk of stock-outs. However, a second important parameter for form postponement that needs to be considered is the value and number of variable parts. As an example, a large number of color variants of the plastic covers or keypads leads to higher demand fluctuations because the individual demands tend to be more diverse than aggregate ones. Therefore, short replenishment cycles are needed to enable quick responses on customer preferences which are particularly difficult to predict in the early ramp-up phase. Additionally, costly variable parts are often the result of higher complexity due to required design elements. This does not only affect the product complexity as discussed in one of the previous chapters but also the behavior of the supply chain in general. More costly parts tend to create more problems in the outgoing inspection area of the suppliers and the incoming inspection area of the manufacturing facilities. This results in lower yields at supplier factories, leading to missing parts at the manufacturing line or higher scrap rates due to non-conforming parts.

**Table 4: Logistic facility- and design for logistics measures**

Name	Description	Data type
<i>Facilities</i>		
LS <sub>1.1</sub> LS <sub>1.2</sub>	The number of basic transceiver and sales package factories	Metric, discrete
LS <sub>2.1</sub> LS <sub>2.2</sub>	The number of supply networks for basic transceiver and sales package parts	Metric, discrete
<i>Design for logistics</i>		
LS <sub>4</sub>	The number of BTR variants	Metric, discrete
LS <sub>5</sub>	The cost of variable parts that are needed at sales package level [EUR]	Metric, discrete

*Proposition 5a: Lower numbers of logistic facilities are associated with higher ramp-up performance.*

*Proposition 5b: Logistic-friendly products are associated with higher ramp-up performance.*

### **3.5 The external environment**

Certain factors can not be grouped under the other characteristics as they do not succumb to Nokia's control. These factors relate to the target markets of the products and refer to the forecast pattern per region as an influential factor. Nokia divides the world into six regions for which separate forecasts are made. The regions are North America, Latin America, Europe, Middle East and Africa, Asia Pacific and China. Forecast changes are critically influential characteristics as the reaction time to these changes is lengthy. Some components like displays have lead-times of more than 10 weeks which makes quick supply adaptations difficult. The additional factor of the total volume plan per region is a characteristic that might be needed for the ratio building with other measures.

**Table 5: Forecast accuracy measures**

Name	Description	Data type
EE <sub>1</sub>	The total volume plan per region	Metric, discrete

EE <sub>2</sub>	<p>The forecast change during the development phase from PD0 to PD3 (for the period of six months after PD3):</p> $\text{forecastchange} = \frac{\text{volume forecast at PD3}}{\text{volume forecast at PD0}} - 1$	Metric, continuous
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*Proposition 6: Lower forecast variance over the product development cycle is associated with higher ramp-up performance.*

**3.6 Ramp-up performance**

An assessment of ramp-up performance can only be carried out if it is based on an appropriate measurement system. According to Beamon (1999), a performance measure or a set of performance measures is used to determine the efficiency and/or effectiveness of an existing system and to compare competing alternative systems. The inclusion of four characteristics is imperative for the creation of such a system (Beamon, 1999):

- inclusiveness (measurement of all pertinent aspects)
- universality (allows comparison under various operating conditions)
- measurability (the required data is measurable)
- consistency (the measures are consistent with the organizational goals)

To achieve these goals, most of the established performance measurement systems consist of a set of performance measures and indicators. Following the simple definition of Browne *et al.* (1997) we define a *performance measure* as a description of something that can be directly measured. A *performance indicator* is defined as a description of something that is calculated from performance measures. A *performance measurement system* is a complete set of performance measures and indicators preventing the problem of inclusiveness. Several authors have proposed different measurement frameworks that are supposed to approach the problem from a company’s strategic point of view.

