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PRODUCTION MANAGEMENT

Practice-oriented methodology for increasing production ramp-up efficiency in global production networks of SME

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Abstract
An increasingly uncertain, customer-centric, and dynamic environment nowadays challenges manufacturing companies on a global scale. To handle this challenge, enterprises are distributing their production in global production networks. To deal with the growing demand for individualization, companies need to diversify their product portfolio. This leads to a growing number of production ramp-ups. Large companies are used to production ramp-ups on a global scale and have developed established tools and methods to optimize ramp-ups. Small and medium-sized enterprises (SME), however lack a consistent and efficient methodology to deal with global production ramp-ups. For this reason, this article presents a practice-oriented methodology for efficiently managing the production ramp-up at different production sites. The methodology consists of three elementary phases: the analysis of the target system and relevant influencing factors, the planning of different phases in the production ramp-up, and the integration of a disruption management model to robustly control ongoing production ramp-ups. For testing its practical suitability, the procedure is exemplarily applied to the production ramp-up of a device for engine management in the automotive supplier market at different sites worldwide.

Keywords Global production network · Ramp-up · Small and medium-sized enterprise

1 Introduction

Production in global production networks (GPN) is playing an increasingly important role in the context of intensifying worldwide competition and accelerated globalization of sales and procurement markets. This has resulted in GPN characterized by diverse supply and service interdependencies between individual internal company locations and locations of external players such as suppliers and customers [1].

To remain competitive and to be able to respond to individual customer requirements, companies must constantly develop their products and services further [2]. This means that companies are forced to start the production of new products at invariably shorter intervals and to make corresponding adjustments in their production network [3]. Due to diverging target systems integrating e.g. time, costs, quality, complexity, and uncertainty, the production ramp-up represents a critical phase in the life cycle of a product [2]. Accordingly, the ability to introduce products within the given time, cost, and quality framework becomes a decisive competitive advantage [4]. Practitioners often fail certain targets during production ramp-ups due to the complexity of the task [5].

The duration influences the success of the ramp-up since earlier market entry can lead to high prices compared to competitors. In addition to the profits lost due to ramp-up delays, the direct ramp-up costs are also relevant for a successful ramp-up [6]. Inefficiencies in the ramp-up process should therefore be avoided despite its complexity [3]. On average, direct ramp-up costs account for around 20% of the investments in buildings and equipment made by enterprises [7]. They are incurred for the training of newly hired employees, for building up additional safety stocks to maintain delivery readiness, or for new operating equipment [5]. The reasons for the large differences in production ramp-up costs, times, and qualities between companies in different industries are mainly due to the complexity and management of the ramp-up process so that companies with extensive

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experience in ramping-up can achieve significant benefits [6].

If a production ramp-up takes place in an enterprise with more than one production plant, further challenges arise due to the dynamics as a result of the mutual influences between the production plants and the supplier relationships [8]. This results in new global influencing factors for the production ramp-up in networks. Furthermore, different production plants in GPN have different cultural, process or product influences which need to be considered when managing production ramp-ups [5]. Currently, there is no methodology for efficiently managing the production ramp-up parallel at different production plants that integrates analysis of the above-mentioned aspects of the target system, influencing factors, and the planning and control of production ramp-ups in GPN. Therefore, this paper introduces a practice-oriented methodology for the efficient management of production ramp-ups in GPN.

2 Fundamentals

Products are provided by GPN which uses specific resources and competencies of distributed production plants [1]. The structure of a GPN is defined by open-ended edges and nodes. Nodes represent different production sites, related suppliers and customers. The edges are connections between the sites and can imply material, information, or financial flows [9]. The environment of GPN is typically dynamic and complex. The above-mentioned perspective distinguishes GPN from common supply chains which focus on the step-by-step provision of industrial goods [1].

A specific stage in the product life cycle of each product is the unique ramp-up of production. It is characterized as the stage between product development and series production. In comparison to the following series production, the production ramp-up has characteristic features that must be considered during management. Due to the degree of novelty of product and process as well as the lack of experience, especially in SMEs, more errors occur in the production ramp-up than in stable series production [10]. For this reason, it may be necessary to interrupt production frequently to rectify the problems that occur. Hence, there are greater uncertainties and thus more risks during production ramp-up. The production ramp-up can be divided into three phases (see Fig. 1) [11].

Before the actual start of production (SOP), the pre-series and pilot series take place. In the pre-series, the initial production of larger quantities is an attempt to bring production closer to series conditions [11]. The aim is to obtain information on the optimal design of the production process itself, as well as on the tools and machines used [12]. In the pilot series, production is as close as possible to series production conditions for the first time. This means that only series tools are used in a pilot series and that the procurement of all materials and parts also corresponds to the later series conditions. The pilot production aims to check whether the planned production process can continue to be carried out without problems under series production conditions and ultimately produce a product of required quality. Once the trial runs of the series production in pre-series and pilot series have been completed and the identified potential for improvement has been implemented, the actual production for the market begins. The phase after SOP, which aims at reaching the planned production quantity is called production run-up. During the run-up, the company needs to identify and eliminate possible problems and malfunctions in production at an early stage to achieve a stable production process with the previously defined quality level in the shortest possible time [11].

Production ramp-ups in GPN are influenced by external factors and their uncertain future developments. They are influenced, for example, by cultural or political factors that differ between different production sites in a GPN [1]. One methodology to support decisions in an uncertain environment is the scenario technique. The scenario technique is based on the principles of interlinked thinking and multiple futures. The principle of interlinked thinking focuses on the analysis of the interlinkage of external influencing factors. The principle of multiple futures develops visions of the future based on the development paths of these influencing factors [13].

Production ramp-ups can be categorized as projects due to the defined start and endpoint, the measurement of time, cost, and quality, and their measure: the degree of fulfilment, or the efficiency [2]. A project is defined as an "initiative that is characterized by the uniqueness of its conditions as a whole". For ramp-ups, necessary conditions are external influencing factors, but also restrictions on personnel and cost [3]. Therefore, ramp-up management can be described as project management which is defined as "all leadership tasks, organization, techniques, and means that are necessary

Fig. 1 Phases in industrial production

for the initiation, definition, planning, steering and completion of projects" [4].

During production ramp-ups, several tasks in the field of planning and managing are necessary. These tasks are combined with to term "management of production ramp-ups" [14]. For the successful fulfilment of the tasks, processes are defined where disruptions might occur. Disruptions are deviations from the target state of a system or a project [15]. In disruption management, one differentiates predictive and reactive disruption management. While predictive disruption management aims to minimize the occurrence of disturbances in advance, reactive disruption management takes place when a disruption already occurred. [5]

3 Literature review

In the following section, existing approaches concerning ramp-up management in GPN are presented.

Surbier et al. give an overview of the international state of research on the topic of the production ramp-up. They claim that the approaches in the literature are mostly only research studies or field studies, as ramp-up management is still a young field of research. Few studies contain quantitative models that describe the system behaviour utilizing key performance indicators [6]. However, different authors have identified key performance indicators related to the ramp-up [8, 16, 17]. The further work of Surbier et al. deals with the exchange of information between the stakeholders of the ramp-up process. Utilizing a model for analysing the interfaces between the stakeholders: "research and development", "production", "purchasing and procurement", "quality" and "factory management", during the ramp-up process the information flows can be examined for weak points and possible improvements [18]. Di Benedetto looks at strategic, tactical, and information-related activities that influence the success of a new product launch. His survey of individual activities of past product launches in companies concludes that successful product launches have been achieved by cross-functional teams from marketing, production, and logistics [19]. Quick and Renner present aims and corresponding key performance indicators for the ramp-up in supply chains, whereby supply chain aims are assigned to the ramp-up goals according to the SCOR model and are thus implicitly considered by the ramp-up goals [14]. Renner conceives a guideline for the development of a ramp-up-specific "Performance Management System", considers the influencing factors of the production ramp-up and categorizes them in complexity and novelty of products and processes as well as dynamic aspects. Influencing factors in global production networks are not explicitly addressed so that their possible target effects are not considered. For example, it remains open which product- and production-related factors are of particular relevance according to the location factors at a particular production site. Further, the research does not focus on the extent to which the complexity and novelty of products and processes exist at globally distributed locations due to corresponding site-specific production adjustments, relevant stakeholders, and different location roles or strategies [20]. Ulrich aims for the goal of developing a methodical procedure for the targeted handling of disturbances in the production ramp-up. For the targeted use of measures, he designs a comprehensive characterization of disturbances related to the categories "disturbance objects", "types", "locations", and "causes". Their characteristics are further refined and described. However, they are not considered in the course of the model development. It is a toolbox that contains a multitude of methods for dealing with disturbances. Within this toolbox, the individual methods are assigned to the different phases of disturbance management. The author describes the individual methods in detail. However, it remains unclear how these methods have to be applied and to what extent they are helpful in practice. A validation by experts and an implementation in a software demonstrator are missing [21].

