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RESEARCH ARTICLE

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Abstract

The importance of the “Ramp-up bridge” covering the gap between product development and serial production, as well as the speed at which this bridge can be crossed, has increased, providing companies with a significant competitive advantage.

However, a significant percentage of project aiming to introduce new products do not achieve their goals. [(60 percent of the automotive supplier ramp-up projects fail on either the technical, or the economic side (Bischoff, 2007)].

The author explores the possible reasons, then makes suggestions regarding the support of successful ramp-up projects, through practical examples taken from the industry.

Through the continuous improvement of ramp-ups, a new core competency can be achieved, with a decrease in time-to-market. This core competency is difficult to duplicate, and can provide an additional competitive advantage for companies manufacturing products with high technical complexity.

Keywords

ramp-up, time-to-market, core competency, continuous improvement, TQM, quality management, high technical complexity

1 Introduction

The effects of globalization processes have resulted in competition between companies which only a few decades ago would never have come into contact, or some which might not have even existed. The resources allocated to research and development have increased several-fold. The speed of development has also vastly increased: we need look no further than the automotive industry, where only a few decades ago developing of a new model took 5-7 years decreasing to a mere 30 months by 2008 (T-Systems, 2008). The time-to-market factor has been drastically reduced. Due to the increasing range of products and the simultaneously shortening product lifecycles, the ramp-up process become increasingly important for the success of the companies (Lanza and Fleischer, 2005; Kampker et al., 2013; Schmitt and Schmitt, 2013). This statement is especially valid for the technically complex manufacturing fields of vehicle, agriculture, forestry and construction machine production.

The importance of ramp-up becomes clear if the great impact of production ramp-up delay on the profit of a company is considered. (Lanza, 2005; Westkämper, 2003). Let us examine the individual elements of these losses by using a vehicle manufacturing example, to explore the reasons which might not be apparent at first. Two significant types of losses can be differentiated. First are the forgone sales, including losses due to the late market launch, customer migration, and reduced production capacity. Secondly, we must consider increased costs, which themselves comprise a number of different elements: increased costs of production, development, resources used for ramp-up/SOP (start of production), warranty and goodwill, as well as the cost of changes, especially late changes. What, then, would the overall total come to?

Assuming 500 000 units produced annually, a product launch delay of 6 months, and a manufacturing time of 7 years, McKinsey analysts have calculated the total loss to be USD 6.465 billion. A summary of the above can be seen in Fig. 1. Is it possible to reduce these extremely high losses, and if yes, how? Investigating this issue is the aim of this research paper.

In Section 2, the ramp-up process is positioned in the field of competitive strategies, competitive advantages, market

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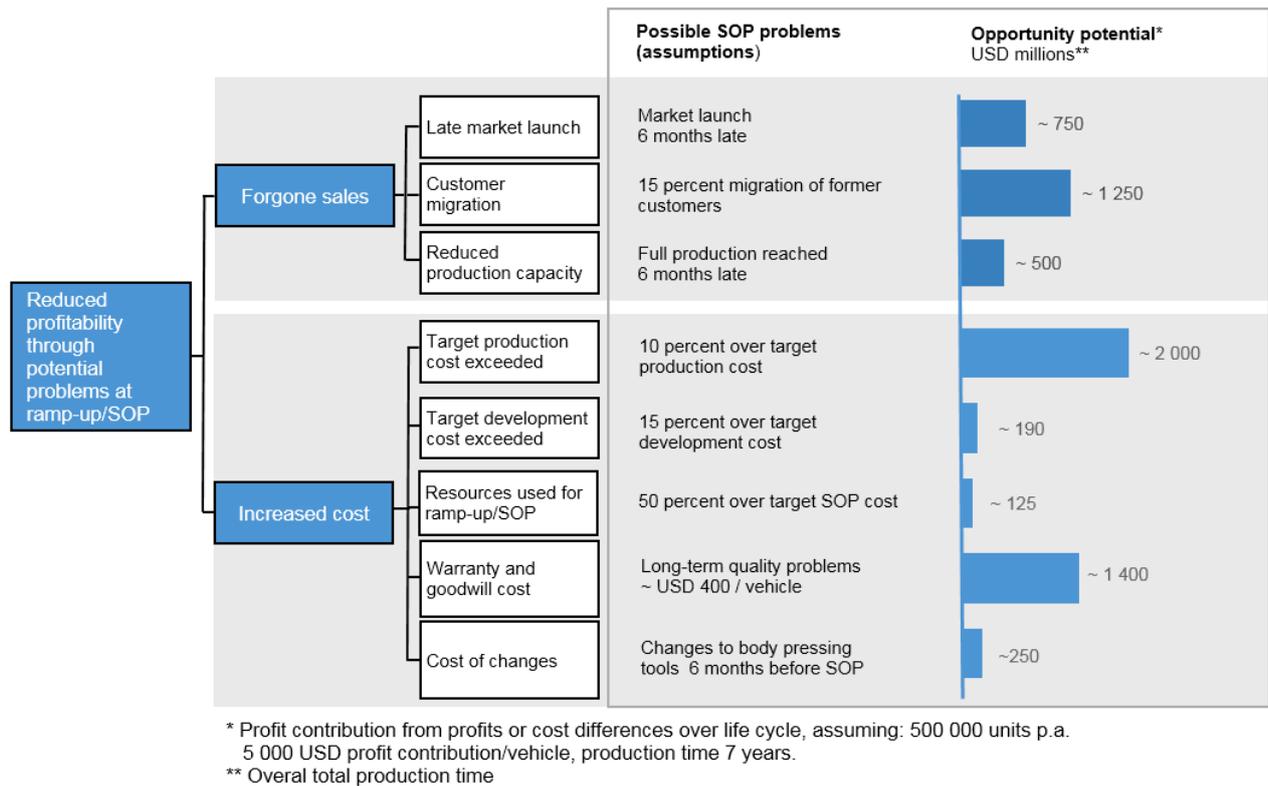