The classic approach to performance measurement can be described best by the Sink and Tuttle model (Sink and Tuttle, 1989). The model claims that the performance of an organizational system is a complex interrelationship between seven performance criteria: effectiveness, efficiency, quality, productivity, quality of work life, innovation and profitability. However, the most popular model has been the "Balanced Scorecard" proposed by Kaplan and Norton (1996). This concept identifies and integrates four different categories of performance (financial, customer, internal business and innovation and learning perspectives). Another measurement framework has been developed by Kennerly and Neely

(2000) as a result of several identified shortcomings of the Balanced Scorecard. One weakness is that the concept does not include a competitive dimension and a human resource perspective. Kennerly and Neely (2000) developed a framework stating that the results of an organization (measured as stakeholder satisfaction) are a function of four determinants: strategy, processes, capabilities, stakeholder contribution. De Toni and Tonchia (2001) enhance this list by two additional models that are found frequently in the literature. The "frustrum" model, that separates traditional cost performance measures (production cost, productivity) from the non-cost measures (quality, time, flexibility) and the models that distinguish between internal (cost and non-cost) and external performance (perceived by the customer). Although this short overview provides a useful classification of the most common measures on a strategic level we need to narrow them down in order to explore ramp-up performance on a more operational level. The difficulty is to create a ramp-up performance measurement system that is consistent with the overall business goals and does not lead to conflicts between the different functions (as reported e.g. by Shapiro (1997)). In addition, a major problem of the existing literature on performance measurement is the fact that it is so diverse. Individual authors had the tendency to focus on different aspects of performance measurement system design (Neely *et al.*, 1995). As a result, we are building our measurement system on the work of Slack *et al.*, (2001), De Toni and Tonchia (2001) and Neely *et al.* (1995). It will be amended by the work of Brown and Eisenhardt (1995), Mallick and Schroeder (2005), Terwiesch *et al.* (1999) and Almgren (2000) to narrow it down on the specific area of ramp-ups. Additionally, several interviews with managers within the Mobile Phones business unit were executed to condense the proposed concepts and to adapt them to the company specific needs. As already mentioned in the beginning of this chapter ramp-up performance can be determined in terms of effectiveness and efficiency.

Efficient ramp-ups are characterized by a superior operational performance. In our case, efficiency is a measure of how economically the firm's resources are utilized (Slack *et al.* (2001). Operational performance is characterized by a high percentage of sold products under the assumption of a highly effective capacity utilization rate of the manufacturing system. Both measures are detailed in Table 6 and based on the final verification efficiency measure proposed by Almgren (2000) and the effective capacity utilization measure proposed by Terwiesch *et al.* (1999). The period of time shortly after the ramp-up start is extremely critical because the sales and promotion activities are already started while many improvement and configuration activities are still in progress. Especially in projects with a strong focus on time to market, project teams are striving for accelerated product

development, often negating the time gained in earlier stages of the development cycle during an inefficient ramp-up caused by heavy ramp-up problems. Voigt and Thiell (2005) support this view. They argue that the focus on pure ramp-up speed is economically not wise because quality and other cost drivers can accumulate to a level that can sustainably affect the overall company competitiveness. To quantify the operational performance during this phase we measure the actual invoiced quantity over 12 weeks and calculate a ratio with the confirmed quantity for this period. This provides a closer link to profitability than measures that are purely based on manufacturing output. For example, any manufacturing output that is according to plan but build to stock or without settled account would reveal a strong manufacturing performance but does not at all contribute to profitability. In addition, manufacturing output that is contributing to profitability has to be achieved under a high capacity utilization rate. We use the concept of effective capacity utilization by Terwiesch *et al.* (1999) to quantify the share of the manufacturing system to the operational performance. The measure is calculated as the ratio between the actual production output and the reserved capacity. Using this ratio, we can incorporate all the losses which lower the capacity utilization like break-downs, yield losses, downtimes and controlled engineering trials. Additionally, we measure the capacity utilization at three different stages in order to gain a more thorough understanding of the critical areas in Nokia's multi-stage manufacturing process. These sub-measures are not explicitly added to the performance measurement system but they will later be used for the interpretation of the overall capacity utilization measure.

