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**Coordination and Cooperation during Production Ramp-up: An Empirical Study of the  
European Manufacturing Industry**

Uwe Gross

Technology and Innovation Management Research Group, RWTH Aachen University,

Kackertstrasse 15-17, 52072 Aachen, Germany

phone +49 241 809 9175

fax +49 241 809 2367

email [gross@tim.rwth-aachen.de](mailto:gross@tim.rwth-aachen.de)

Tim Renner

Chair of Business Theory, RWTH Aachen University

Templergraben 64, 52056 Aachen, Germany

phone +49 241 809 6178

fax +49 241 809 2179

email [renner@lut.rwth-aachen.de](mailto:renner@lut.rwth-aachen.de)

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## ***Abstract***

Production ramp-up appears to be the main challenge during the late phases of innovation processes: new product specifications have to walk along with new production processes and even new production facilities. Bringing new products to market at a required level of quality while meeting targeted time and cost, is the main goal of production ramp-up management. Literature stresses the importance of coordination and cooperation mechanisms during production ramp-up. Unfortunately up to date no empirical study has been conducted to confirm this issue. Our paper aims to fill this gap based on a survey among 71 manufactures in Germany and other European countries. We analyze a multitude of possible impact factors on production ramp-up success and show that coordination and cooperation have a significant influence. Surprisingly this influence does not turn out as expected.

*Keywords: production ramp-up, management, coordination, cooperation*

## **1. Introduction**

Previous publications on production ramp-up motivated their research by the necessity of managing production ramp-up due to a reduction of product life cycles, an abbreviation of new product development times respectively time-to-market and an increasing amount of product variants respectively variant diversity (Carrillo, Franza 2006; Quick, Brunner, Schuh 2009; Terwiesch, Bohn 2001; Winkler, Slamanig 2008). We take this as given and ask, how a successful production ramp-up project would look like and how such a project has to be managed. Although the importance of production ramp-up management for new product success is acknowledged more and more in many companies throughout many industries, the general level of managerial experience is quite low. When asking for the success of new product projects literature focuses on organization, success and influencing factors of the whole innovation process or new product development process (for an overview see (Ernst 2002)). Production ramp-up itself is rarely analyzed at least in scientific literature. The few existing studies concentrate on ramp-up strategy formulation (Schneider 2006), human resources management for production ramp-up processes (Gerpott 1991), process modeling for production ramp-up (Stirzel 2008) and coordination and cooperation with suppliers within production ramp-up networks (Denzler 2007; Fitzek 2006).

In contrast practitioners of the automotive industry are relatively experienced in managing the production ramp-up as case studies show (Schuh, Stölzle, Straube 2008a; Wangenheim 1998; Wildemann 2006). Best practices have to be found here, especially when taking the ultimate objective into account not only to focus on these practices within firms throughout the automobile industry but also to adopt them in other industries with other products and different processes. To identify best practices the first problem that needs to be solved, is the

determination under which conditions a production ramp-up can be called successful. This is not as easy as it may seem, since many measures of success cannot be applied during production ramp-up and an evaluation can only be accomplished ex post. In addition these measures hold the flaw of having many influencing factors besides production ramp-up, which would make it hard to differentiate. Furthermore the scope of action during production ramp-up is quite narrow since many decisions e.g. concerning the product, machinery and technologies have already been made. As a result the environment of the project production ramp-up is highly predetermined and it can be hypothesized that most decisions which may affect the success of production ramp-up are management related.

As managing the production ramp-up means to plan, organize and control the process as well as information flow, our paper aims to analyze the importance of these activities for production ramp-up success and give implications for practitioners and further research. Therefore the paper is divided into six sections: First we review the relevant literature in section 2, focusing on success of production ramp-up and the mechanisms leading to it. Here we propose that success of production ramp-up should be reinterpreted in favor of a concept closer to performance. Furthermore we concentrate on management issues that may be connected to success. In section 3 we describe the data set and the methodological approach of our structure equation modeling, followed by the presentation of our results in section 4. In section 5 we discuss our findings and expatiate on the managerial implications. Finally we summarize the contributions of our work, disclose the respective limitations and give an outlook on possible future research.

## **2. Review of Relevant Literature and Propositions**

While first established and analyzed in the automobile industry, the significance of ramp-up management in other branches becomes more and more apparent as companies are struggling to

meet the rising requirements caused by the diminishing ratio of lifecycle and development time as well as increasing complexity in product architecture and production processes. Unfortunately effectively managing the production ramp-up process is not discussed in empirical literature at all. So far, only conceptualizations exist (Ender 2009; Feigl, Oeten, Schmitt 2007; Harjes, Bade, Harzer 2004; Kuhn, Bandow 2008; Nässer, Müller 2007; Scholz-Reiter, Krohne 2006; Schuh, Desoi, Tücks 2004). The following literature overview shall provide an introduction to the concept of production ramp-up and its definition. Moreover existing literature on success in production ramp-up shall be discussed as well as possible impact factors.

## **2.1. Production Ramp-up**

In general the term *production ramp-up* is used when integrating new or substantially modified products or technologies into an industrial production system. Accordingly Gustmann and Rettschlag define production ramp-up as the integration of innovation and industrial production (Gustmann, Rettschlag, Wolff 1989) while Langowitz speaks of the initial commercial manufacture of a product (Langowitz 1988). A more specific definition of production ramp-up is given by Terwiesch and Bohn, describing production ramp-up as the period following the product development phase during which a manufacturing process makes its transition from zero to full-scale production at targeted levels of cost and quality (Terwiesch, Bohn 2001). In automotive industry production ramp-up usually summarizes all activities of developing a production system and improving its performance after major product modifications or product developments (Gentner 1994; Kuba 1987; Risse 2003; Wangenheim 1998). According to Romberg and Haas in contrast to a rather short ramp-up phase ramp-up management starts much earlier, in the best case at the same time product development begins, since planning needs to

take place before the actual event (Romberg, Haas 2005). According to Schuh et al. we define production ramp-up as follows (Schuh, Stölzle, Straube 2008b):

*Production ramp-up is the time span during product creation of a firm, beginning after product development with a first production run during which the respective product is manufactured on close-to-series machinery and ending when full scale production has been reached.*

Hence, on one hand the production ramp-up is defined as part of the new product development process and on the other hand it constitutes the linkage between product development and production.