Fig. 1 Impact of maturity on profitability (McKinsey, 2002)

characteristics and required quality management systems. In Section 3, ramp-up process improvement practices will be presented, based on manufacturing experiences with products of high technical complexity. The result of the research paper, included in Section 4, will demonstrate the application of the presented process improvement practices, potentially leading to a new core competency that is difficult to duplicate. This core competency can provide an additional competitive advantage for companies manufacturing products with high technical complexity.

The researcher's long-term objective is to further develop the described ramp-up improvement processes, in order to create a flexible Total Ramp-Up (TRU) system for companies manufacturing products with high technical complexity.

2 Competitive strategies

A company's competitiveness is determined by both internal and external factors. The internal factors comprise the core competencies derived from the operation of the company, while the external factors are defined by external market success factors. Competitiveness is defined by how well a company can withstand competition, and is based on acquired experiences, inherited talents or acquired knowledge (Marosán, 2001).

The competitive strategy of a company can be either explicit or implicit, but in either case, it defines the operation of the company's divisions, or even the company as a whole (Porter, 1993).

Table 1 Generic strategies (Porter, 1993)

		Competitive advantage	
		Lower cost	Differentiation
Competitive scope	Broad target	Cost leadership	Differentiation
	Narrow target		Focus

Differentiating strategies can be very diverse. The company could focus, for instance, on short delivery times, low prices, high quality, meeting specific customer needs, flexibility, custom manufacturing, a wide range of built-in options, variants, dependability and extended warranty periods, or any combination of these factors. The competitive strategy best suited for achieving a leading position in the market is always dependent on the specific market requirements, which can in turn depend on or be influenced by global political events. As an example, we may consider the types of products that would be required by the population of a country in a post-war period (today's Syria or Iraq, for instance).

During the post-World War II period, the dominant corporate strategy was to keep costs low (cost-based competition) (Stalk, 1988). Later, more focus was given to the reduction of overall costs (scale-based competition). In the 1970s, by contrast, once the major corporations had all become able to produce their products at similar costs, additional competences became necessary to achieve competitive advantage. This new type of competitive advantage was quality (quality-based competition). By the 1990s, however, the production of high-quality, low-cost

products was also no longer sufficient for achieving competitive advantage. A new competitive factor appeared, which was time (time-based competition) (Chikán and Demeter, 2001).

Time characteristics can also be grouped, as per the following table by De Toni and Meneghetti:

Table 2 Internal and external time performances (De Toni and Meneghetti, 2000)

		Time performance	
		Internal	External
Phase	Product Development	TTM (Time-To-Market)	FI (Frequency of introducing) - new products - existing products improvements
	Procurement	LT (Lead Time)	DT (Delivery Time)
	Production	- procurement	- speed
	Distribution	- production - distribution	- punctuality

In the period of time-based competition, companies firstly attempted to reduce the direct (external) time factors which would be immediately noticeable by the customers, then moved their focus to the indirect (internal) time factors. (Kalló, 2010). Generally speaking, the time-based competition approach was first adopted by companies in the manufacturing sector, then in sales and distribution, and finally in the field of innovation (Stalk, 1988). Thus, time-based competition is also possible by improving the various time factors related to Supply Chain Management (Ji, 2008).

Naturally, the specifics of the market where the company is operating must still be taken into consideration. Management must focus the company's resources on those internal or external time factor reductions which can be perceived and appreciated by customers.

We must keep in mind that these optimization processes are never an end in themselves. At a minimum, they serve to reduce costs, which itself translates to a competitive market advantage. The relationship between market characteristics and strategies are presented in Table 3.

Table 3 Market characteristics and strategic orientation (De Toni and Meneghetti, 2000)

Market sensitivity to frequency of introducing or improving products	High	Product time-based competitor	Product & Process time-based competitor
	Low	Design /Production cost-based competitor	Product & Process time-based competitor
	III.		IV.
	I.		II.
		Low	High
		Market sensitivity to delivery time (speed and punctuality)	

As a result of recent research, we are also able to determine the quality system necessary for achieving specific fundamental objectives (see Table 4) as well as how these systems are interconnected, and how they build upon each other (Szabó and Szabó, 2014).

Table 4 Connection of quality system and fundamental objective (Szabó and Nagy, 2009)

Minimal required quality system	
Fundamental objective	Required quality system
Meet the specification	Quality control
Meet the function requirements	Statistical quality control
Meet the evident customer demands	Total quality control
Meet the hidden customer demands	TQM
Meet the environmental and society demands	Integrated systems

In high value added markets, which are characteristic of the automotive, agricultural machine manufacturing or electronic industries, among others, we find Segment IV to be dominant (see Table 3), meaning time-based competition on the product and process levels (the market is highly sensitive to the frequency of introducing or improving products, as well as to delivery time). These demands require the application of TQM and integrated systems (see Table 4). Table 5 shows the applicable TQM methods.