The aforementioned approaches show that the management of production ramp-ups is a relevant field in the context of global production research. In practice, there are many company-specific procedures for managing production ramp-ups which often miss a methodological support. Therefore, an integrated consideration of the target system, influencing factors, and the management of production ramp-ups with a focus on SMEs lacks in research and practice.

4 Methodology for an efficient production ramp-up in GPN of SME

The following chapter describes a practice-oriented methodology for an efficient production ramp-up in GPN of SME. The focus of the approach is the straightforward and integrated consideration of aims, influencing factors, and the management of production ramp-ups. The methodology is divided into three steps which are inspired by classical project management [22]: First, the analysis of the target system and influencing factors of the considered ramp-up; second, the in-detail planning of relevant tasks during the ramp-up integrating the setting of milestones and a project plan; third, the integration of a disturbance management model to handle disruptions in the ramp-up ensuring a successful realization of the ramp-up project (see Fig. 2).

4.1 Analysis of target system and influencing factors

The aim of the first phase of the presented methodology is the analysis of the target system and relevant influencing factors of production ramp-ups in GPN.

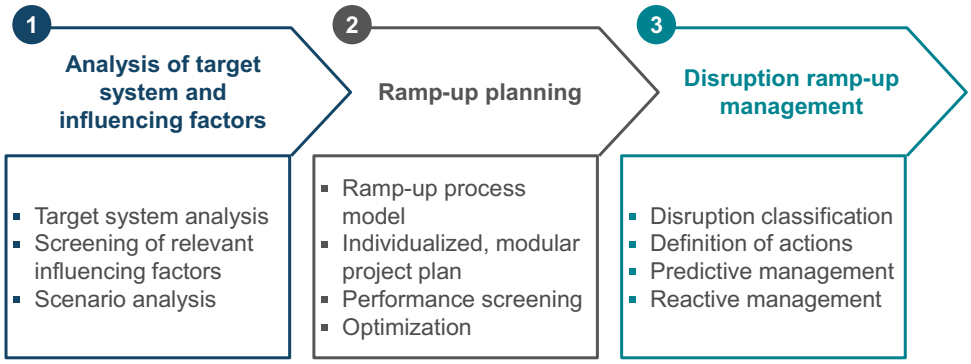

Fig. 2 Overview of the methodology for efficient production ramp-ups in GPN

To efficiently design production ramp-ups, both the knowledge of all methodical and content-related targets of the ramp-up and suitable key performance indicators for monitoring, are necessary. Based on an extensive literature review and expert workshops, seven six targets were identified. Despite the three classical targets cost, quality, and time, flexibility, risk and sustainability were also identified. For each of these targets, suitable key performance indicators were identified. In total, 45 key performance indicators were developed and can be used for measuring the efficiency of ramp-ups. The targets can be individually hierarchized with the help of an Analytical Hierarchy Process (AHP). Hence, a company-specific target system is generated.

Second, classical influencing factors of global production were identified based on a comprehensive literature review. These are generally divided into the subject areas "network factors (displayed in Fig. 3)", "location factors", "product and production-relevant process factors", "production adjustments", "plant roles and stakeholders" in general. The influencing factors are relevant for the network, plant, process, and product level. Each factor has different influences on the production ramp-up depending on the ramp-up itself. In total, 33 key influencing factors were identified. These factors are displayed in the following excerpt of a morphological box (see Fig. 3). They help SME by structuring their production ramp-up and enable them to gain a deeper insight into relevant factors. The full list of relevant key influencing factors can be found in the Appendix 1.

Thus, companies can carry out a self-assessment to estimate how complex the considered production ramp-up is. This is called the influence profile of the production ramp-up.

These key influencing factors are the basis for the scenario analysis based on Gausemeier and Fink [13]. In the first step, the scenario preparation, the objective of the production ramp-up has to be determined. It is determined by the target system. In the second step, the design field, relevant influencing factors are identified. The influence profile is used for this step as only influencing factors with a high complexity are considered. During the third step, future projections of the influencing factors are generated and combined into consistent scenarios [13].

Area	Influencing factor	Specifications		
		Low complexity		High complexity
Network	Value-added stage	Second Tier Supplier	First Tier Supplier	OEM
	Industry	Automotive (Fuel Engine)	Machinery and Equipment	Automotive (e-mobility)
	Plant role	Offshore Factory Outpost Factory	Server Factory Source Factory	Lead Factory Contributor Factory
	Network strategy	Process-oriented	Product-oriented	Market-oriented

Fig. 3 Excerpt of the morphological box of key influencing factors

4.2 Ramp-up planning

The second phase of the methodology for efficient production ramp-ups in GPN aims to create a detailed plan for the ramp-up project and to connect it with the target system and the key influencing factors.

Production ramp-ups consist of a large number of complex and interdependent processes. A decisive challenge companies are facing during production ramp-ups is the planning, organization, and control of these processes. Despite their high complexity, ramp-up projects have common features that enable the development and use of ramp-up reference processes. A ramp-up reference process is a transparent description of the chronological and logical sequence of processes, sub-processes, and milestones as well as the responsible functional areas of a production ramp-up. The ramp-up reference process aims to map the processes in a holistic and generally valid way. It therefore represents a modularly adaptable and reusable template for a large number of ramp-ups to derive specific ramp-up processes.

At the top level of the ramp-up reference process, the most important functional areas of a manufacturing company are human resources, research & development, factory planning, production, logistics, procurement and purchasing as well as marketing & sales. A detailed explanation of the ramp-up reference process can be found in the Appendix 2.

A total of 28 processes is assigned to these seven functional areas on the second level. They cover the entire product development process and thus ensure a holistic view of the production ramp-up. The respective processes are displayed clearly in the form of arrows in chronological order. However, to be able to exactly define the start and end time of a process, the start date and the process duration must be defined for this process within the framework of a specific ramp-up project. If possible, the immediate predecessor process of the process must also be determined. For example, the immediate predecessor of the recruitment process is "headcount planning". This means that the recruitment process can only be started after the planning of personnel requirements has been completed. It is important to also determine the predecessor process, since this may affect the start date of the process. The longest process sequence, in which each process has an immediate predecessor and there are no breaks between processes, is called the critical path in project management. The delay of a ramp-up process in a critical path results in the postponement of the entire production ramp-up. If the immediate predecessors of the different processes and thus also the critical path is known, such a delay of the production start can be detected early and counteracted.

On a third level of the ramp-up reference process, further detailing is possible by assigning additional sub-processes and interfaces to external actors to the individual processes. For reasons of clarity, a maximum of three sub-processes and a possible interface to external actors are assigned to each process. Therefore, the identified sub-processes only represent a selection of all possible sub-processes of a ramp-up. To illustrate the relationships just described, Fig. 4 shows the "Personnel Requirements Planning" process with the three sub-processes "Diagnostic Phase", "Forecast Phase", "Action Phase". The diagnostic phase is used to determine the current headcount. In the subsequent forecast phase, the future headcount is forecasted. The actions of the personnel acquisition are then determined in the action phase. All relevant tasks are displayed in the description of the sub-processes.

Milestones are introduced as part of the ramp-up process planning to be able to evaluate the progress of the project

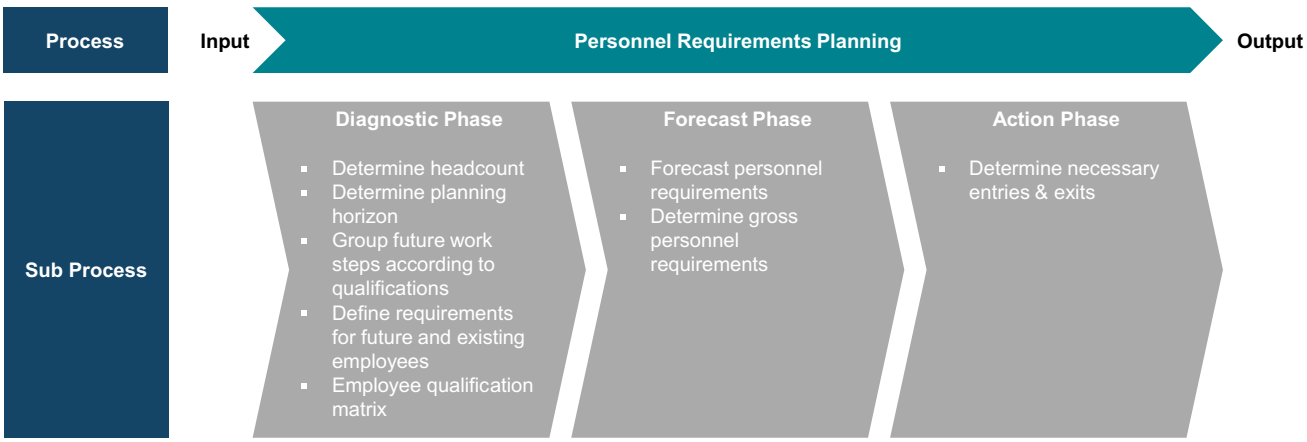

Fig. 4 Exemplary process "Personnel Requirements Planning" with sub-processes

and the synchronous progress of the parties involved at a later stage and to thus be able to make decisions on how to proceed.