Furthermore the management of production ramp-up can be interpreted as project management. This statement can be supported by common definitions of project characteristics. According to Schmidt (Schmidt 2000) a project is always unique, has high relevance for the company, involves several functions and has a certain beginning and ending, while the total duration is irrelevant. Moreover formal project organization needs to be installed: responsibilities need to be assigned, a certain budget has to be approved and milestones need to be defined. The only characteristic that may be doubtful is the uniqueness, since most companies strive to apply standardized processes. However, important attributes of production ramp-up are high complexity, time pressure and dynamic, which constitute most problems arising during this time period and can be seen as indicators of uniqueness. Thus, it is not only possible to handle production ramp-up as a project but it actually fits the definition most accurately.

Sticking to this classification of production ramp-up as part of the innovation process and as a project, we have to review literature on production ramp-up as well as literature on innovation and especially innovation projects.

## **2.2. Success in Production Ramp-up**

Studies on new product development use the opinion of interviewed managers to differentiate between success and failure. In most cases the respondent is provided with a definition of success based on commercial indicators (Balbontin, Yazdani 1999; Balbontin *et al.* 2000; Calantone, Di Benedetto 1988; Cooper 1979a; Cooper 1979b; Cooper 1982; Dwyer, Mellor 1991; Mishra, Kim, Dae Hoon 1996; Parry, Song 1994). Cooper developed several systems of success measures and success dimensions for example integrating measures concerning commercial success, market shares and opportunity window (Cooper 1984a; Cooper 1984b; Cooper 1985; Cooper, Kleinschmidt 1987b; Cooper, Kleinschmidt 1987c).

The definitions based on the opinion of respondents are not that useful since they are not objective. This problem could be mitigated by integrating the possibility to evaluate the success of a project on a more elaborate scale. A further problem that applies to almost every solution is the integration of indicators that can only be assessed after market launch.

Griffin uses a system of success measures that is based on measures concerning financials and market but also relative measures concerning the extent to which the programs objectives are met (Griffin 1997). Baccarini focuses more on a stakeholder view (Baccarini 1999). Cohen broaches about the trade-off between different dimensions of success (Cohen, Eliashberg, Ho 1996). All three approaches accentuate meeting time, cost and quality objectives, which is quite common in project literature (Babu, Suresh 1996; Griffith 2006; Pollack-Johnson, Liberatore 2006; San Cristóbal 2009; Shenhar *et al.* 2001).

On search for the meaning of success in production ramp-up, there are not many sources to cite. This fact is not surprising since most measures of success, such as sales, turnover, earnings or even costs, can only be applied if the respective product is actually being sold. In principle, it is

possible that first sales are accomplished during production ramp-up. But this can only happen if the channels of distribution can be filled before full scale production is reached, which cannot be assumed for every production ramp-up. Some authors mention success in connection with performance. Ginn and Rubenstein use a construct consisting of organizational, technical and commercial success (Ginn, Rubenstein 1986). Langowitz states that a production ramp-up is successful, if the technical and organizational capabilities are adapted to the product's specifications or vice versa (Langowitz 1988). Terwiesch measures yield, rework, testing hours, process induced failures, tact time and downtime (Terwiesch, Bohn, Chea 2001). Acknowledging the fact that all of these articles are based on case studies and their respective measures of success are not the same, success shall be operationalized as a construct of objectives and the related achievement. In the following we give an overview of these objectives beginning with objectives for the whole new product development and subsequently focusing on production ramp-up.

### **2.3. Production Ramp-up Objectives**

As indicated in the previous section a broad spectrum of literature relates to the combination of objectives related to the dimensions quality, time and cost. In the 21<sup>st</sup> century especially low cost products with high quality are demanded by customers, responsive to their changing needs (Gunasekaran 1999). For product development Clark and Fujimoto suggest speed-to-market, product performance and development cost as key objectives (Clark, Fujimoto 1991). Since these objectives are conflicting many authors propose a trade-off (Bayus 1997; Cohen, Eliashberg, Ho 2000; Driva, Pawar, Menon 2000). The combination of these targets during production ramp-up is quite dominant in literature with regard to ramp-up objectives (Herrmann, Wenda, Bruns 2009; Romberg, Haas 2005; Scholz-Reiter, Baumbach, Krohne 2008; Scholz-Reiter *et al.*

2007; Urban, Seiter 2004; Winkler, Heins, Nyhuis 2007). For example Peters and Hofstetter formulate the underlying objectives during production ramp-up would be to minimize functional defects, to improve production quality, and to reduce both time and cost needed for production (Peters, Hofstetter 2008). Unsurprisingly these objectives are just as conflicting during production ramp-up as during product development. On basis of the combination of the three objectives quality, time and cost, some authors propose more sophisticated systems of objectives, while others accentuate single objectives.

Kuhn et al. developed a model, in which secondary objectives are added to the three basic objectives mentioned above. These secondary objectives are: flexibility of the systems, efficiency of the facilities, compliance with required quantities, availability of prefabricated parts, and a comprehensive documentation of production ramp-up. Though these secondary objectives are more specific, they are still hard to trade-off: Failing to produce the required quantity could result in increasing both time and costs (Kuhn *et al.* 2002).