Table 5 Classical QM and new TQM methods (Szabó G. Cs., 2013)

Classical QM methods, what partly used by TQM	Comprehensive, new TQM methods
- Error analyze methods: -> Pareto/ABM, -> Ishikawa -> FMEA/FMECA -> TIPHIB	- Data collection, visualization, analyze, - Benchmarking, - SWOT analyze, - Environment and market analyze, - Portfolio analyze, - Organization analyze,
- Problem solving, - QFD/QH (quality house), - Quality teams, - List of open points, check lists, - Quality audits, - Statistical methods, - Flowcharts, - Statistical process control cards, - 5W+1H	- Mission, vision, - Management style, - Company culture and development, - Communication analyze, - Motivation analyze, - Conflict and risk management, - Environment protection and culture, - Company audit, - Human resource analyze and development,
- 5S, - 7 steps problem solving, - Sampling methods.	- Work safety, health, work culture, - JIT, TPM systems, - PQC, SQM, - 7M, 9M, - PDCA problem solving, - Method systems (PDCA, six-sigma, lean), - QM method extension to non QM areas, - Decision making process and delegation analyze.

The key to the integrated systems' success is management itself.

Research and Development, Quality Management and Production are not exclusively responsible for the successful introduction of a new product; all other management elements must also bear responsibility (see Table 6). All management areas of the company must be present in the product introduction project. The management system as a whole can never be stronger than its weakest link (Szabó, 2014a).

Table 6 12 elements of TQM (Szabó, 2013)

12 elements of TQM	
Strategy management	Project and teamwork management
Quality and reliability management	Accounting and Finance management
Human Resource management	IT management
Research and Development management	Management of quantitative methods
Marketing management	Production and technology management
General management culture, decision system, leadership theory	Issue based problem solving

SWOT analyses and related programmes for the individual areas, including, for instance, Pareto based development programmes, deliver substandard results from the entire company's point of view, because departments not assigned an A category (the notation "A" referring to the class A used in Pareto-analyses) are not developed, and therefore remain weak. In the researcher's opinion, it would be beneficial to abandon the generally adopted approach of categorizing a company's internals into main and supporting processes, and stronger and weaker departments. It is more worthwhile to have a weaker but unified level of management across the whole organization than to have only one extremely strong department. Therefore, an even distribution of resources among the different management departments is vital (Szabó, 2014b).

The focus should not be exclusively on Production. The same priority should be given to Purchasing, Supply Chain Management, Quality and Human Resource Management, as well as IT. However, these decisions must always be made with a clear understanding of the organization's specific circumstances, allowing the company to grow in the fastest and most efficient way.

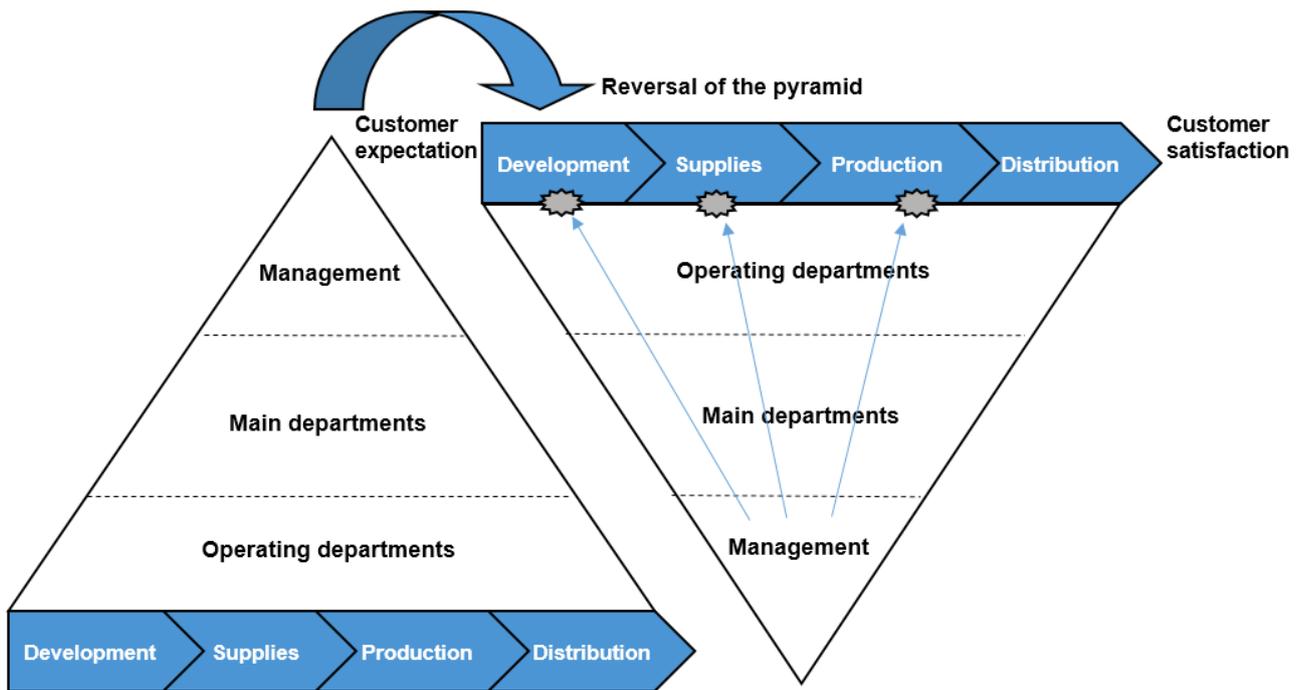


Fig. 2 Organization pyramid reserve through continuous improvement approach (Gobetto, 2014)

The speed of growth has become extremely high, according to Klaus Schwab, Founder and Executive Chairman of the World Economic Forum: "In the new world, it is not the big fish which eats the small fish, it's the fast fish which eats the slow fish." The most successful companies will be those able to respond the fastest to market demands.