Effectiveness compared to efficiency refers to which extent customer requirements are met (Slack *et al.*, 2001). A large amount of Nokia's business consists of business to business transactions in which customer requirements play a key role. Under these conditions the violation of agreed delivery dates can result in penalty clauses or lost sales with a negative effect on the product business in general. Other examples that refer to effectiveness are cases in which seasonal peaks have to be satisfied. Opportunities like Christmas or the Chinese New Year celebration can only be taken if planned volumes can be delivered according to agreed customer schedules. It requires excellence in dependability and flexibility to meet customer requirements like these. We measure these dimensions as the ratio between the actual production outcome over a period of 12 weeks and the confirmed sales quantities that have been agreed upon 12 weeks before the start of ramp-up. This ratio provides insights into the overall planning accuracy of new products which is also reflected in the financial reporting of the company. A timeframe of 12 weeks has been chosen due to the standard launch procedure and the ordering of long lead time components

that has to be initiated three months before the ramp-up at the latest. In an environment that is characterized by stable volume forecasts this would be sufficient. However, due to environmental effects triggered by competitor activities, portfolio changes, new technology introductions and ramp-down decisions for other projects, the volume forecast is highly unstable. To include this factor in our calculation, the dependability ratio is adjusted by the change in market demand. For example, a product ramp-up might perform extremely well if it is measured, based on the previously agreed numbers (e.g. 12 weeks before the ramp-up) but it might lose a major opportunity if the market demand would double in the meantime. A potential weakness of this measuring method is the fact that it assumes the ramp-up speed to be adjusted for maximum profitability. This is practically guaranteed by regular reviews of the product business case by the Product Program Manager as ramp-ups in fast clockspeed industries with short lifecycles will always face the dilemma that they have to balance the rate of asset investments, material risk orders and the available ramp-up speed. Higher investments in tools, resources and manufacturing equipment or early risk orders for potential immature material would allow for steeper ramp-ups, but only at the expense of cost and risk. Although such a strategy could pay off in the beginning and claim premium prices, there is the drawback of potential obsolete materials or under utilized assets later on.

The last performance measure deals with customer perceived quality and is hence related to effectiveness and efficiency. Traditionally, quality has been defined in terms of conformance to specification. Hence, quality-based measures of performance have focused on issues such as the cost of quality (Neely *et al.*, 1995). With the advent of total quality management the emphasis has shifted away from "conformance to specification" towards customer satisfaction or customer perceived quality. This is still seen as one of the most important performance indicators in the high-technology industry as it refers to the concept of lost sales and customer retention. However, it is one of the most difficult to measure. There are many factors that have an impact on customer perceived quality, for example device reliability, functionality, design, price and service. However, within this study we focus on the firm's overall manufacturing and delivery performance. We rather focus on the problems that can result in providing a perfect order to the customer than on the perception of the customer towards the new product and service. The dimensions that are related to a perfect order are multifaceted and include issues like non-damaged shipments, availability of all items, functionality of all items, correctly picked orders etc. (Bowersox *et al.*, 1999). To quantify these dimensions over the ramp-up period we use the return rate of the first delivery batches as a percentage of the total deliveries.

There are two measures that are frequently proposed in the literature but however are not taken into account: pure cost measures and time to market. Although pure cost measures and time to market are important performance measures there are downfalls in relying on these measures during new product ramp-ups. In the short term, the impact of cost on the overall profitability is minor although this clearly changes in the mid- and long term. Any lost sales and hence lost profits in a fast clockspeed industry will outweigh all the other possible inefficiencies in the value chain by far. Second, cost data is often only available too late or based on the wrong activity levels (Möller, 2005) and consequently not relevant for the decision making or performance evaluation during ramp-up. Finally, each of our selected performance measures has several internal effects, but all of them are affecting cost. Concerning time to market there are authors like Clark and Fujimoto (1991) that consider this as a critical dimension of product development performance. However, we will not include time to market in our model because of two reasons. First, time to market is often measured as the time between concept generation and sales start. As such it is more a measure of product development performance than of ramp-up performance. Second, we follow Mallick and Schroeder (2005) who argue that time can rather be viewed as a resource. Thus, we include time to market as a critical variable of the new product development process and as a depended factor within the product development area (factor PDP<sub>1</sub>) into our conceptual model. There is empirical evidence that increased pressure on time to market during new product development projects may lower development time but at the expense of other performance measures like effort, quality or ramp-up quantity.