Risse sub-classifies production ramp-up objectives into four categories: employee, process, object and result. The first category focuses on the grade of qualification of employees and their motivation. The second category deals with process capabilities and capacities. The third category object is divided into two subcategories: product concept and materials/parts. While the first subcategory discusses the factors cost, time and service level, the second subcategory contains topics of due-schedule supply and availability of component parts. At last, the result category deals with economical elements like total costs and marginal returns, though non-economical objectives as customer satisfaction are also considered (Risse 2003).

Bayus suggests two options when developing new products: fast development of low-performance products or development of first-to-market products with high performance level

(Bayus 1997). Both scenarios tend to make timing the most important factor for new product development success. Literature shows similar tendencies: Many scientist and practitioners agree on timing being the most important objective during product development (Gaynor 1993; Patterson 1992; Rosenau 1990; Rosenthal 1992; Smith, Reinertsen 1997). Several authors advise to avoid product introduction delays (Cooper, Kleinschmidt 1994; Hendricks, Singhal 1997; Hendricks, Singhal 2008) and to decrease time-to-market (Brooks, Schofield 1995; Carrillo, Franza 2006; Cohen, Eliashberg, Ho 1996; Pawar, Menon, Riedel 1994) since early launch and presence of a new product would boost market penetration, increase market share and eliminate competitors (Clark, Fujimoto 1989; Pawar, Menon, Riedel 1994; Terwiesch, Bohn 2001; Terwiesch, Bohn, Chea 1999; Terwiesch, Bohn, Chea 2001). On the other hand decreasing time-to-market may cause increasing development costs (Mansfield 1971; Smith, Reinertsen 1991). Making speed-to-market the main objective might result in imprudent management decisions and low performing products (Utterback *et al.* 1992).

Due to unique product features, it is often possible to charge premium prices, which would grant above average improvements in profits (Pawar, Menon, Riedel 1994; Rüstig 2007). Historic examples yet show what damage on image, sales and income early product introduction of underperforming products may cause (Bayus 1997).

If suggesting product quality as the main objective as some authors do, certain quality criteria have to be achieved by the time of market entry, even if this means increasing cost or a delayed product launch (Cooper, Kleinschmidt 1987a; Führer 2008). Therefore quality capabilities of production processes are of major importance to avoid interferences during production ramp-up and ensure product quality.

Others stress the importance of cost and due date (Berger 2003; Leenders, Henderson 1980) and recommend to include flexibility and cost objectives while controlling the high rate of change during the ramp-up phases (Hinrichs, Rittscher, Hellingrath 2004). Additionally there are authors suggesting to minimize modification efforts (Kirsch, Buchholz 2008) and to emphasize the flexibility and stability of designed production systems in order to deal with changes (Reinfelder, Wuttke, Blumenau 2004).

Obviously a trade-off between time, quality and cost has to be made on a case-by-case decision depending on several product factors, company situation, and industry environment. In a general perspective it is widely agreed that an effectively and efficiently executed ramp-up phase would greatly increase the success of a product due to the possibility of an earlier market entry, higher quality in products as well as in processes, fewer production problems and lower costs (Chiu *et al.* 2005; Hultink *et al.* 1997; Scholz-Reiter *et al.* 2007). On the other hand the selection of objectives that should be pursued during the production ramp-up, and in particular their weighting, can diverge significantly among specialists. Nevertheless, the common appearance of objectives connected to the three dimensions quality, time and cost is striking.

So far success was defined as multi-item variable including all dimensions: budget, quality and time. Urban and Seiter suggest to distinguish between success measurement of ramp-up and production initialization projects but fail to give an operative recommendation (Urban, Seiter 2004). Winkler differentiates between the objective quality which is contingent upon time (effectivity) and the objective to meet the planned budget (efficiency) (Winkler 2007). As we presume cost objectives to be adjustable easier and being less predictable during production ramp-up than timing and quality objectives, we favor Winkler's approach. Accordingly we choose two separate success variables: *ramp-up success* and *ramp-up cost achievement* are self

reporting measures of achieving targets in time and quality respectively budget. Therefore we define ramp-up success as the achievement of quality and time objectives while keeping budget adjustable to the required amount.

#### **2.4. Impact of Coordination and Cooperation**

Identifying success factors for companies in general has been a major concern in literature just as well as research on factors that influence success of new product development. In consequence there are many different studies on this topic and just as many influencing and success factors. “The structure of an organization can be defined simply as the sum total of the ways in which it divides its labor into distinct tasks and then achieves coordination among them.” (Mintzberg 1979) Hence, the division of labor is precondition for the necessity of coordination and furthermore coordination needs to be achieved and does not come by its own. Coordination denotes the orchestration of decisions and actions between different deciding parties (Steffenhagen 1975). Kieser and Walgenbach point out that all efforts have to be oriented towards the organizational objectives (Kieser, Walgenbach 2007).

Here we assume that the strategy in production ramp-up is compliant to the company’s objectives, but that the participating parties have different objectives. The overall problem is to effectively and efficiently coordinate production ramp-up concerning these participants. Main approaches are to strengthen cooperation boosting the base of knowledge involved in the respective project, to strengthen communication and hence the transfer of knowledge and to support the project by controlling. Controlling combines the service function, creating, processing and delivering information, but also serves by controlling the pursuit of right objectives and shaping the management system. The deciding parties during production ramp-up can be identified as the different functions of the company e.g. production, and product

development. Moreover there may be a special project team and a designated manager for the production ramp-up project and possibly even external parties namely suppliers and customers are to be considered. To align the actions and decisions of the participating parties, a basic strategy is needed which should be connected to the strategy of the company.