This philosophy demands a much higher speed of product development and realization compared to earlier approaches.

The most challenging and most complex phase of this process is the ramp-up phase, when the project moves from prototype production to the serial production phase during product development and manufacturing (see Fig. 3) (Schuh et al., 2005).

New product introduction projects for automotive suppliers are so complex that they often fail during their ramp-up phase. 60 percent of projects cannot meet the technical and/or economical requirements (Bischoff, 2007).

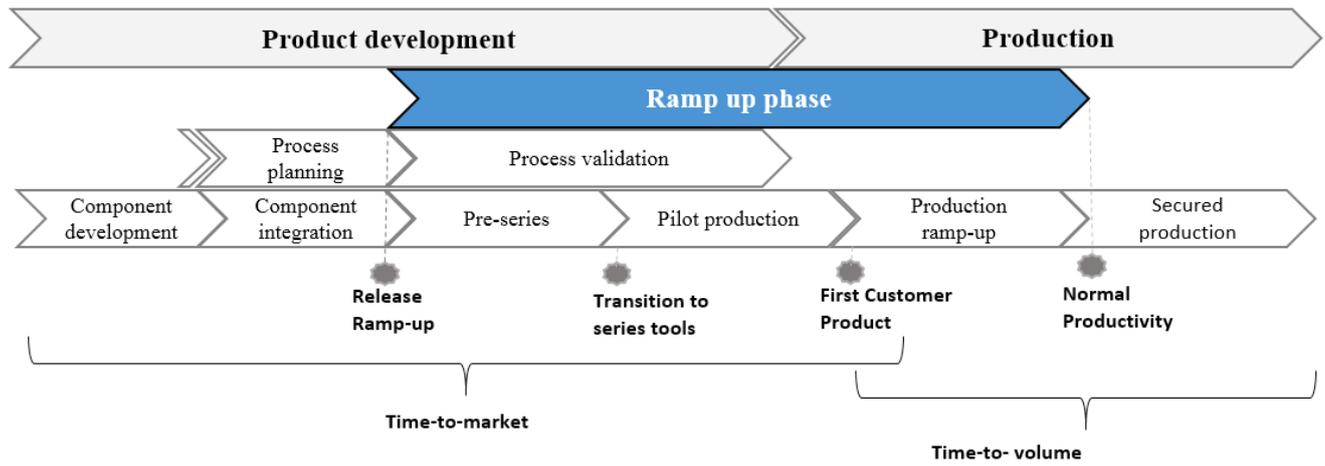


Fig. 3 Alignment of ramp-up phase in the product development process (Schuh et al., 2005)

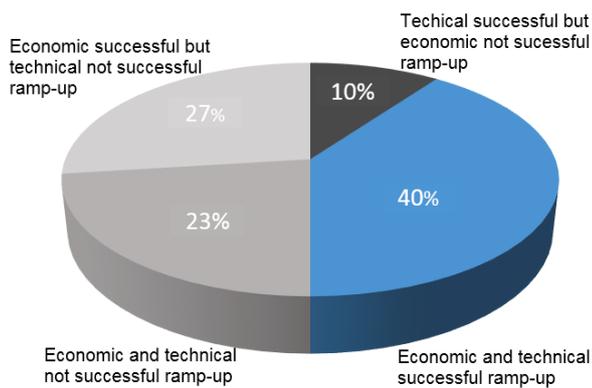


Fig. 4 Technical and economic achievement of production ramp-ups in the European automotive supplier industry (Bischoff, 2007)

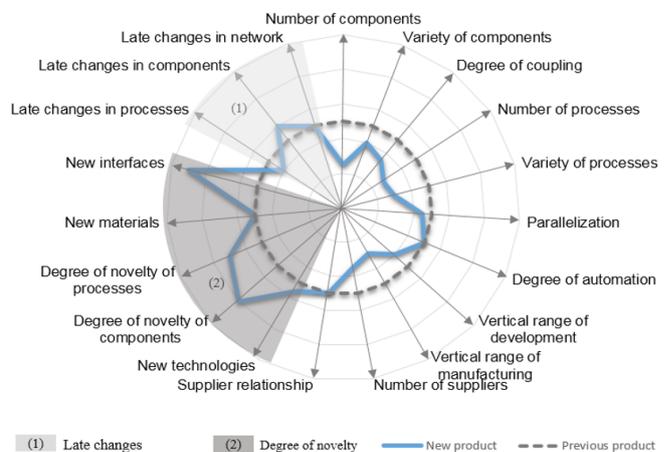


Fig. 5 Identification chart for detailed analysis (Elstner and Krause, 2014)

What are the root causes of this phenomenon? What are the reasons behind the delays? What causes the significant discrepancies from the project targets? Are there any elements of the process which would predict an unsuccessful ramp-up phase?