The key influencing indicators can now be mapped individually to the sub-processes of the ramp-up reference process. With the help of the relevance profile of the overall ramp-up, each process is checked regarding an influence. The ramp-up manager gets an easy overview of each relevant external factor for the different ramp-up processes which helps steer the ramp-up efficiently.

The processes are integrated into a project management chart (see Sect. 5, Fig. 6). The chart is completely modular for the user and can be individualized. Further, the identified target system is implemented in the chart. For optimization purposes, the shortest-path method is integrated as the main target regarding time [23, 24]. For SME, time is the most decisive factor of production ramp-ups due to resource commitment [3]. Other targets can also be displayed in the project management chart for performance screening purposes.

4.3 Disruption ramp-up management

The last phase of the practice-oriented methodology for efficient production ramp-ups in GPN of SME aims at integrating a disruption management approach to the planning of ramp-ups. With disruption management, the control of ongoing ramp-ups is enabled.

The categorization of disruptions is based on the 5M of the Ishikawa diagram [25]. The Ishikawa diagram is widely used and is therefore suitable for usage in SMEs. The 5M are specified for the production ramp-up as man, machine, material, process (method), environment (measurement). All possible root-causes of disruptions can be displayed in the Ishikawa diagram. A detailed description of possible disruptions is made for each root-cause. 58 possible disruptions are identified by literature review and complemented by expert workshops. They are categorized and can be found in the Appendix 3.

The production ramp-up at a new production plant is a challenge, especially for SMEs. They often lack experience and knowledge they can rely on [21]. If disruptions occur during the production ramp-up, these must be dealt with as quickly as possible by action measures to correct the deviations from the plan and to not jeopardize the successful implementation of the ramp-up. The derivation of suitable measures is a decision-making process which, against the background of the lack of experience, takes too long depending on the disruptive situations in SME [11]. To accelerate this decision-making process, the methodology, based on the designed categorization system, includes more than 200 reactive and action measures. The reactive and action or preventive measures can be found in the Appendix 4.

To clarify disruptions and measure, an example is given in the following: a disruption occurs during a production ramp-up due to poor quality of the delivered components. The cause for this lies at the supplier site. According to the categorization system, "quality" is the decisive factor. For this disturbance, the following reactive action measures are defined and can be selected by the company: supplier support by experts of the company, definition of a standardized test procedure for quality control, carrying out initial audits, let suppliers develop measures to eliminate the weaknesses (e.g. increase process reliability, improve quality control), follow-up review or audit to check the implementation of measures. For predictive purposes, several action measures are defined to minimize the happening of disturbances during production ramp-up.

All modules of the methodology are implemented in a software demonstrator for SME based on Microsoft Excel. With the help of the demonstrator, the SME can take advantage of the knowledge and the processes of the methodology. Hence, an efficient production ramp-up for SMEs is prepared.

For demonstration purposes, the KPI “Overall Equipment Effectiveness” is at the center of analysis in the displayed case coming from the target system. Relevant milestones are defined, KPIs are updated and mapped, influencing factors are tracked and disturbances are integrated (see Fig. 5).

5 Application to industrial use case

The methodology for efficient production ramp-ups in GPN has exemplary been applied to a company in the automotive supplier industry. The production program of the company includes different engine management systems. The GPN consists of three production sites located in Europe, Asia, and Central America. The network strategy can be described as market-oriented. Each product is manufactured at only one production site. Therefore, there is no internal movement of parts in the GPN and no fragmentation of value creation. For the production ramp-up, a product for middle-class engine management is focused. It is manufactured in the production plant in Central America. The production plant in Central America can be categorized as a lead plant.

In the course of phase one, the target system was hierarchized. For the enterprise, the most important target when launching the product is to meet the specified product quality. Deviations in quality cannot be tolerated because customers do not accept them. For tracking, the enterprise used the following KPI:

Fig. 5 Software demonstrator for efficient production ramp-ups in GPN

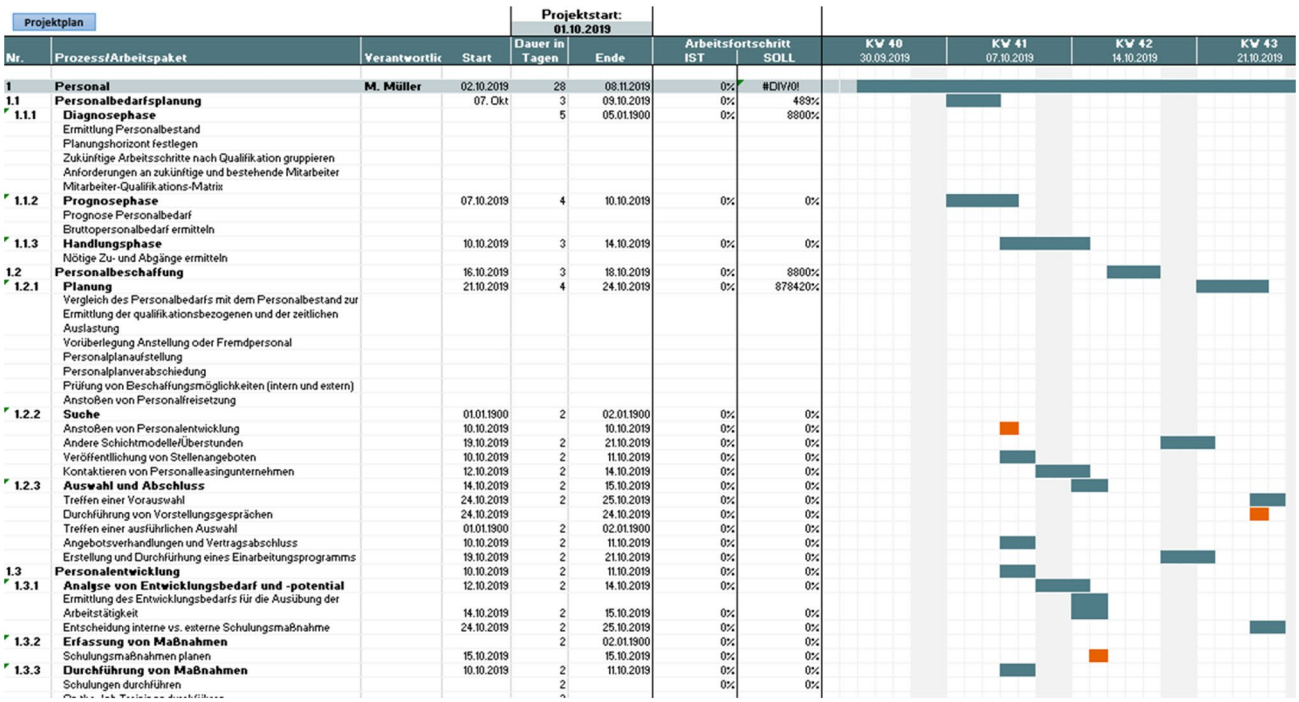

Fig. 6 Excerpt of the production ramp-up process model from the SME

$$Fulfillmentofinternalqualityrequirements = \frac{Numberofinternalgoodparts}{Totalnumberofmanufacturedparts} \times 100\% \quad (1)$$

The requirement of product quality is closely followed by the time requirement. The company has made precise framework agreements with the customers as to which product quantities are to be delivered and at what times. Since the customers' production systems are based on just-in-time principles, the company risks high contractual penalties and consequently high financial losses if the delivery is too late due to a slow ramp-up. For internal tracking, the enterprise used the following KPI:

$$Rampuptime = Totaltimefromprojectstarttocurrentstatus \quad (2)$$

Additionally, the third important requirement is efficient supplier management. The reason for this is that the availability of parts from a supplier is one of the biggest challenges and one of the main reasons for delays in the start of production of engine management products. Precisely, those delays have to be avoided due to the strict time requirements of the customers. For the tracking, the enterprise used the following KPI:

$$Outgoingontimerate = \frac{Numberofontimedeliveriesofproducts}{Totalnumberofdeliveries} \times 100\% \quad (3)$$

The qualification level of the employees in Central America was defined as most important influencing factor. As the new product was very complex in structure and production processes, there was a need for higher qualified employees. The first line construction and the pre-acceptance of the line took place in Central America. During this pre-acceptance, experts from the headquarters came to the location in Central America to inspect the machines and to test the process capability. During the pre-acceptance, the qualification of the later factory functions and line workers also took place as a result of the influencing factors of the ramp-up (see Sect. 4). During the first pre-acceptance, many process errors still occurred and the required quality and cycle time were generally not yet achieved at the individual machines and production stations. These problems, as well as the visible process improvements and bug fixes, enabled workers to develop a good understanding of the process at an early stage. Through this understanding of the processes, the workers can later pay closer attention to possible sources of error that they have already observed during the creation and rectification and avoid them. Due to this early qualification of the workers during commissioning and process analysis, the later error rate in the ramp-up and serial production decreases. This results in a higher quality level. A scenario analysis was not conducted by the enterprise due to time limitations.