In a first step in assessing the impact of coordination, we start again reviewing literature on new product development. First of all there are some metastudies on success respectively performance in new product development that need to be taken into account. Reviewing the metastudies we concentrate on results concerning our scope, namely organization and coordination, since other factors can be interpreted as given. They can either not be influenced because the respective decisions are made before production ramp-up or they can only be evaluated retrospectively after the product has been to market for a considerable amount of time. Montoya-Weiss and Calantone make a distinction between research on factors leading to success or failure, and success measures. They distinguish between two organizational success factors: internal and external relations and other organizational factors. The first factor is explicitly defined as coordination and cooperation within and in between the firms. The correlation to success was analyzed in three out of 12 studies with results ranging from 0.145 to 0.604 leading to a relatively large average absolute correlation of 0.305 in comparison to other correlations (Montoya-Weiss, Calantone 1994).

Balachandra and Friar undertook an in-depth analysis of 19 (out of 60) studies. Six of these studies identified high levels of management support, three the commitment of project staff, three the compatibility of business and technology strategy and six planning of the R&D process to have an impact on success. Furthermore organizational factors made up the main share of all factors analyzed in the studies (Balachandra, Friar 1997).

Henard and Szymanski analyzed 24 predictors of new product performance, where only those correlations were taken into account that had been analyzed in more than nine studies. Two of these predictors are cross-functional integration and communication, where the latter is one of the most frequently modeled predictors. However the mean correlations for these two factors turn out to be not statistically significant (Henard, Szymanski 2001).

Ernst also analyzed studies on the relationship of potential success factors and new product success. Based on studies by Cooper, Kleinschmidt and others, he points out the essentiality of organizational success factors, namely cross-functional teams, project leadership, assignment of responsibility, commitment of the team and intensive communication (Ernst 2002).

Additionally we want to refer to some studies with regard to the three main approaches cooperation, communication respectively knowledge transfer and controlling. Cooperation between different functions such as R&D, production and marketing respectively the formation of cross-functional teams is widely recognized as a coordination mechanism but has been analyzed with different results (Sethi, Smith, Park 2001; Sherman, Berkowitz, Souder 2005; Song, Montoya-Weiss, Schmidt 1997; Song, Thieme, Xie 1998; Terwiesch, Bohn, Chea 2001). Special attention to communication, its quality and its impact on success has been paid to by some authors. Problematically this construct is almost in every case connected to some other construct such as cooperation or collaboration (Griffin, Hauser 1992; Maltz 2000; Sarin, O'Connor 2009; Song, Parry 1997). Kahn addressed this problem in a study and explicitly differentiates between the constructs collaboration and communication. He finds that collaboration has significant impact on success unlike communication (Kahn 1996).

A factor that has not been mentioned in the metastudies is controlling. Based on a survey by Ahn main functions of controlling are of planning, control and provision with information (Ahn

2003). The effect of controlling has been analyzed by several authors. Balachandra et al. analyzed 78 R&D projects concerning termination decisions and found that in every case project monitoring procedures were used (Balachandra, Brockhoff, Pearson 1996). Johne finds that experienced product innovator firms use formal control mechanisms to coordinate efficient development (Johne 1984). Furthermore Johne and Snelson state that controlling of new product development projects is mandatory to ensure the firms survival and they found that control should be more formal and rigid in phases closer to market launch than in the beginning of the innovation process (Johne, Snelson 1988). Larson and Gobeli use the ability to control costs as a success measure for different types of organizations (Larson, Gobeli 1988).

Cooper et al. discovered that controlling the innovation process, clear definition of goals and the linking to overall business goals are best practices in new product development. Furthermore the best performers keep track of project performance, use metrics to control how well the new product development process is working and have rigorous gates (Cooper, Edgett, Kleinschmidt 2004a; Cooper, Edgett, Kleinschmidt 2004b; Cooper, Edgett, Kleinschmidt 2004c).

To our knowledge the impact of organizational factors on the success of production ramp-up has only been analyzed by Ginn and Rubenstein in a quantitative study. They present evidence that the presence of more super-ordinate goals and conflict is positively connected to project success. The coexistence is explained by the situations' complexity and uncertainty, where the installation of superordinate goals moderates conflict (Ginn, Rubenstein 1986). Furthermore conflict can be positively interpreted as the result of cooperation and communication. Vasconcellos comes close to the topic but only presents descriptive evaluation of his data (Vasconcellos 1994).

In conclusion the effects of cooperation, communication and controlling on success have been analyzed in a multitude of studies for the whole innovation process with different results.

Unfortunately the authors use different termini respectively a variation of similar constructs concerning cooperation and communication.

## **2.5. Hypotheses and conceptual Model**

With respect to the chapters 2.1 to 2.4 we state the following hypotheses. Our first general hypothesis is: Having a basic production ramp-up strategy concerning objectives and processes and thereof using standardized processes and methods during production ramp-up is positively associated with coordination of production ramp-up. The mechanisms of coordination are defined as cooperation, communication and controlling and are included in H1, H2 and H3.

**H1:** *The degree of cooperation with suppliers during the innovation process is positively affected by the implementation of a ramp-up strategy.*

**H2:** *The degree of knowledge transfer during and in between production ramp-up projects is positively affected by the implementation of a ramp-up strategy.*

**H3:** *The degree of controlling in production ramp-up projects is positively affected by the implementation of a ramp-up strategy.*

Despite H1, H2 and H3 there are underlying assumptions, as described concerning the nature of coordination and success in production ramp-up. As coordination is split into its mechanisms, overall production ramp-up success is split into ramp-up success (concerning time and quality) and ramp-up cost achievement. Hence our following hypotheses are divided into two parts, one referring to ramp-up success (a) and one referring to ramp-up cost achievement (b).