3 Critical ramp-up success factors from industrial practice

The examples presented are based on practical experiences, and can find application in the automotive, agricultural, construction, or forestry machine manufacturing industries, which all involve the manufacturing of products with high technical complexity.

3.1 Planning

It is worthwhile to prepare a radar chart at the very beginning of the ramp-up project's planning. Here we are able to compare the required resources of a new product ramp-up with the required resources of an earlier, reference ramp-up. An example of a radar chart is shown in Fig. 5.

By inspecting the complexity identification radar chart, we can receive visual feedback about whether the provided resources will be sufficient for the new ramp-up team (compared with the resources provided to an earlier, successful ramp-up team). By applying this method, it becomes clear where further enhancements are necessary, and which areas require more resources. According to the author's opinion, it is particularly important to understand that we should not restrict our investigations merely to the development project and its realization phase. The project should be mapped onto the time horizon of the full corporate product development portfolio. We can call this portfolio a product road map. This road map is required for us to be able to securely provide each and every project with the required resources, and to show us the synergies between our various development projects. Moreover, with this product road map approach, we can avoid different research and development projects entering the ramp-up phase simultaneously. This is significant, because entering the ramp-up phase at the same time could dilute the resources of the production company in question, which can lead to the failure of the projects.

3.2 Complexity and resource allocation

Let us pose a theoretical question: If a project team was barely able to achieve an introduction project for a product with low technical complexity, then given the same team number, composition, and work hours, will the team be able to complete a similar project for a product with high technical complexity? The answer is not known. However, presumably, a re-allocation of project resources will be required.

The key element of the ramp-up projects is their complexity. What are the main factors capable of influencing the complexity of ramp-up projects? The summary of these factors is shown in the figure below:

Degree of novelty	Network complexity	Process complexity
New technologies	Vertical range of development	Number of processes
New components	Vertical range of manufacture	Variety of processes
New processes	Number of suppliers	Coupling of processes
New materials	Supplier relationship	Degree of automation
New interfaces		
Product complexity	Late changes	
Number of components	Late changes in processes	
Variety of components	Late changes in components	
Degree of coupling	Late changes in network	

Fig. 6 Indicators for the main influencing factors (Elstner and Krause, 2014)

These influencing factors should be limited, reducing the complexity as much as possible. Standardization is necessary, otherwise we will be unable to achieve our original objective: bringing the new product to market as quickly as is feasible, and reducing the time-to-market factor to the greatest extent possible.

Planning should be managed with standardized raw materials, standardized technologies and standardized parts as much as is practicable. If this is not possible, then it should be investigated whether the company has previously manufactured similar components to the one in question. These previously manufactured parts could possibly be usable for the new design

as well. (Some 3D modelling software tools are already capable of finding identical or similar components from the archive database, based on the geometry used, and offer these previously designed components to the designer for use.)

Our primary objective is to modify the processes for products with high technical complexity, in order to lower the technical complexity and level of resources required [design and validation time, searching for new suppliers, building up new supply chain management, testing prototypes, inventory risks, modifying and procuring manufacturing and logistics tools, full-scale processing of the parts in the enterprise resource planning (ERP) system, technical documentation management, training, education]. On the whole, the product with high technical complexity should be “pushed” towards the centre of the complexity identification radar chart (see Fig. 5) and on at lower resource level, the resource demands should be managed using standardized processes.

3.3 Standardized processes

Moving on from the component level, the entire product development process should be standardized and traceable. Process steps and reports should be clear and easy to understand. It should not be up to the project team to guess the n+1th step of the process during the development project itself. The steps should be pre-defined, reducing recurring consultation times and the associated costs. The design scope and solution space will then be narrowed, reducing the time-to-market (see Fig. 7) which can result in a better competitive position for the company.

The development phases should be divided into milestones. At the end of each phase, a detailed milestone meeting is required, where the result of the phase is presented in a standardized milestone report form. Figure 8 below illustrates a possible new product introduction process pyramid. Naturally, the number of milestones could be increased or decreased as necessary, or even