Overall, the selected performance measures are summarized in Table 6 and well in line with the results of an earlier survey within Nokia that an important characteristic of good performance measurement systems is simplicity (Joas, 2003).

**Table 6: The ramp-up performance measurement framework**

Name	Description	Data type
RUP <sub>1</sub>	Operational performance, measured as: $\text{operational performance} = \frac{\text{actuals invoiced over a period of 12 weeks}}{\text{CSVP}_{\text{at the start of ramp-up}}}$ <p>Actuals invoiced over a period of 12 weeks = sold quantity over a period of 12 weeks</p> <p>CSVP<sub>at the start of ramp-up</sub> = (confirmed sales volume plan) output quantity confirmed to sales for a period of 12 weeks at the start</p>	Metric, continuous

	of ramp-up	
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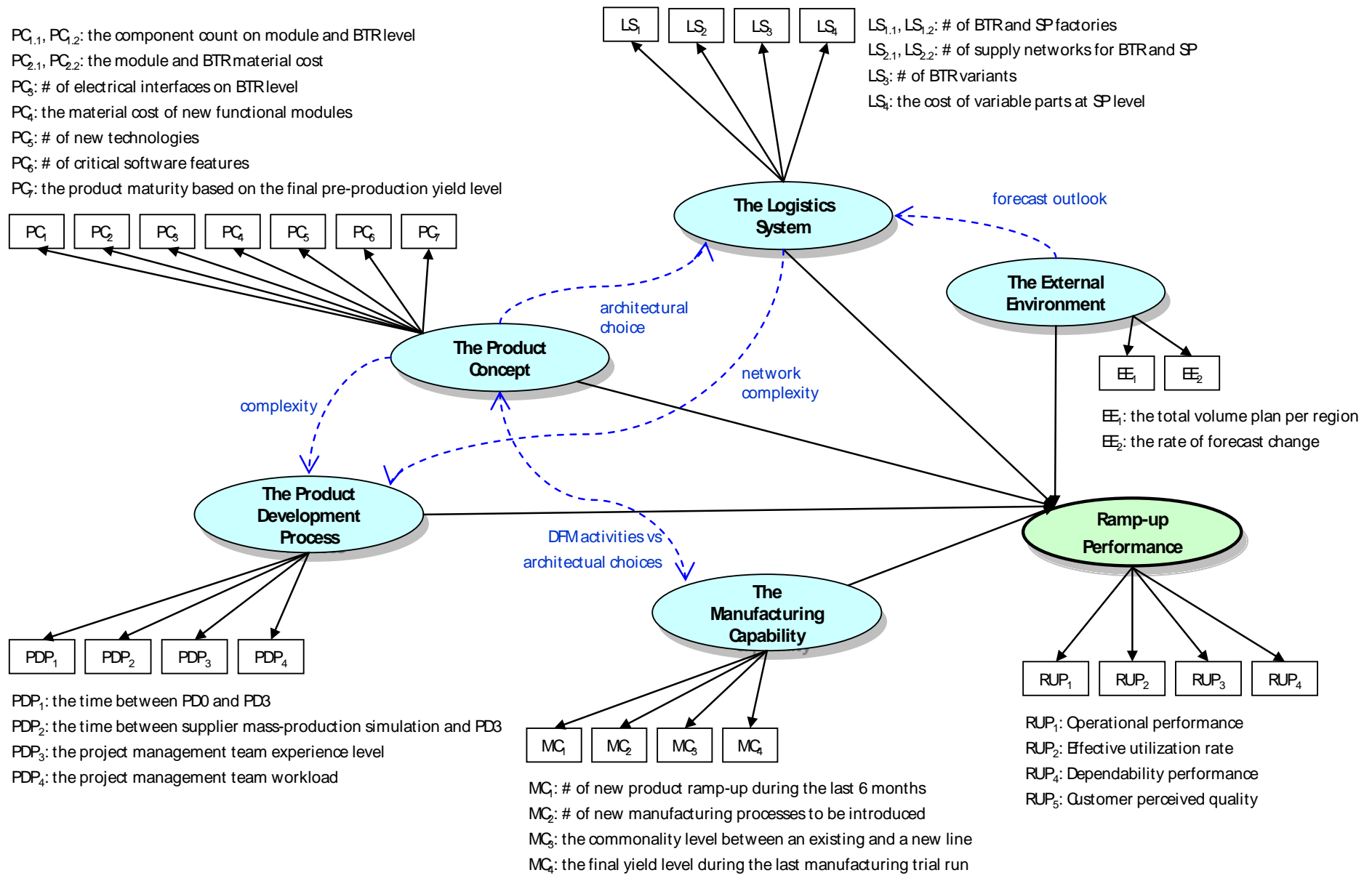
RUP <sub>2</sub>	<p>Effective utilization rate, measured as:</p> $\text{effective utilization rate} = \frac{\text{actuals produced over a period of 12 weeks}}{\text{MMC}_{\text{at the start of ramp-up}}}$ <p>Actuals produced over a period of 12 weeks = production quantity over a period of 12 weeks after ramp-up start</p> <p>MMC<sub>at the start of ramp</sub> = (manufacturing and materials capability) reserved and available materials and manufacturing capacity over a period of 12 weeks at the start of ramp-up</p>	Metric, continuous