In the second phase, the production ramp-up was planned in detail. Due to the knowledge of the employee qualification, the time of the respective process was estimated precisely. An excerpt of the production ramp-up process model is displayed in Fig. 6. An in-detail view of the specific processes is not possible due to confidentiality reasons.

In the last phase, the ramp-up disturbance model was used to control the production ramp-up in Central America. As displayed in the disturbance management chart in Fig. 7, one can see a transparent overview of the actual number of not solved (open) disturbances and the total number of disturbances. The chart helps the ramp-up manager to track the pain points of the ramp-up project.

One exemplary disturbance was the failure of a supplier due to financial reasons. The developed model recommended not to rely on single sourcing which was implemented by the SME before the ramp-up based on the disturbance catalogue (see Appendices 3 and 4) as a preventive method. This led to the efficient handling of the disturbance. Obtaining more than one supplier primarily results in greater independence from any delivery difficulties and greater flexibility in the event of fluctuating or increasing order quantities. Also, independence from individual suppliers creates a better negotiating position due to competitive pressure among suppliers. Above all, a high level of delivery security is crucial for an efficient and secure implementation of the production ramp-up. Since delivery problems can also arise from suppliers, especially in the early phases of the ramp-up, single

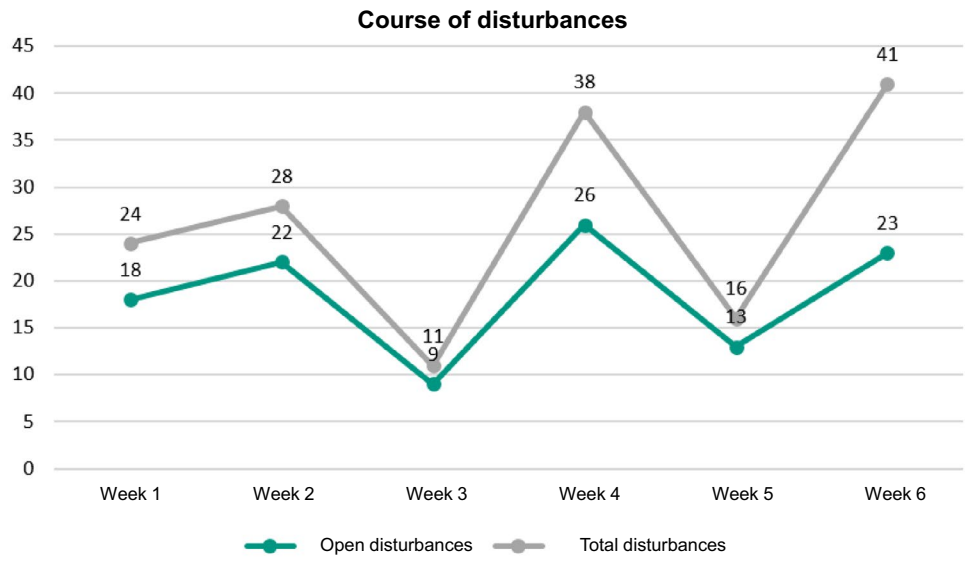

Fig. 7 Course of disturbances of the exemplary ramp-up

sourcing should be avoided as far as possible in favor of greater flexibility.

With the help of the disturbance management model and the integrated charts, the ramp-up was 16.9% ahead of the calculated time which leads to an early market entry of the engine management product and it was based on the high-quality database for disruption management and the solid planning process. Further, the quality and the supplier base were solid and led to an efficient production ramp-up regarding the overall target system.

6 Conclusion

This paper presents a practice-oriented methodology for efficient production ramp-ups in GPN of SMEs. The methodology is divided into three phases: analysis of the target system and influencing factors, ramp-up planning, and ramp-up disturbance management. The novelty of the methodology lies in the integrated consideration of target systems, internal and external factors, and operative ramp-up management. The method was successfully applied to a production ramp-up of engine management systems at a production site in Central America. In the use case, the target system and the in-depth analysis of the influencing factors helped to estimate the effort of a new production ramp-up before the ramp-up. Further, the actions of the disturbance management speeded up the internal processes during the ramp-up. Overall, the production ramp-up was 16.9% ahead of the proposed time which was a success for the company. A possible extension of the model could include the series planning phase before the ramp-up and the transition to the later series production phase to achieve a more efficient complete product lifecycle. Furthermore, one can adapt recent research focusing on an integrative KPI network for ramp-up purposes [26].

Appendix

Key influencing factors

Area	Influencing factor	Specification					
		Low complexity		Mid complexity		High complexity	
Network	Value-added stage	2nd tier Supplier	0.3	1st tier Supplier	0.7	OEM	1
	Industry	Automotive (conventional)	0.3	Mechanical and plant engineering	0.7	Automotive (electrical drives)	1
	Plant role	Process-oriented	0.3	Product-oriented	0.7	Marked-oriented	1
	Network strategy	Offshore/outpost	0.3	Server/source	0.7	Lead/contributor	1
Location	Novelty	Existing	0.3	Adjusted	0.7	New	1
	Cluster	Germania Europa	0	East-Europe	0.3	Confucian Asia	1
				Latin America	0.7		
	Availability and quality of infrastructure	High	0.3	Middle	0.7	Low	1
	Mother location time difference	Very low (0–1 h)	0	Middle (5–7 h)	0.7	High (< 7 h)	1
		Low (2–4 h)	0.3				
	Distance to value-creation partners	Low	0.3	Middle	0.7	High	1
	Geographic and climate influences	No	0	Middle	0.7	High	1
		Low	0.3				
	Culture and mentality	Very similar	0,3	Partially different	0.7	Very different	1
	Skilled Workforce	High	0.3	Middle	0.7	Low	1
	Employee turnover	Low (fluctuation rate < 7%)	0.3	Middle (fluctuation rate 7–15%)	0.7	High (fluctuation rate > 15%)	1
	Local partners	Yes	0			No	1
	Business friendliness of a country	High (ease of doing business rank < 50)	0.3	Middle (ease of doing business rank 50–100)	0.7	Low (ease of doing business rank > 100)	1
	Trade barriers	Low	0.3	Middle	0.7	High	1

Area	Influencing factor	Specification					
		Low complexity		Mid complexity		High complexity	
	Protection of intellectual property	High (international property rights rank < 50)	0.3	Middle (international property rights rank 50–100)	0.7	Low (international property rights rank > 100)	1
	Legal and political stability	High (rule of law rank < 50)	0.3	Middle (rule of law rank 50–100)	0.7	Low (rule of law rank > 100)	1
Process	Novelty	Existing	0.3	Adjusted	0.7	New	1
	Novelty of suppliers and infrastructure	Existing	0.3	Adjusted	0.7	New	1
	Personnel novelty	Predominantly existing employees with experience	0			Many new employees with little experience	1
	Complexity	Low	0.3	Middle	0.7	High	1
	Number and variety of suppliers	Low	0.3	Middle	0.7	High	1
	Test environment	Serial line	0.3	Pilot line in main location	0.7	Pilot line in separate location	1
	Degree of automation	Low	0.3	Middle	0.7	High	1
	Productivity	High	0.3	Middle	0.7	Low	1
	Economies of scale	High	0.3	Middle	0.7	Low	1
	Ramp-up frequency	High (several times per year)	0.3	Middle (every 1–3 years)	0.7	Low (less frequent then 3 years)	1
Product	Novelty	Existing	0.3	Adjusted	0.7	New	1
	Complexity as a whole	Low	0.3	Middle	0.7	High	1
	Complexity of supply parts	Low	0.3	Middle	0.7	High	1
	Number of parts on line	Low	0.3	Middle	0.7	High	1
	Lifecycle	Long (> 6 years)	0.3	Middle (2–6 years)	0.7	Short (< 1 year)	1

Ramp-up planning processes

Area	Process	Phase	Work package
1. Personnel	1.1 Personnel requirements planning	1.1.1 Diagnosis	Determine headcount Determine planning horizon Group future work steps according to qualifications Define requirements for future and existing employees Employee qualification matrix
		1.1.2 Forecasting	Forecast personnel requirements Determine gross personnel requirements
		1.1.3 Action	Determine necessary entries and exits

Area	Process	Phase	Work package
	1.2 Recruitment	1.2.1 Planning	Comparison of staffing requirements with headcount to determine skill-related and time utilization Preliminary consideration of employment or external personnel Personnel plan preparation Personnel plan adoption Examination of procurement possibilities (internal and external) Initiation of personnel release
		1.2.2 Search	Triggering personnel development Other shift models/overtime Publishing job offers Contacting staff leasing companies
		1.2.3 Selection and conclusion	Making a preliminary selection Conducting interviews Making a detailed selection Negotiating offers and concluding contracts Creation and implementation of an induction program
	1.3 HR Development	1.3.1 Analysis of development needs and potential	Determination of the development needs for the performance of the work activity Decision internal vs. external training measure
		1.3.2 Recording of measures	Plan training measures
		1.3.3 Implementation of measures	Conduct trainings Conduct on the job training
2. R&D (product)	2.1 Product definition and planning	2.1.1 Idea search	
		2.1.2 Idea development and selection	
		2.1.3 Concept development	
	2.2 Product development and design	2.2.1 Product development	Define requirements (specifications + requirements specification) Product specification Construction kit definition/decision Make/buy decisions Profitability calculations
		2.2.2 Product design	Planning and organization of technical development Prototype planning
		2.2.3 Design validation	Produce technical drawings Validate product designs internally and externally Design freeze
	2.3 Prototyping and testing	2.3.1 A-sample	Visual prototype Proof of concept Presentation prototype Documentation prototype Testing/functional testing Quality gate/development iteration
		2.3.2 B-sample	Presentation prototype Documentation prototype Testing/functional tests Quality gate/development iteration
		2.3.3 C-sample	Presentation prototype Documentation prototype Testing/functional tests Quality gate/development iteration