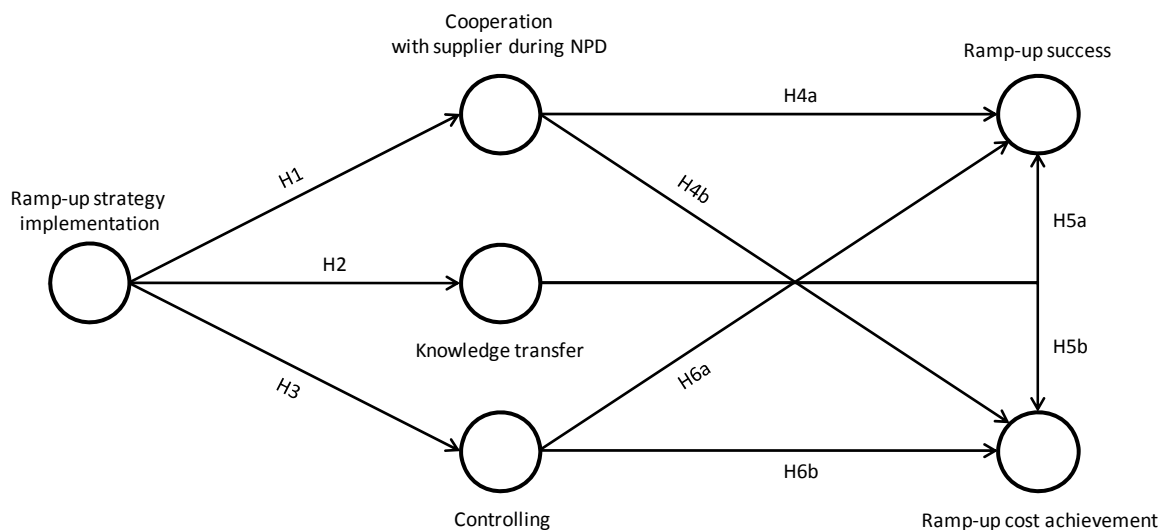
**H4a/b:** *The success of production ramp-up projects is positively affected by the degree of integrating suppliers in early phases of the innovation process such as product development.*

**H5a/b:** *The success of production ramp-up projects is positively affected by the capability of transferring knowledge from previous ramp-up projects to current projects and in between the project team.*

**H6a/b:** *The information flow created by cooperation and communication needs to be planned and controlled. Thus the success of production ramp-up projects is positively affected by utilization of a controlling system.*

Consequently, our conceptual model is built out of these hypotheses and presented in Figure 1.

**Figure 1: Conceptual Model**



Our conceptual model is a generic model to analyze interdependencies within a given sample of variables representing our hypotheses. As our variables the model was built on findings of a literature analysis and matching these findings with our variables. According to our hypotheses our model represents our first general hypothesis of strategy implementation positively affecting coordination mechanisms and our second general hypothesis of coordination mechanisms positively affecting production ramp-up success.

### **3. Methodology**

To test our hypotheses we decided for a survey design as methodological research approach. In comparison to other methods like field experiments or observations, we regarded a survey as the only possible way to get appropriate data concerning our research topic. We assume that the ramp-up process is integrated in other value creation steps. Therefore we asked people reporting to have a good insight in firm intern process characteristics. For that purpose our questionnaire was disseminated among companies of the German speaking manufacturing sectors.

#### **3.1. Data Collection and Sample**

Overall 185 questionnaires were sent out to manufacturers of passenger cars and their suppliers all throughout Germany, Swiss, and Austria. 71 questionnaires were sent back, hence, the response rate is 38.4 %, which is typical for operations management studies (Hensley 1999; Jonsson 2000; Kidd, Kanda 2000; Tsikriktsis, Lanzolla, Frohlich 2004).

A first descriptive analysis of the sample composition revealed that out of the 71 participating companies, 12 identified themselves as Original Equipment Manufacturers (OEM) all others are Tier 1 or less suppliers. Key informants came from production or logistics departments (43.6 %) and held positions in middle or top management (67.6 %). Important for further analysis was the answer to the question regarding the positioning of the ramp-up process within the new product development process. We find that most of the participating companies had temporary project structures to manage the production ramp-up (58%). Others had fixed project teams (17.5%), a separate ramp-up management department (17.5%) or could not give any details about their ramp-up organization (7%).

Furthermore we collected data on firm characteristics like size and experience in production ramp-up management. On average, the participating companies had 23.000 employees and sales

of 6.2 billion Euros. Within the last three years before data collection date on average 77 ramp-up projects were executed with an average duration of 21 months and an average product lifecycle of 65 months. Unfortunately 14 datasets of participants had to be eliminated due to missing values of the self reported ramp-up success items. Therefore all analyses are based on a sample of 57 participants.

### **3.2. Questionnaire and Measures**

The questionnaire was structured in seven different categories, which represent an engineering perspective on production ramp-up management. Our factors were built on an analysis of the literature and matched to items built into the questionnaire.

Our independent variable represents the degree of a *ramp-up strategy implementation* as a fundamental prerequisite for ramp-up operations, objectives, and success, similar to corporate strategy in strategic management (Bowman, Helfat 2001). Our variable *ramp-up strategy implementation* expresses how strong ramp-up operations are based on the existing ramp-up strategy and how frequently standard planning processes are used. As all our variables used in this analysis *ramp-up strategy implementation* is a multi-item measurement built on items which were answered on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Other variables, such as *cooperation with suppliers during new product development (NPD)*, *knowledge transfer* and *controlling*, represent the degree of their application during production ramp-up. For details on these and all other variables and their respective items see Table 2.