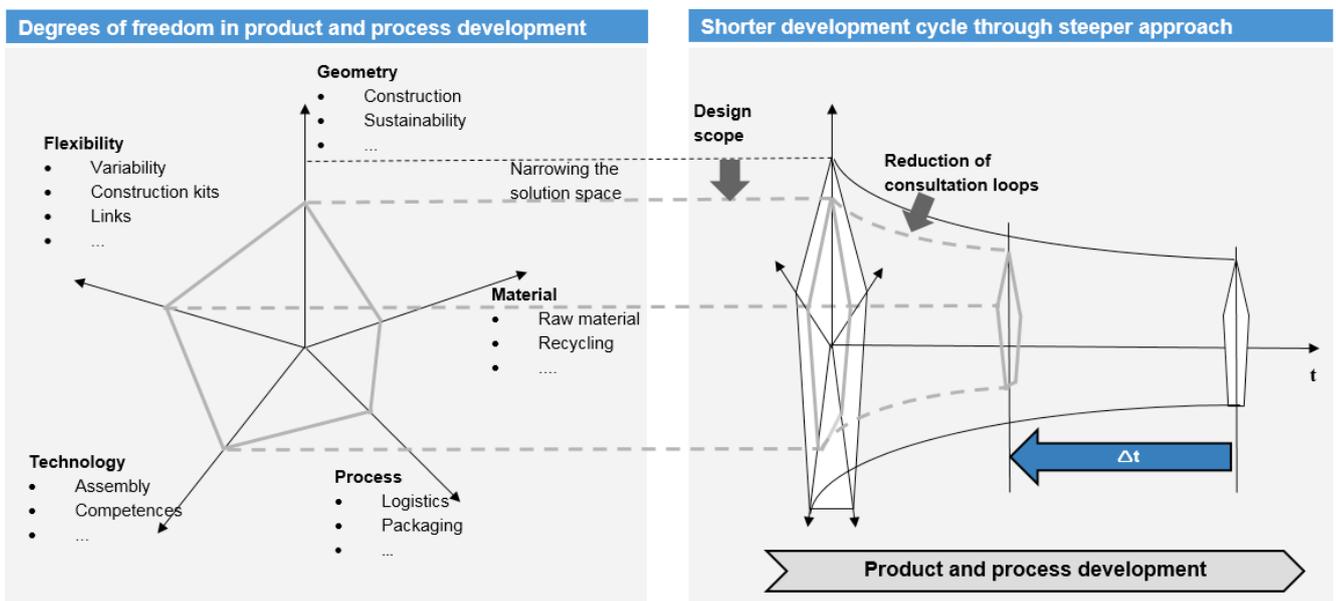


Fig. 7 Time-to-market benefits due to standardization (Kampker et al., 2014a)

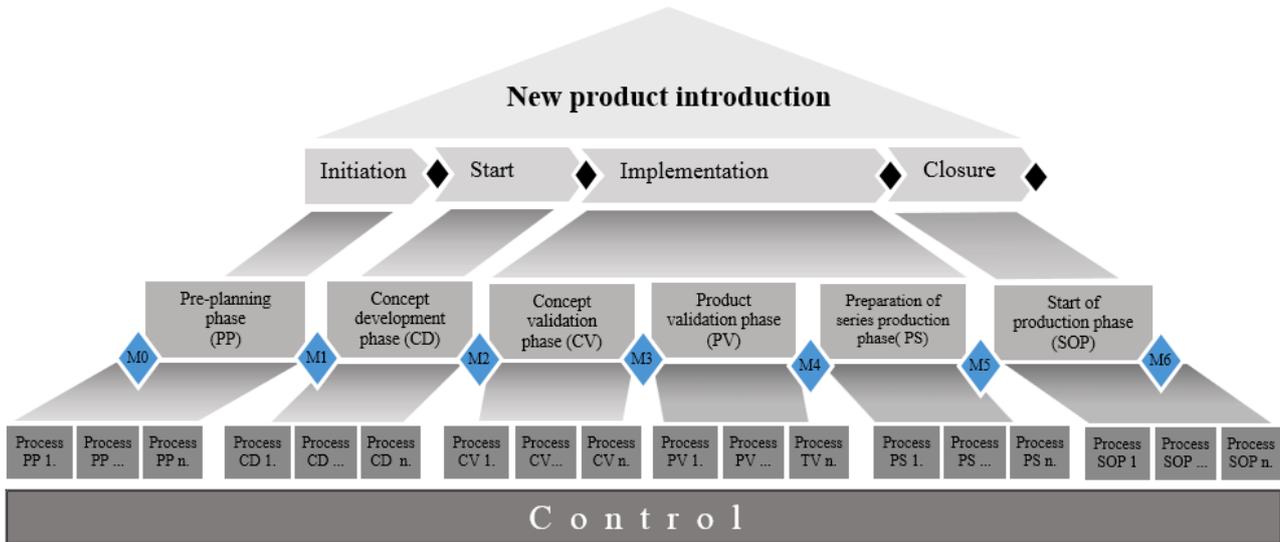


Fig. 8 New product introduction process pyramid (Own figure)

merged, depending on the complexity of the project. The content of each milestone should also be pre-defined. Every team member should be fully aware of what their task is, and what results are expected of them. The result of the project evaluation should be clear and pre-determined. (The researcher calls attention to the importance of the project members operating on the corporate project portfolio level, as opposed to the level of a single project.)

3.4 Process evaluation

Many companies apply the red, yellow and green traffic light criteria to evaluate the processes. This, however, is not always sufficient to indicate the actual status of the product development or the realization processes.

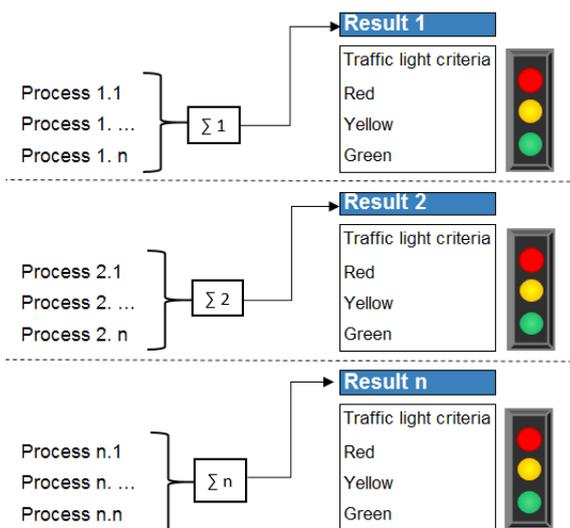


Fig. 9 Traffic lights (Own figure)

The author suggests the implementation of a numeric scale with five values, where the first stage does in fact mean that the project needs to be aborted, and the other four stages can be interpreted as follows:

- 1 - **STOP**;
- 2 - 1-33%;
- 3 - 34-66%;
- 4 - 67-99%;
- 5 - **Completed (100%)**

It is important to define in advance, and in writing, what precisely is meant by the standard process being, for example, 1-33%, or 34-66%, or 67-99% complete.