Area	Process	Phase	Work package
3. Factory planning	3.1 Location check	3.1.1 Analysis of location competencies	Check site capabilities, analyze existing competencies, technology, process, supplier, knowledge, procurement, logistics, etc.
		3.1.2 Evaluation of operating resources	Current status/assessment of site role
		3.1.3 Analysis of personnel	
	3.2 Site planning	3.2.1 Review of input parameters	Rough selection of potential countries for production site Determination of the required output/capabilities at the location Review of corporate goals Comparison of objectives with corporate strategy Determination of a need for action Definition of the site role (offshore factory, …) Determination of required competencies and technologies at the site Derive need for change until ramp-up Define requirements for legal security, ease of doing business and know-how protection
		3.2.2 Development of the site strategy	Evaluation of the new site in the overall network (analysis of product, process and network structure and formation of clusters)
		3.2.3 Systematic site selection	Comparison of requirements profile and actual profile of potential sites/site evaluation Rough selection of sites Creation of requirement profiles Search for potential sites Evaluation at regional, country and local level Qualitative and quantitative evaluation of alternatives Decision for location
	3.3 Building planning and realization (extension or new planning)	3.3.1 Structural planning, building planning	
		3.3.2 Building realization	
		3.3.3 Technical building equipment	
	3.4 Area and layout planning	3.4.1 Rough planning	Structural design Rough planning Ideal planning
		3.4.2 Detailed planning	Real planning Space requirements planning Layout optimization Detailed layout planning Layout optimization
4. Production (processes)	4.1 Production process planning, production concept	4.1.1 Production concept planning	Scheduling Planning and determination of production principle (e.g. workshop production, flow production) Determination of the degree of automation
		4.1.2 Production process planning	Capacity allocation planning/sequence planning
		4.1.3 Material provision planning	Determine material staging concept

Area	Process	Phase	Work package
	4.2 Production planning and control	4.2.1 Production requirements planning	Determination of the required production input factors (material, employees, energy, information)
		4.2.2 Deadline and capacity planning	Determination of output factors (quantity, type, time) Derivation of the capacity requirements
		4.2.3 Order release and production control	Order release Production control
	4.3 Equipment planning, procurement and production (equipment, tools and test equipment)	4.3.1 Resource planning	Information planning Resource planning Material planning
		4.3.2 Procurement/production of operating resources	Material procurement Procurement of operating resources Production of operating resources (molds, tools, etc.) Plant engineering
		4.3.3 Production equipment setup	Plant internal transport Plant layout Plant removal
	4.4 Testing and commissioning (processes, equipment, tools, …)	4.4.1 Preparation of process tests	Definition of the process requirements Assessment of the working conditions Identification and assessment of hazards associated with testing Selection and definition of technical protective measures Preparation of operating instructions Selection of qualified personnel Instruction of employees/qualification and selection of employees Implementation of planned protective measures Planning of process testing
		4.4.2 Execution of process tests	Comparison of actual/target cycle time Comparison of actual/target quality Derivation of improvement measures Process approvals (machine capability, production parameters, safety)
		4.4.3 Start-up	
	4.5 Pilot series (pre-series and pilot series)	4.5.1 Pre-series	Construction of pilot line Adaptation of machines and equipment Training of personnel pilot series
		4.5.2 Zero series	Functional tests (equipment Functional tests (material) Load tests (material) Load tests (equipment) Evaluation of the pilot series
		4.5.3 Release by the customer	Production acceptance by the customer (PPAP)
	4.6 Production ramp-up	4.6.1 Preparation for start of production ramp-up	Preparation for transfer of responsibility to series production management Continuous updating of production program
		4.6.4 Execution of the production ramp-up	Job 1 (first customer-ready product) Increase of output (quantity and quality)
		4.6.3 Control of the production ramp-up	Process monitoring and implementation of any adjustments Ridge line reached and target quality met

Area	Process	Phase	Work package
	4.7 Secured production	4.7.1 Documentation and knowledge transfer	Evaluation of production ramp-up (processes, suppliers, planning deviations) Transfer of responsibility to series production management
		4.7.2 Series maintenance	Adjustment of production processes (work steps, tools, machines, …)
		4.7.3 Preparation of further production starts	Interface definition of previous and future production sites (teams)
	4.8 Production optimization	4.8.1 Continuous improvement process	Define PDCA cycle Install company suggestion system for improvements
		4.8.2 Standardization	Derive process standards
5. Logistic	5.1 Warehouse planning and management	5.1.1 Warehouse planning	
		5.1.2 Warehousing	
		5.1.3 Warehouse optimization	
	5.2 Transport (planning) (external and internal)	5.2.1 Transport planning	Transportation planning Load carrier planning Packaging planning and definition of cleanliness requirements
		5.2.2 Ongoing operations	
		5.2.3 Transport optimization	
	5.3 Provisioning (-planning)	5.3.1 Deployment planning and provisioning	Provisioning planning (JIT, JIS, Milk Run, …) Disposal planning
		5.3.2Disposal planning and disposal	
6. Procurement & Purchasing	6.1 Supplier development	6.1.1 Supplier strategy	Planning sourcing concept (global vs. local, delivery frequency, …)
		6.1.2 Supplier selection	Request for proposal Creation of a supplier requirement profile Supplier audit Technical offer analysis of operating resources Supplier evaluation (qualitative) Supplier evaluation (quantitative) Negotiations Longlist with suppliers Shortlist Supplier determination
		6.1.3 Supplier enablement	
	6.2 Supplier management	Supplier monitoring and assessment Initiation of improvements at supplier sites (process reliability, quality, output quantity, delivery intervals, …) Formation of task forces for possible supply bottlenecks at suppliers	

Area	Process	Phase	Work package
	6.3 Quality management	6.3.1 Definition of quality controls	Component qualification QA/test planning Test equipment planning Definition of a quality database (including integration of suppliers)
		6.3.2 Quality controls	Process acceptance at suppliers Acceptance of supplied parts Inspections during production Calibration of test equipment Process maturity measurements Problem investigations Plant inspections Process monitoring
		6.3.3 Quality measures	Initiation of quality measures
		6.3.4 Definition of quality requirements	
	6.4 Orders	6.4.1 Ordering of sample parts 6.4.2 Ordering of test and operating equipment 6.4.3 Ordering of serial parts	
7. Marketing, Sales & Customer Service	7.1 Market Research	7.1.1 Definition and design 7.1.2 Data collection 7.1.3 Data analysis	
	7.2 Idea generation		
	7.3 Market launch	7.3.1 Identification of distribution partners 7.3.2 Communication and advertising	

Classification of disruptions

Cause	Secondary cause 1st order	Secondary cause 2nd order
Human	Availability	Absence
		Staff shortages
		Fluctuation
	Qualification	Employee qualification
		Experience level of employees
	Character	Employee motivation
		Culture and mentality
	Employee management	Synergies
		Communication
Machine	Availability	Technical availability
		Delay (machine installation/commissioning)
	Technical problems	Compatibility
		Manufacturing technology
		Quality
		Programming
Material	Availability	Material delay
		Replenishment time
		Quantity deviation
	Technical Problems	Technical product change
		Maturity
		Quality
		Complexity

Cause	Secondary cause 1st order	Secondary cause 2nd order
Process	Organization	Communication
		Data organization
		Standardization
		Unambiguity of responsibilities
	Planning	Requirements planning
		Milestone planning/maturity planning
		Budget planning
		Material planning
		Resource planning
		Personnel planning
		Production process planning
		Internal/external logistics planning
	Modifications	Product change
		Process change
Environment	Political-Legal	National legislation
		Directives, regulations and standards
		Political stability
	Ecological	Geographical and climatic influences
		Natural disasters
		Man-made disasters
	Infrastructure	Working conditions (internal)
		Transportation
		Connection
		Time difference to headquarters
	Supplier	Capacity
		Information exchange
		Supplier availability
		Quality
		Deadline delay
	Customer	Information exchange
		Product request
		Quantity change
		Logistics request
		Deadline change

Reactive measures

Cause	Secondary cause 1st order	Secondary cause 2nd order	Activities
Human	Availability	Absence	Use of qualified jumpers Creation of a "double duty roster"