Our measurement of ramp-up success as dependent variables were modeled as self reporting measures of achieving targets in budget, quality and time. Target achieving rate had to be answered on a five-point Likert scale, which was ranging from strongly disagree to strongly

agree. Arithmetic mean of all values, ranging from 1 (strongly disagree) to 5 (strongly agree) was meant to be a proxy variable for production ramp-up success. As already mentioned in chapter 2.3 several production ramp-up objectives have to be traded off. Thus ramp-up success is modeled as the achievement of quality and time objectives while keeping budget adjustable to the required amount.

## **4. Analysis and Results**

### **4.1. Measurement Validation**

Concerning our measurement of ramp-up success a confirmatory factor analyses confirmed a separation of cost achievement items and quality or timing items. Hence, one success variable was constructed including all quality and timing items (ramp-up success) and one including cost items only (ramp-up cost achievement). At the end we had two dependent variables. Both our success variables are normally distributed when tested using Kolmogorov-Smirnov test. Analysis was conducted using SPSS software. Whereas Table 1 summarizes limits for our measurement validation, Table 2 gives detailed measurement items and their characteristics for all variables used in this study. Overall measurement validation requirements were fulfilled by all our constructs and items.

**Table 1: Limits for Measurement Validation**

<b>Global</b>	Critical value	Source
R <sup>2</sup>	> 0.40	(Chin 1998)
Q <sup>2</sup>	> 0.00	(Fornell, Cha 1994)
f <sup>2</sup>	> 0.15	(Chin 1998; Ringle 2004)
Path coefficient	> 0.20	(Chin 1998; Ringle 2004)
<b>Local</b>		
Indicator reliability	≥ 0.70	(Johnson, Herrmann, Huber 2006)
Composite reliability	≥ 0.70	(Chin 1998; Hair <i>et al.</i> 2006)
Average variance for each factor	≥ 0.50	(Fornell, Larcker 1981)

We further tested performance criteria for our independent measurements. A check for scale reliability by using Cronbach's  $\alpha$  showed that we had to modify our constructs. Two construct re-specifications had to be made to meet all requirements. Our constructs ramp-up strategy and controlling were specified as three-item variables. In each construct one item had to be eliminated to ensure composite reliability. Thereby, all our constructs meet the suggested standard of 0.7 for composite reliability and demonstrate the significance of all our factors. Indicator reliability for all our indicators exceeded suggested standards of 0.70. This means indicators are sufficient in representing their constructs. As the average variance extracted also meets standard criteria of 0.5, our constructs explain a sufficient amount of variance. Overall, all measures suggest a good convergent validity.

**Table 2: Measurement Items and Reliabilities**

	<b>Factor loading</b>	<b>Composite reliability</b>	<b>Average variance</b>	<b>Fornell/Larcker</b>
<b>Ramp-up strategy implementation</b>		0.821	0.698	0.70>0.31
Ramp-up strategy formalization	0.734			
Ramp-up planning standardization	0.926			
<b>Cooperation with supplier during NPD</b>		0.968	0.885	0.89>0.10
...during project management	0.994			
...during product development	0.994			
...during product verification	0.994			
...during product modification	0.758			
<b>Knowledge transfer</b>		0.858	0.668	0.67>0.31
Exchange of experiences in company	0.799			
Lessons learned system exists	0.863			
Knowledge management system exists	0.788			
<b>Controlling</b>		0.773	0.630	0.63>0.27
Controlling of costs	0,760			
Controlling of timing	0,827			
<b>Ramp-up success</b>		0.864	0.614	0.61>0.27
Achievement of timing targets	0.731			
Satisfaction with timing	0.746			
Achievement of quality targets	0.862			
Satisfaction with quality	0.788			
<b>Ramp-up cost achievement</b>		0.878	0.782	0.78>0.38
Achievement of cost targets	0.861			
Satisfaction with costs	0.907			

## 4.2. Model Validation and Testing

Model validation is satisfactory for our sample size. Even though according to Chin (Chin 1998) R-squared is sufficient for one dependent variable only, our second success measure is close to a good approximation. Q-squared meets all requirements given by Fornell and Cha (Fornell, Cha 1994). F-squared is sufficient for all supported hypotheses.

**Table 3: Model Validation (part I)**

Construct	$R^2 > 0.4$	$Q^2 > 0$	Path coefficients
Ramp-up strategy implementation	-	-	see model
Cooperation with supplier during NPD	0.049	0.036	see model
Knowledge transfer	0.151	0.100	see model
Controlling	0.101	0.064	see model
Ramp-up success	0.400	0.144	see model
Ramp-up cost Achievement	0.343	0.209	see model