The results can be weighted according to the importance of the process, as not all the processes are of equal value to that of some missing translations of technical drawings (into the mother tongue of the production workers). However, according to the original traffic light criteria, both processes would have been assigned the same red light. With the more precise stages, and their assigned weights, a more objective indication of the project status can be gained. Thus, the different ramp-up projects become comparable. With this approach, it is possible to avoid an overly optimistic view of the project, which could otherwise lead to significant extra costs later on.

In summary, we would be able to switch from a quasi-objective evaluation system to a fully objective evaluation system.

3.5 Schedule and resource allocation

The time schedule of projects are becoming ever shorter due to the high expectations set by the market. In our example, let us reduce the time allocated by 33%, from 3 years to 2 years, while not altering the engineering resources or engineering work hours available. This will result in an overload in product development, which can spill over and cause delays in connected areas, such as Tool Manufacturing, Purchasing, Supply Chain Management or Human Resource Management. This can result in the necessary tools for production not being available on time, or a suboptimal selection of suppliers. For instance, the quickest suppliers will be given the opportunity to deliver the parts for the pre-series, as opposed to the optimal suppliers. This means that the structure of the supply chain will

also not be optimal. There will be no time left for knowledge transfer, which would otherwise improve production and speed up the ramp-up process. These delays will generate additional, unplanned extra costs for the project.

It is clear that the allocation of resources is not optimal. If the realistic project time schedule plan is decreased by 33% (the time-to-market is decreased by 33%) but all other conditions remain unchanged, the number of engineering hours should have been increased by at least 33%, to prevent the occurrence of unplanned increased costs at the connected departments. A good example of an increase in unplanned extra costs would be the late completion or modification of a component, which could then incur further costs on the order of €100 000 for tool modifications. In the worst-case scenario, the new tools end up having to be scrapped, as modification proves to be impossible under the circumstances.

If time-to-market is significantly reduced in the project, then resource allocation always becomes necessary as well! This step is often skipped in projects, even though investments into earlier project phases can often save the company additional later costs that would be several times greater.

Let us consider the automotive industry, where car recalls and the associated scandals are becoming increasingly common. In the United States alone, nearly 75 million vehicles were recalled in 2014, as can be seen in the chart below:

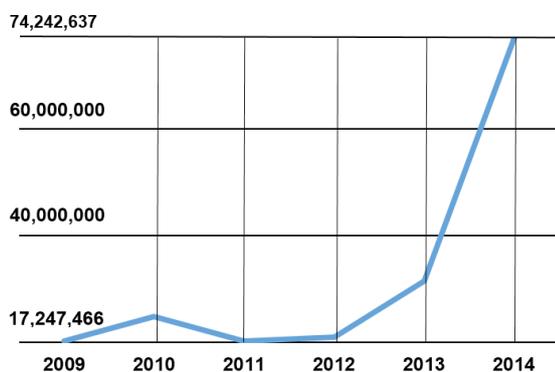


Fig. 10 Vehicle recalls in the U.S.A. (Fortune magazine, 2015)

The incidence and prevalence of errors is not equal during the various phases of product development and project realization, meaning that resources should likewise not be equally allocated!

The cost to repair 74 242 637 cars, using an average of \$400/repair (McKinsey, 2002) comes to \$29 697 054 800. Using an average engineering hourly fee of \$60, this sum would have bought a total of 494 950 913 engineering hours. This number of hours would involve 237 957.16 years of work for a single engineer, or one year for 237 958 engineers (calculating with a 40-hour workweek). This number is high enough to assume that the issue could have been prevented by involving more engineers and more engineering hours. These resources should

have been deployed in the M1-M2 concept development phase of the new product introduction project (see Fig. 8). The author would like to call further attention to the fact that the car recall data refers only to the United States of America. The actual number of global recalls and the related repair costs could be much higher than the above simplified calculation would suggest.

Overall, it can be stated that in the ramp-up phase, focus should be on the prevention rather than the management of errors, and in the time-to-market changes, the resource allocations should be managed proportionately, commensurately with the rate of change.

3.6 Plan implementation into daily production, product realization

A fundamental condition of error prevention is for each and every involved individual to have the information necessary for completing their assigned task.

Otherwise, the ramp-up projects will only move along the “actual development state” function, as opposed to converging strongly towards a stable target-development level (see Fig. 11). The researcher calls attention to the fact that the target-development level is not constant: it increases with time.