RUP <sub>3</sub>	<p>Dependability performance, measured as:</p> $\text{dependability performance} = \frac{\frac{\text{actuals invoiced over a period of 12 weeks}}{\text{USVP}_{\text{at the start of ramp-up}}}}{\frac{\text{CSVP}_{12 \text{ weeks before the estimated ramp-up start}}}{\text{USVP}_{12 \text{ weeks before the estimated ramp-up start}}}}$ <p>Actuals invoiced over a period of 12 weeks = sold quantity over a period of 12 weeks</p> <p>CSVP<sub>12 weeks before the estimated ramp-up start</sub> = (confirmed sales volume plan) output quantity confirmed to sales for a period of 12 weeks, agreed 12 weeks before the estimated ramp-up start</p> <p>USVP<sub>at the start of ramp-up</sub> = (unconstrained sales volume plan) sales forecast at the start of ramp-up</p> <p>USVP<sub>12 weeks before the estimated ramp-up start</sub> = (unconstrained sales volume plan) sales forecast, 12 weeks before the estimated ramp-up start</p>	Metric, continuous
RUP <sub>4</sub>	<p>Customer perceived quality, measured as the average batch failure rate during the first 12 weeks. This represents the percentage of returned devices as a result of quality issues.</p> $\text{early batch failure rate} = \frac{\text{returned devices over a period of 12 weeks}}{\text{actuals invoiced over a period of 12 weeks}}$	Metric, continuous

### 3.7 Model overview

Figure 5 shows a summary of the elaborated factors and measures that have been identified and selected in the previous sections. The main elements are the colored ellipses,