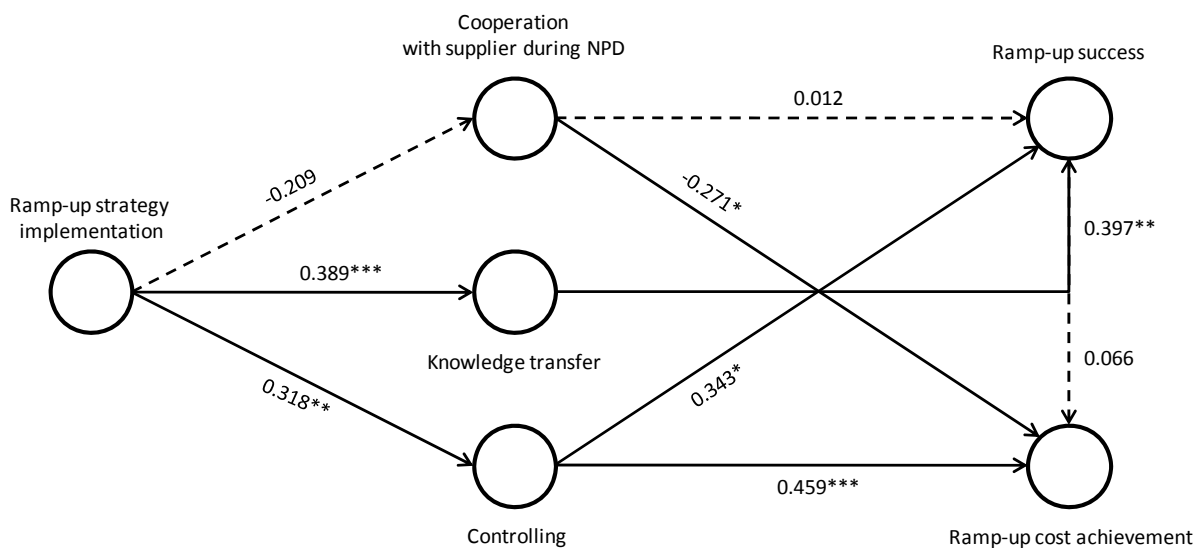
**Table 4: Model Validation (part II)**

	Ramp-up strategy implementation	Cooperation with supplier during NPD	Knowledge transfer	Controlling	Ramp-up success	Ramp-up cost achievement
$f^2 > 0.15$ (medium) $f^2 > 0.02$ (small)						
Ramp-up strategy implementation	-	0.051	0.178	0.112	-	-
Cooperation with supplier during NPD		-	-	-	0.000	0.108
Knowledge transfer			-	-	0.183	0.005
Controlling				-	0.152	0.219
Ramp-up success					-	-
Ramp-up cost achievement						-

The structural equation model was tested with smartPLS based on data of all 57 participants. For paths coefficients see Figure 2 and Table 5. Of all nine hypotheses tested, three were rejected in our model (dotted lines in Fig. 2). This means only six hypotheses could be supported. Out of these six hypotheses five were supported in impact and direction. One could not be supported in the direction expected.

Interrelationships between the implementation of a ramp-up strategy and the degree of coordination, which represents our first general hypothesis, are supported only for two out of three hypotheses (H1, H2 and H3). How often and how intense working with suppliers during new product development could not be shown to be dependent on the degree of implementation of a production ramp-up strategy (H1). However the implementation of a production ramp-up strategy affects coordination mechanisms such as knowledge sharing and using experience from former project and project members (H2) and the controlling of production ramp-up processes and milestones (H3).

**Figure 2: Results for the Structural Equation Model of the Study**



Our second general hypothesis, which states that coordination during production ramp-up is essential for the success of production ramp-up projects, could be supported by our model for four of six hypotheses (H4a/b, H5a/b, H6a/b). The degree of integrating suppliers in early innovation phases, especially during new product development, could not be shown to have any influence on the timing and quality achievement rate during production ramp-up projects (H4a). Otherwise cost achievement rate is affected by the degree of supplier integration (H4b). Unforeseen it is affected in the opposite direction as it is negatively affected.

An expected impact of transferring knowledge during production ramp-up projects could be supported for ramp-up success at the timing and quality level (H5a) but not at the cost level (H5b). Confirmation of a coordination mechanism that positively affects both success measures in our model could be found in production ramp-up controlling. Having a controlling system in place and using it to check and balance cost aspects (H6b) respectively timelines and quality requirements (H6a) helps to achieve production ramp-up objectives and therefore be successful.

**Table 5: Path Coefficients**

	Coop. with supplier during NPD	Knowledge transfer	Controlling	Ramp-up success	Ramp-up cost achievement
Ramp-up strategy impl.	-0.209	0.389***	0.318**	-	-
Coop. with supplier d.NPD	-	-	-	0.012	-0.271*
Knowledge transfer	-	-	-	0.397**	0.066
Controlling	-	-	-	0.343*	0.459***

\*\*\*. significant at the 0.001 level (2-tailed)

\*\*. significant at the 0.010 level (2-tailed)

\*. significant at the 0.050 level (2-tailed)

## **5. Discussion and Implications**

*Coordination has a crucial impact on production ramp-up success*

Our results confirm the importance of coordination mechanisms (compare section 2.4), such as cooperation, communication and controlling for a successful production ramp-up. The relevance of each coordination mechanism is given on several levels.

*Strategy is a fundamental premise*

In order to coordinate production ramp-up projects a set of standardized processes and ramp-up objectives are necessary, which preferably are derived from the companies' production ramp-up strategy directly. This ensures consistency in ramp-up projects and related activities as well as decisions. Implementing a production ramp-up strategy is a key prerequisite for establishing organizational entities as controlling or knowledge management for production ramp-up. Coordination can take place as soon as available resources and processes are defined. Hence strategy is the fundamental premise for successful managing production ramp-ups and ensuring consistency over time.

Not very surprisingly production ramp-up strategy does not have any supported affect on integrating suppliers into new product development. As these decisions are made long before the actual production ramp-up project starts during product planning and product conceptualization. Managing production ramp-up means dealing with restrictions established and shaped during product development (compare chapter 1).

Controlling is about control of achievement in objectives, planning and development of activities to accomplish the aspired objectives and the development of objectives themselves (compare section 2.4). To fulfill the latter quest, controlling itself needs orientation provided by ramp-up strategy. Drawing the arc, controlling is needed to ensure that the objectives during production

ramp-up not only match the ramp-up strategy but also on a higher level strategy and objectives of the firm. Otherwise the controlling system, which should ensure orientation of activities during ramp-up, loses orientation itself.