Cause	Secondary cause 1st order	Secondary cause 2nd order	Activities
		Staff shortages	Use of a task force with aggregated knowledge Introduce dual function of staff (induction/training in cross-functional activities) Use external support teams Capacity adjustment through overtime Capacity adjustment through temporary workers Capacity adjustment through additional shift/short-time work Seasonal adjustment of number of staff and hours worked per employee Forecast of future demand/orders and derivation of long-term optimal working hours and number of personnel in a shift Identification of possible tender channels incl. determination of the maximum achievable number of potential applicants per channel Preparation and publication of tenders Determination of functions/positions to be filled with the help of headhunters Enhancement of the recruitment process with suitable assessment centers Creation of company-wide standardized interview guidelines
		Fluctuation	Introduce dual function of employees (familiarization/learning of cross-functional activities) Improve the hiring process (sustainable) Conduct employee survey to identify motivations Conduct feedback interview Ensure work-life balance for employees Express appreciation to employees Protect health through health promotion, including Company Cares
	Qualification	Employee qualification	Drawing up a list with an overview of all qualifications required in the individual areas (brainstorming) Informing the employees about the general qualification measures Conduct employee trainings (e.g., on facility maintenance, conduct, duties) Carry out on-the-job training during free shifts Apply individual qualification measures for employees with high potential (mentoring program etc.) Use simulation tools Provide eLearning content Conduct lessons learned workshops
		Experience level of employees	Conduct follow-up trainings Implement transparent knowledge management Conduct lessons learned workshops Determine qualified employees in all areas who are suitable to pass on professional knowledge and experience to new employees

Cause	Secondary cause 1st order	Secondary cause 2nd order	Activities
	Character	Employee motivation	Adapt Maslow's pyramid of needs to employees Introduce incentive systems for employees (in the form of rewards) Agree on performance transparently and value performance openly Encourage employees Implement information and knowledge management Conduct feedback discussions Ensure work-life balance for employees Protect health through health promotion Conduct company events
		Culture and mentality	Train management level about different cultures Offer country-specific services Communicate corporate culture (training) Offer language trainings
	Employee management	Synergies	Establish/assign responsibility Increase focus on teamwork Conduct targeted, effective feedback, criticism and performance reviews Consistently apply the appropriate leadership style in each case Establish a culture of cooperation
		Communication	Clear structure of the organizational structure in the ramp-up Clear allocation of responsibilities Addressing those responsible directly Consultation (employee-specific) Convey information/concerns in a complete, concise, understandable and structured manner
Machine	Availability	Technical availability	Implement escalation strategy Procure operating equipment through rental or repair Use replacement machines Repair Maintenance Adjust capacity by procuring/displacing equipment Check capacity of maintenance personnel and adjust if necessary Adjustment of maintenance strategy (preventive, condition-based maintenance) Identification of existing production capacities (e.g. based on the number of machine hours available) Load balancing by splitting/advancing/deferring orders FMEA Introduction of failure-reducing product planning Minimize causes of downtime (define operating specifications/work instructions, carry) Introduction of a Total-Productive-Maintenance-System
		Delay (machine installation/commissioning)	Adhere to information chain Creation of a general checklist for employee familiarization Production area-specific training and practical instruction of employees regarding the functions of the equipment Provision of the required materials and tools (at the correct workplaces) Definition of the instructions for the individual work steps incl. required materials, tools, etc. Creation of a schedule that is accessible to the employees at all times Identification and execution of prescribed tests to check all functions

Cause	Secondary cause 1st order	Secondary cause 2nd order	Activities
	Technical problems	Compatibility	Adhere to information chain Inform maintenance Targeted formulation of requirements Creation of work instructions Check process parameters and adjust if necessary Carry out system audits Use of virtual tool development Assembly of other components or objects Network integration Assign rights
		Manufacturing technology	Adhere to information chain Inform maintenance Implement escalation strategy Define the instructions for the individual work steps incl. required material, tools, etc. Execute escalation strategy Provision of test/series tools Increase capacity at bottleneck systems (e.g. by introducing additional shifts) Carrying out production tests
		Quality	Adhere to information chain Inform maintenance Implement escalation strategy Repair Maintenance Adapt maintenance plans Consider specifications and adjust if necessary Conduct audits to verify quality management Hire an experienced employee to perform audits Identify and conduct prescribed tests to verify all functions Perform stress tests Targeted control of processes in which (increased) errors were found in order to identify further sources of error Review and adapt the control methods currently used in the company Draw up concrete work instructions for the test procedures Check capacity of maintenance personnel and adjust if necessary Increase qualification of machine operators to be able to independently rectify minor faults Quality function deployment for quality assurance
		Programming	Analyze software errors Fix programming errors Check suitability of software Create evaluation reports by experts
Material	Availability	Material delay	Implement escalation strategy Consult with suppliers Draw on safety stock Introduce inventory monitoring Introduce kanban as material staging

Cause	Secondary cause 1st order	Secondary cause 2nd order	Activities
		Replenishment time	Enforce realistic deadline setting Use direct communication channels Adjust dimensioning of safety stock Include scrap rate in pilot series and production ramp-up in demand planning Select appropriate ordering policy (e.g. q,S-/s,T-policy) Internal optimization of the period between the time of notification and the time of ordering (e.g. by using an IT system) Reduce replenishment time by auditing and qualifying the supplier's internal processes Encourage suppliers to change the means of transport Identify suppliers available at short notice Reduce replenishment time by selecting suppliers with shorter delivery times
		Quantity deviation	Initiate new purchase orders Improve alignment between production and procurement through IT support (e.g. ERP/MES system) Select suitable order policy (e.g. q,S-/s,T-policy) Adjust reorder level (for stock items) Adjust safety stock (for stock items) Adjust order quantity (for stock parts) Perform laboratory tests Logging
	Technical Problems	Technical product change	Execute escalation strategy Create and use a standardized protocol for documentation Implement and monitor change management
		Maturity	Implement escalation strategy in case of urgency Distribution of responsibilities Target coordination of specifications Implement and maintain list of open points (LoP) Apply maturity assurance and analysis methods Convene regular maturity meetings
		Quality	Execute escalation strategy Block defective parts Set up error message Analyze manufacturing processes internally and externally Scrap monitoring and analysis Create missing parts list, perform missing parts search Introduce and maintain list of open points (LoP) Conduct audits to verify quality management Hire an experienced employee to carry out audits Create and work through a specific checklist for systematic inspection of goods Carry out random, irregular checks of production processes Reviewing and adapting the control methods currently used in the company Clear definition of standardized inspection procedures and processes Quality function deployment for quality assurance
		Complexity	Improve knowledge management Identify and analyze possible alternatives Introduce a flexible material flow system Drive product modularization

Cause	Secondary cause 1st order	Secondary cause 2nd order	Activities
Process	Organization	Communication	Establish clear hierarchies Investigate interfaces Implement efficient knowledge and information management Detailed documentation of information on individual processes Division and structuring of information according to production areas Define communication processes between different instances Define standardized problem reporting process Use measures for problem identification (6W questioning technique, audits, Balanced Score Card (BSC), Fault Tree Analysis (FBA)) Use reference models Expand rule communication
		Data organization	Implement efficient knowledge and information management Drive uniform IT systems Identify and implement a suitable document structure Standardize document structure and documentation concept Define and assign clear access rights Maintain and synchronize data Adapt software and hardware Check network integration Create work instructions
		Standardization	Create transparency of processes Define clear and consistent processes Process mining Compare actual state and target state Standardization of basic data (material master data, routings, …) Documentation of standardization in flow chart Apply critical chain project management
		Unambiguity of responsibilities	Clear distribution and increase in transparency of responsibilities Addressing unresolved responsibilities Conduct clarifying discussions with employees Regular review of employees' know-how with regard to their area of responsibility and adjacent areas Problem and interface characterization Adjustment of the start-up-specific structural and procedural organization
	Planning	Requirements planning	Revise unclear requirements Identification of the importance and target achievement of the requirements Creation of a standardized requirements specification Standardized, detailed documentation of the requirements in requirement specifications Creation of a checklist and tracking of requirements with the help of the checklist Digitization of the requirements Load balancing by splitting/advancing/deferring jobs Perform benchmarking Process audits Use Six Sigma