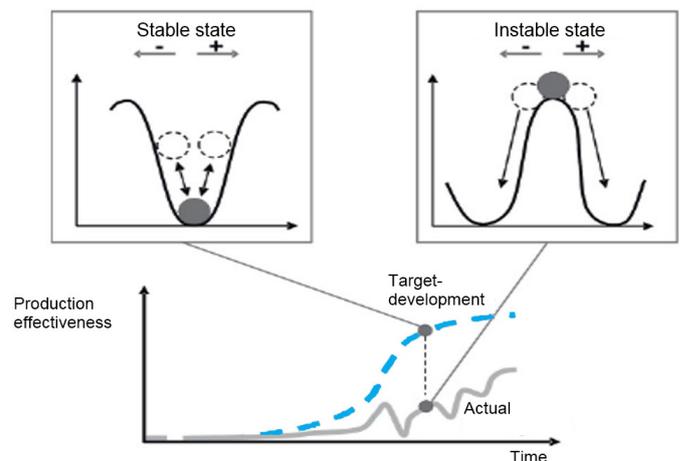


Fig. 11 Stability and instability in ramp-up (Basse et al., 2014)

As the learning curve refers to the cumulative number of product output and declines with every produced unit, the assumption that the learning curve is independent of managerial decisions suggests itself. In fact, there exist more drivers than the cumulated number, which influence the decline of the curve, i.e. the learning rate (Terwiesch and Bohn, 2001). The learning rate is shaped by the form of qualification (Kampker et al., 2014b). The level of qualification, in turn, is determined by previous experience, skills and abilities, the quality of technical education as relating to introduction of the new product, the immediate availability of education materials, and their ease of interpretation (2D, 3D assembly instructions, see Fig. 12).



Fig. 12 Manual assembly workstation equipped with a touchscreen (Schuh et al., 2015)

On the whole, it can be stated that knowledge transfer not initiated at the appropriate time (done too early leads to forgetting, while done too late, the conversion of knowledge to skill will remain incomplete) leads to significant delays in all ramp-up projects. Therefore, the mentors (e.g. design engineers, production support engineers and/or assembly workers involved in the production of functional and/or prototype machines) have key roles in accelerating the ramp-up phase. These mentors need to be very familiar with the components and functions of the new product. At the beginning of pre-series production, during the ramp-up phase (see Fig. 3), the mentors can support the production process and the individual production steps by providing professional advice, taking part in the process either personally or virtually.

3.7 Error management during the production

The quality and speed of error management during the ramp-up phase is of high priority.

Such errors and situations calling for decision-making can arise during ramp-up, when the right expert involvement can result in an immediate decision, preventing additional costs or further significant delays. If possible, any occurring errors should be recorded digitally, as opposed to on paper, and in as detailed a form as possible. Errors can also be recorded on video (this is easily doable with modern mobile phones). The errors should be categorized, then each error should be reported to the expert responsible as soon as possible, who can then either accept the request, or forward it to a different competent expert with free capacity. When the error has been delegated to the appropriate expert, he or she will be required to give feedback about the estimated time needed for a solution to the individual recording the original error. What is vital is for all errors to be recorded and reported to the relevant experts as well as to the project manager, who then has the opportunity to respond and prepare a “lessons learned” document (Bauer et al., 2014).

It is important that a sufficient amount of expert support be available for error management, (also taking time-lag into consideration for international projects), otherwise, the lack of capacity will lead to further delays and unsolved errors, which will then become integrated into the upcoming products and processes as well.

3.8 Ramp-up, post-production delay

During pre-series production, it is important to ensure the necessary supply of spare parts. Missing spare parts could lead to delays and a high level of customer dissatisfaction, which can result in potential customers being turned off from the company’s new product.

An overly optimistic approach should be avoided: it is important to be realistic. Additional production resources should to be planned for the ramp-up. These extra production resources will be needed to repair any technical faults in the ramp-up products. This post-production repair phase can be very time consuming, because it is likely to be performed under prototype conditions, as opposed to the production line.

3.9 Ramp-up motivation

During the entire ramp-up process, the motivation of workers and operators performing physical work on the production line is particularly important. If they are not sufficiently motivated, or even if the workers are penalized for errors in the new product, the time-to-market factor will be increased which is precisely the opposite of our goals.

3.10 Learn from the mistakes, develop continuously

After each completed ramp-up phase, the company should learn from its mistakes. Project managers should prepare lessons learned documents, and share these documents with the project team members, as well as with other ramp-up project team members working on different production sites within the group. The aim of these documents is to avoid the recurrence of the same mistakes, and continuously develop the ramp-up processes.

The importance of reducing the time factors has also been confirmed by empirical research, which show that the companies supporting the time-based competition methods are able to perform better than the ones who do not take advantage these opportunities (Kalló, 2010; Nahm et al., 2006; Vickery et al., 1995; Narasimhan and Jayaram, 1998).

4 Conclusion

In order to achieve the targeted production time within the ramp-up phase as soon as possible and without errors, the existing operational processes of the company must be reviewed and continuously analyzed [by applying TQM methods, among others (see Table 5)]. The ramp-up phase can be interpreted as a pressure test of the production system, as it serves to clearly identify areas requiring improvement.

As a result of continuous ramp-up improvements, vehicle, agriculture, forestry and construction machine manufacturers have the potential to achieve a flexible but standardized production system, able to manage products of high technical complexity with a large number of variants. These companies will not only significantly reduce time-to-market, but they will simultaneously greatly improve their own operations. New core competency will be achieved which is difficult to duplicate, and provide further competitive advantage for the company. Losses due to late market launches, customer migration, or higher production costs can be mitigated (see Table 1). The production system will improve, while the net present value, project returns, and customer satisfaction will all increase.

Additional research is planned to further develop the improvement processes listed above, in order to create a flexible Total Ramp-Up (TRU) system for the manufacturers of products with high technical complexity.

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