representing the top level factors that affect ramp-up performance. The dependencies between these factors and the dependent elements of ramp-up performance are indicated by solid lines. We assume a direct dependency between these five factors and ramp-up performance because ramp-up performance as such does not reveal any short term respectiveness in this context. There are certainly mid-term dependencies in the opposite direction as a reaction to the actual ramp-up performance but the analysis of these dependencies is out of the scope of this work. Next and connected with every main factor are the variables or measures that define and quantify every factor. The boxes represent the earlier defined measures and indicate the names of the variables. Furthermore, there are some dotted lines that connect the top level factors. These lines are crucial for the statistical data analysis as they present the dependencies between the factors that might at worst indicate multicollinearity. As an example, there is a strong bidirectional dependency between the product architecture and the manufacturing capability. A strong design for manufacturing culture can affect the product architecture if manufacturing requirements are taken into account within the product design. On the other hand, the major driving force behind the manufacturing configuration is the product architecture. Although the manufacturing lines are standardized to a high degree the product architecture defines the level of product specific production equipment and the needed manufacturing processes. A similar but only unidirectional dependency exists between the logistic system and the product development process. A multiple supply base including several manufacturing plants requires the project to schedule more trial runs, more mass production simulations and adds more effort to the team compared with a simpler logistic network. There is also a dependency between the logistic system and the product architecture. A logistic friendly product architecture requires a less sophisticated logistic system with lower lead-times and fewer risks. This is the result of architectural details that enable late- and easy variation, simple customization and short supply networks. Finally, the overall setup of the logistic network is to a major degree the result of the global volume forecast. Empirical evidence shows that high volume products, sold in all regions of the world, require multiple supply chains and multiple manufacturing locations. There are several driving forces behind these decisions but most of them are either depending on the expected sales volumes, import taxes, customs duties and transportation costs, or depending on the needed customer service levels. In general, these interactions and dependencies have to be considered during the analysis in order to achieve a high internal validity of the model.



**Figure 5: An overview of the conceptual model**

## 4 Methodology

The overall design of this study is based on a case study methodology (Yin, 2003) with a combination of quantitative and qualitative data collection methods. This is based on the research need to gain a detailed understanding of the factors that affect the ramp-up performance at Nokia. The basic observable entity that is analyzed in this study or the unit of analysis for which data is collected are Nokia mobile device sales packages. Our expected sample size is planned to consist of around 60 mainstream products developed and manufactured between 2003 and 2009 (this represents probably 20% of the population in this timeframe). We are going to randomly collect products from different price categories to cover most of the facets of Nokia's overall mobile device population. For every product, data sets are collected that are taken from several highly reliable sources, namely:

- Product data management systems that provide information about the type and number of components used in a product.
- Production data reporting systems that provide real-time access to manufacturing data like yield and output.
- Project management reporting databases that provide information about project milestone dates and milestone slippages.
- Document management systems are used to gather further information about technology, software features and implemented manufacturing processes to complete the other data.
- Interviews (divided into a structured- and an open ended part) are used to gather non-documented data like the project management team experience, the team work-level or general information about the product development phase. Project managers from different projects and different functions are being interviewed to enhance the already existing datasets and to collect qualitative data that supplements the existing framework.

To enrich the data sets, we finally pursue a longitudinal study in two mobile device projects in which the researcher is involved as a project manager. This process of data collection will lead to a data base with around 6000 data entries. In order to reduce the complexity of the data analysis we will initially split the data sets into two groups that are analyzed independently. First, we analyze the interaction between the product architecture and the product development process on ramp-up performance. Second, we analyze the impact of the logistics system, the manufacturing capability and the external environment on ramp-up performance. Finally, all pre-results are consolidated, analyzed and discussed on a holistic level. This partition enables us to gain an in-depth understanding of single factors before

analyzing combined and interrelated effects on the level of the general model. As we hypothesize that our model factors are relevant predictors of ramp-up performance, we use multiple regression analysis as the dominant statistical method (under the assumption that the relationship is linear or can be linearized). This method will be supported by other descriptive techniques like data plots, cross classification tables and factor analysis.

## 5 Conclusion

This paper is the first step in exploring the essential characteristics that affect the product ramp-up performance in Nokia's mobile phones business group. It draws upon the existing literature and the experience within Nokia to develop a conceptual model that describes the relevant factors in a detailed and measurable way. As such it provides the foundation for the next steps as we believe that research in this area has to be based on a well defined construct to "secure" the further research that is mainly based on data collection and statistical analysis. However, the final goal of this study is to find a predictive model that will not only allow assessing past performance but also stimulate future action.

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