Cause	Secondary cause 1st order	Secondary cause 2nd order	Activities
		Milestone planning/ maturity planning	Conduct regular maturity meetings Maturity assurance Formulate quality gates Use buffers Create a checklist and track requirements using the checklist Introduction of a list of open points (LoP) Quantification of target values on the basis of a planning forecast Determine procedure for project documentation Process visualization (ProVis) Carry out performance measurement Introduce cumulative quantity concept
		Budget planning	Educate about business contexts Link goals and measures Carry out budgeting round Standardization of costing procedures Establish a standardized reporting system in production controlling
		Material planning	Revise specifications Implement information and knowledge management Adjust delivery dates if the planned start date of the associated production order is delayed/other parts are delayed Classify materials/products into A, B, and C parts
		Resource planning	Reduction/increase of production capacities Evaluation of machine and production process data Capacity planning based on historical production data and current production program planning data Lot sizing and, based on this, exact program and process planning in order to be able to fulfill all customer orders on time Load adjustment by placing/accepting orders Revision of economic, human and organizational targets
		Personnel planning	Assignment of jumpers Creation of task forces Development of the personnel information system Definition of task content and time structure Definition and detailed description of professional and nonprofessional requirements, soft skills as well as physical and mental prerequisites to cope with the tasks (requirement profiles) Carry out sales and demand forecasts & plan the exact number of employees based on these forecasts Identification of (seasonal) fluctuations in overtime that are common in the industry Adjustment of staff in a shift as well as the respective working hours Forecasting of future demand/orders and derivation of long-term optimal working hours and personnel in a shift Active sourcing
		Production process planning	Consultation with the development department Detailed identification of all functionalities of the end product Planning of all functions in all application fields of the end product when creating the prototype Determining the processing steps on the basis of the design documents Coordination of the work steps and contents Creation of comprehensible operating instructions Creation of precise work instructions Revision of the assembly sequence plan Load test Production test Use simulation tools

Cause	Secondary cause 1st order	Secondary cause 2nd order	Activities
		Internal/external logistics planning	Standardize logistics processes Examine interfaces Define clear responsibilities Determine required quantity as well as order timing, storage space requirements, supplier distance, and JIT capability from past order periods Obtain information (price, distance, reviews, etc.) on potential logistics service providers Definition of a suitable supplier portfolio based on various weighted criteria (P/L, quality, delivery time, …) Determination of possible seasonal, cyclical or other influences on warehouse dimensioning Analysis of possibilities for variable warehouse dimensioning (e.g. short-term renting or leasing of warehouses in order to expand or reduce warehouse size) Optimize warehouse organization (e.g., arrange warehouse items based on retrieval frequency) Check availability of means of transport and increase if necessary (e.g. by reducing loading times or increasing capacity by purchasing additional means of transport) Reduce warehouse access times by introducing a warehouse management system Reduce warehouse access times by installing warehouse technology with a higher degree of automation Joint identification of possible alternatives to reduce empty runs (e.g. possibilities for warehouse reduction) Standardizing the use of load carriers throughout the internal logistics and supply chain Minimization of the number of required transport routes in the layout (e.g. one main aisle with branches)
	Modifications	Product change	Use direct communication channels Use change management Define change process (change management) in flow chart Identify possible variants of the product Identify the production parts and steps to be changed for each variant Identify the individual production parts that can be standardized (common parts concept) Procurement of appropriate standard parts and use in the design process Digital mock-up
		Process change	Define change process (change management) in flow chart Inform all parties involved Initiate change of documents Identification of possible changes at each production station incl. probability of occurrence and effects in case of change Provide the appropriate measures for the employees at the respective production station Determine workflows for transition phase Project documentation Process visualization (ProVis)
Environment	Political-Legal	National legislation	Relying on external advice
		Directives, regulations, and standards	Use change management Ideal implementation of building design considering all legal requirements Identification of all relevant restrictions Introduction of the DIN EN ISO 9001 standard
		Political stability	Rely on external consulting

Cause	Secondary cause 1st order	Secondary cause 2nd order	Activities
	Ecological	Geographical and climatic influences	Adapt stock keeping Support flexible deployment (machine/employee)
		Natural disasters	Implement emergency plan Use time buffer
		Man-made disasters	Implement emergency plan Use time buffer
	Infrastructure	Working conditions (internal)	Addressing employee needs (depending on culture) Country-specific adaptation of the workplace Ergonomic adaptation Safety-related adaptation Additional equipment Exchange with employees
		Transportation	Search for alternative ways Communicate close suppliers
		Connection	Analysis of new opportunities Definition of essential target criteria (location factors) regarding the optimal location of the company
		Time difference to headquarters	Agree on communication channels and times Define clear responsibilities
	Supplier	Capacity	Supplier support by experts of the company Have suppliers develop measures to eliminate weaknesses Risk analysis Notify second supplier Use alternative area
		Information exchange	Deposit of the correct contact person (incl. contact data) for all suppliers and for each order item Define uniform processes Consider global language barriers Service interface agreements Recording the frequency and type of information exchange using the SIT table Complete synchronization of the IT systems of all suppliers with regard to orders, contact, planning and development
		Supplier availability	Use safety stock Perform market analysis Weigh and weight according to various criteria Obtain quotations from new suppliers regarding procurement items and compare with costs and qualities of current suppliers; change supplier if better price/performance ratio Identification of the suppliers who take a date-critical role and contractual definition over flexibility regarding the critical factor (delivery quantities, delivery duration, replacement time)

Cause	Secondary cause 1st order	Secondary cause 2nd order	Activities
		Quality	Supplier support by experts of the company Training of own employees as well as supplier employees Company-wide documentation of processes to identify parts/components that are critical to success and susceptible to failure Definition of a standardized test procedure for quality control Carrying out initial audits, e.g. in two consecutive periods, and possible re-certification before expiry of the certificate for renewal Surveillance audits to prove that the certified supplier continues to meet the requirements Regular control of the validity of the certificates of the suppliers Conduct audit/review at the supplier's site and analyze weaknesses Point out deficiencies to suppliers in a personal meeting Have suppliers develop measures to eliminate weaknesses (e.g., increase process reliability, improve quality control, Poka Yoke, design for assembly) Reduce the number of complaints (e.g., reduce damage during transport by improving transport security, reduce errors in picking by introducing labels, partially automated picking systems (pick by light, pick by voice)) Follow-up review/audit to check implementation of measures Define standardized complaints process Introduce list of open points (LoP)
		Deadline delay	Determine team with responsible persons Bring all parties to the table (round tables) Problem solving (5W) Communicate requirements to suppliers and disclose consequences of non-compliance Conduct audit/review at supplier's site and analyze weaknesses Point out deficiencies to suppliers in a face-to-face meeting Introduction of partially automated picking systems (e.g., pick by light, pick by voice, light barriers) Follow-up review/audit to check the implementation of measures
	Customer	Information exchange	Clarify responsibilities on both sides Escalation with participants from both sides Round tables (interdisciplinary teams of experts) Define uniform (complaint) processes Consider global language barriers Establish service interface agreements
		Product request	Document requirements clearly Carry out product audit Consultation with development regarding feasibility Ongoing exchange of information Introduction of DIN EN ISO 9001 standard
		Quantity change	Use change management Document change Information management Adjust reorder point (for stock items) Adjust safety stock (for stock items) Adjust order quantity (for stock items)
		Logistics request	Ongoing exchange of information Clarify feasibility
		Deadline change	Escalate Determine team with responsible parties Bring all parties to the table (round tables) Problem solving (5W) Ongoing exchange of information Show alternatives

Preventive measures

Cause	Secondary cause 1st order	Secondary cause 2nd order	Preventive measure
Human	Availability	Absence	Scheduling of qualified jumpers Scheduling of flexible working hours Hiring of employees according to specific requirements regarding working hours (seasonal effects) Extension of the recruitment process by suitable assessment centers
		Staff shortages	Scheduling staff availability at new locations Hiring loyal and sustainable employees Train employees to perform multiple tasks (floaters) Determine deployment schedule Consider seasonal effects during scheduling
		Fluctuation	Hire loyal and sustainable employees Integration of employees before the first day Employee-oriented management (contracts, flexible working hours, motivation through bonuses and offers (sports, discounts)) Ensure work-life balance Conduct regular interviews to get feedback
	Qualification	Employee qualification	Hiring qualified/trained employees Hiring competent/learning employees Planning regular training (face-to-face, e-learning, language courses) Offer training programs Special programs for job entrants, interns, etc Consideration of country-specific level of education Level of experience of employees
		Experience level of employees	Consideration of the country-specific level of education Lessons learned workshops Group and individual training/instruction Awareness of their efforts
	Character	Employee motivation	Health protection through health promotion, also company cares Build trust and respect Examine country-specific characteristics Goal setting Appropriate job design Regular coaching Planning regular training (face-to-face, e-learning, language courses)
		Culture and mentality	Consider country-specific working conditions (breaks) Communicate corporate culture (training) Schedule experienced managers/employees Offer language and culture courses
	Employee management	Synergies	Pleasant working atmosphere Clear formulation of goals Clear responsibilities Schedule employee meetings Cost-effectiveness calculation of teamwork (ratio of effort and result) Consider team composition Work retreats
		Communication	Consider language barriers Leadership Open forums Active idea management List of open points (LoP) Round tables