### *It's all about experience*

Knowledge and experience are key factors for a successful ramp-up which means cooperating with knowledge carrying entities and usage of existing knowledge is essential. As Terwiesch et al. suggest: "...it is desirable to have the earlier learning locations detect as many problems as possible to reduce the problem in later stages" (Terwiesch, Bohn, Chea 2001). This could lead to the conclusion how important learning from former production-ramp up stages for current projects is and how important it is to enable later stages or even projects to access prior experience. Therefore a knowledge management system has to be in place and should be used during and after production ramp-up projects. Having experience out of former production ramp-ups and reusing this experience or making it available for later production ramp-ups enables managers to deal with problems easier and faster and make decisions under less uncertainty. Lowering uncertainty during production ramp-up projects or even from one project to another reduces the amount of error sources. Innovation research is aware of this issue for new product development processes. Lowering uncertainty also means, at least for innovation activities, sticking to the known and by that innovating on an incremental level rather than on a radical. Transferred to production ramp-up management this would imply newness having an influence on coordination mechanisms and coordination need as well as on the coordination's influence on success of the production ramp-up project.

However, the conclusion that being innovative on a radical level should be avoided to make production ramp-up more successful is false. Rather the management should be aware of more

difficulties that may occur during production ramp-up if the degree of newness is high. This means that required amount of time and budget to reach mandatory quality levels are harder to estimate and therefore should be less determinate.

### *Operation and control*

The control of cost may be one of the earliest applied functions of controlling. Controlling also implies the benefit of structuring a highly complex and dynamic situation and navigating the project team through an ever-changing environment. Furthermore problems with quality are recognized quickly; information is more precise and up to date. This can also be carried forward for the objectives. Controlling can serve superior management to set more realistic and accurate objectives.

### *Is the ramp-up budget out of control?*

Cooperating with suppliers at early stages of the innovation process has a negative effect on cost achievement. How can that be? At the first sight this cannot be explained or verified through literature, but there has to be a reason. Well, the intensity of cooperating with suppliers during new product development could be an indication for the complexity of the final product or the supplied module. Maybe it is also an indication for complexity of the process of integrating supplied modules into the production process. In addition it stands to reason that a high amount of supplied units increases the complexity of a production process.

This leads us to the conclusion that the complexity of the final product, supplied modules, production process but also of the production and supplier network has an impact on the management of production ramp-up and its success, at least in consideration of cost objectives.

Another possible explanation could be seen in the amount of participants at the production ramp-up project and the accessibility to these participants or their priorities. Cooperating with suppliers

does not mean having access to their cost and schedule planning, which makes it much harder to estimate the real cost and time requirements at the supplier's facilities.

Controlling systems and mechanisms favor the achievement of preset goals. This is documented in controlling literature (Bonner, Ruckert, Walker Jr 2002; Lévárdy, Browning 2009). Therefore we allow ourselves to justify our model, which represents this fact very well. On the other hand, it has to be considered, that high cost achievement rate may not be as much the result of a good controlling as it is of good cost forecasting for production ramp-up projects.

## **6. Limitations and Suggestions for Future Research**

### *Limitations*

Our study has several limitations, which shall be discussed in this section. Due to a German questionnaire, only German speaking countries could take part in the study, which gives our study and its results regional constraints. Unfortunately, the participants were not able to rank or even assess the importance of different objectives during production ramp-up. This would have opened the opportunity to integrate weighting into the calculation of our success constructs. Even more problematic is our sample size, which should have been larger to make better estimations for our structural equation model.

Our modeling software was smartPLS, which estimates correlations of our latent variables based on a variance analysis. The method of Partial Least Squares (PLS) tends to overestimate factor loadings and underestimate path coefficients (Chin 1995). To avoid this all used latent variables in the model should be constructs of as many items as possible. AMOS, which is based on covariance analysis, does not tend to overestimate or underestimate. AMOS is able to estimate correlations of constructs with at least two items (Anderson, Gerbing, Hunter 1987). Due to our sample size we had to settle for smartPLS (Jahn 2007).

As this study is based on a questionnaire one may ask why we did not conduct qualitative research on a case study base or interviews. Furthermore our questions aimed to gain insight into best practices of a firm, presuming that all ramp-up projects are the same within a company. In reality that may not be the case. Another approach would be to conduct studies like ours on a project base.

### *Further Research*

One of our goals was to stimulate discussion and further research on production ramp-up on an international level. Unfortunately, production ramp-up seems to be a mostly German topic in scientific literature and practice. We wish to motivate others to pick up this challenging topic on an international level. A first task for these international studies should be to find a common definition and understanding of production ramp-up.

Moreover we want to suggest to keep a focus on coordination and cooperation during production ramp-up as Langowitz already suggested (Langowitz 1988): “In order to avoid mismatches and a rough initial manufacturing experience, it seems to be important to try to have clear definition and use of milestones from the start of a project. Decision-making on such items as materials and suppliers, which have immediate impact upon the factory, should be jointly made by design and manufacturing. Further, an atmosphere of high communication and coordination should be encouraged by senior managers.” Further studies could also concentrate on the moderating effect of the degree of newness on the interconnection of coordination and production ramp-up success. As mentioned earlier in this paper objectives and measures for production ramp-up success are not well defined yet. Future research should find a resilient system of success measurement. Additionally scientists should ask for the overall relevance of production ramp-up management for the firm. For further research it would be crucial to know if a good production ramp-up

management and thereof ramp-up success has any impact on the firm level success measures or at least on new product development success measures.

Recently another topic was introduced by again German researchers (Gössinger, Lehner 2009): Integrating customers during production ramp-up. We are not quite sure if this would make sense at all. However, even though our data could not give proof, during our study we recognized differences in production ramp-up management for companies producing for end customers and those producing for business customers. This would mean management research on production ramp-up would need to distinguish between production ramp-up for B2B or B2C products.

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