Cause	Secondary cause 1st order	Secondary cause 2nd order	Preventive measure
Machine	Availability	Technical availability	Perform Failure Mode and Effects Analysis (FMEA) Schedule maintenance and repair Implement Total Productive Maintenance (TPM) Regular control Log malfunctions Provision of series tools at the production stations
		Delay (machine installation/ commissioning)	Employee training Timely provision of the necessary tools and materials Planning of buffer times during commissioning Scheduling of breaks
	Technical problems	Compatibility	Observe country-specific machine requirements Transparent/clear communication between machines (machine-robot) Provide information about experts to employees Requirements specification
		Manufacturing technology	Increase employee qualification (on-the-job training) Conduct job briefings Establish protocols Adjust maintenance plans Determine escalation strategy Production testing Process visualization (ProVis) Maturity assurance Conduct early technology identification using a product technology roadmap Documentation of existing and new technologies Identification of interactions among each other when technologies are used in parallel Determining strategies for handling machine failures Establish operating guidelines, implement technical changes Introduction of failure-reducing product planning
		Quality	Record exact specification in the requirements specification Consider specification book Perform audits Quality-Function Deployment Six Sigma Regular maintenance of operating and test equipment
		Programming	Consider specifications and requirements Clearly define goals Transparent/clear communication between programs Hire qualified staff and provide trainings
Material	Availability	Material delay	Safety stock Good communication with suppliers Implement dual sourcing Determine escalation strategy Implement Kanban as material provisioning

Cause	Secondary cause 1st order	Secondary cause 2nd order	Preventive measure
		Replenishment time	Identify suppliers in the vicinity Use direct communication channels Adjust dimensioning of safety stocks Knowledge management (lessons learned) Realistic lead times Just in Time concept Consider scrap rate in pilot series and production ramp-up in demand planning Select suitable order policy Alignment between manufacturing and procurement by regular tuning improve Alignment between manufacturing and procurement by IT support (e.g. ERP/MES system) improve Reduce replacement time by selection of suppliers with shorter delivery time In-house optimization of the period between notification time and order time (e.g. by using an IT system)
		Quantity deviation	Perform laboratory tests Set realistic deadlines Determine safety stock Document processes (knowledge management)—improve forecast
	Technical Problems	Technical product change	Carry out laboratory tests regularly to avoid malfunctions Establish protocol (documentation) Monitor process regularly Digital mock-up
		Maturity	Regular measurement Regular control Establish clear quality gates Conduct audits Production testing Maturity assurance
		Quality	Inspection of goods upon receipt for obvious defects with the supplier present Select reliable suppliers Offer employee training Quality-Function Deployment Six Sigma Work area specific training of employees regarding quality requirements in that area by qualified personnel Identification of its quality requirements for the product and their characteristics Documentation of the quality controls
		Complexity	Product modularization Identify possible alternative suppliers Conduct lab tests on a regular basis to develop new materials Knowledge management/lessons learned Sequential variant management
Process	Organization	Communication	Establish a clear structure of the organizational structure in the ramp-up phase Regular communication Clear communication channels Provide infrastructure (drive, software for work organization, internal social media platforms) Build trust and respect (between employees and managers) Establish feedback/evaluation meetings Active idea management Increase information flow Critical Chain Project Management List of open points (LoP) Process Visualization (ProVis) Round tables

Cause	Secondary cause 1st order	Secondary cause 2nd order	Preventive measure
		Data organization	Continuously increase knowledge management Regularly maintain and update data Data backup Provide structured systems Lessons learned workshops
		Standardization	Define procedure in a flow chart Introduction of the DIN EN ISO 9001 standard Provide employee training and information on standards Create documentation Increase motivation of employees through variety of tasks (avoid monotony of tasks)
		Unambiguity of responsibilities	Clear hierarchy and structure of the organizational structure Provide regular information about changes in the company Clear description of activities Schedule regular employee meetings
	Planning	Requirements planning	Consider specifications Documentation
		Milestone planning/maturity planning	Regular meetings with experts Formulate quality gates Use buffers Process visualization (ProVis)
		Budget planning	Clearly define goals Monitor regularly Apply budget planning software to predict trends Consider currency effects and fluctuations, labor costs, material and raw material costs, taxes and duties Consider political and economic stability of countries involved Conduct audits
		Material planning	Improve forecast Consider seasonal effects Consider fluctuations in demand Plan for safety stock and manage it regularly Identify reliable suppliers in the vicinity Just in Time concept
		Resource planning	Clarify legal issues in time Plan flexible capacities Assess quality of resources at selection stage Maintenance and repair Dual sourcing Virtual tool development Tool tracking
		Personnel planning	Hiring of loyal and sustainable employees Active sourcing Employee-oriented management Consider employee availability Always consider possible employee absences Plan for qualified jumpers Plan exact number of employees based on sales and demand forecasts
		Production process planning	Describe and define work steps Provide training Flexible capacity planning Load test Audits Integrate different employees into the product planning team

Cause	Secondary cause 1st order	Secondary cause 2nd order	Preventive measure
		Internal/external logistics planning	Calculate buffer between processes Safety stock Increase supply chain visibility Knowledge management to improve forecasting Apply warehouse management software Maintain software Standardize processes Consider seasonal effects Optimize route Just in time concept Evaluation and ranking of logistics service providers Selection of a suitable delivery concept based on historical, current and forecast data Integration of customers and suppliers in the transportation planning process Regular communication between suppliers, customers and company and control of utilization
	Modifications	Product change	Test management Conduct benchmarkings Design of Experiments Communicate closely with customers and ensure transparency Document changes well (knowledge management) Implement modular design principles Failure mode and effects analysis Digital mock-up (DMU) Common parts concept Lessons learned workshops Rapid Prototyping
		Process change	Analysis of the economic efficiency of the process change Close communication with customers and transparency ensurances Document changes well (knowledge management) Close communication with suppliers (machines, tools) Process visualization Reference models
Environment	Political-Legal	National legislation	Consider national legislation during site selection Hire local staff, based on good knowledge of national laws Regular monitoring of legislative changes
		Directives, regulations, and standards	Consider guidelines, regulations and standards during site selection Regular monitoring of legislative changes Consider country-specific standards (e.g. power supply, exhaust fumes)
		Political stability	Consider location factors Motivate employees by ensuring financial stability Flexible contingency plans in extreme cases

Cause	Secondary cause 1st order	Secondary cause 2nd order	Preventive measure
	Ecological	Geographical and climatic influences	Conduct technical feasibility study Good communication between employees and management Regular monitoring of tools, machines, materials, products, packaging
		Natural disasters	Risk mitigation planning and risk management Build inventory (high risk areas) Increase supply chain visibility Consider risk level of suppliers Employee training (emergency response) Formulate backup plans
		Man-made disasters	Risk mitigation planning and risk control Safety stocks Increase supply chain visibility Software maintenance, continuous updates, high security level for sensitive data Employee training (emergency response) Formulate backup plans
	Infrastructure	Working conditions (internal)	Ensure modern and safe working conditions Respond to employee needs Country-specific adaptation of the workplace Regular renovations
		Transportation	Optimize route Plan alternative means of transport (risk management) Improve supply chain visibility Optimize vehicle fleet Safety stocks
		Connection	Consider connections in site selection Plan for alternative modes of transportation
		Time difference to headquarters	Consider time zones
	Supplier	Capacity	Supplier integration Communicate regularly to be aware of and plan for potential problems Safety stock/ buffer times Determine secondary supplier/dual sourcing
		Information exchange	Exchange information on a regular basis Clarify responsibilities on both sides Compatible information exchange system Consider global language barriers Performance interface agreements Round tables Complete synchronization of IT systems of all suppliers regarding orders, contact, planning and development Regular check-up via IT system whether contact persons (and contact data) are still up-to-date
		Supplier availability	Supplier integration Select reliable suppliers Communicate regularly to be aware of and plan for potential problems Safety stock/buffer time Determine secondary supplier/dual sourcing

Cause	Secondary cause 1st order	Secondary cause 2nd order	Preventive measure
		Quality	Supplier integration Regular exchange of information Safety stocks Clear agreement on procedures in the event of a technical problem Product modularization Establishment of a standardized testing procedure to control quality Selection of suppliers to be controlled by regular audits Investment in qualified personnel (internal or external) to perform the audits Regularly checking the validity of suppliers' certificates Inspection of goods upon receipt for obvious defects with the supplier present Conducting random comprehensive quality control after goods receipt Work area specific training of employees regarding quality requirements in this area by qualified staff Adjust dimensioning of safety stocks Determine escalation strategy
		Deadline delay	Select reliable suppliers Communicate regularly to be aware of and plan for potential problems Safety stock Determine escalation strategy
	Customer	Information exchange	Exchange information regularly Customer integration Clarify responsibilities on both sides Compatible information sharing system Round tables
		Product request	Service interface agreements Customer integration Regular meetings to properly understand requirements Consider requirements specifications/ specification sheets Round tables Conduct benchmarkings Digitization of the requirements Creation of a unified set of requirements Identification of the importance and target achievement of the requirements Standardized, detailed documentation of the requirements in requirement specifications Fulfillment of mandatory requirements with the help of the checklist
		Quantity change	Plan with buffers to respond quickly to potential changes in volume Flexibility of lines and personnel Knowledge management
		Logistics request	Consider and provide logistics operations Regular monitoring of inventories Regular maintenance/servicing
		Deadline change	Customer integration/good relationship and communication with customers Information exchange Flexible capacities Safety stocks

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