



# A comprehensive KPI network for the performance measurement and management in global production networks

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## Abstract

The trend of globalization has led to a structural change in the sales and procurement markets of manufacturing companies in recent decades. In order not to be left behind by this change, companies have internationalized their production structures. Global production networks with diverse supply and service interdependencies are the result. However, the management of global production networks is highly complex. Key performance indicator (KPI) networks already exist at the corporate level and site level to support the management of complex systems. However, such KPI networks are not yet available to support the management of entire production networks. In this article, a KPI network for global production networks is presented, which links the key figures of the site level and the corporate level. By integrating both levels into a comprehensive KPI network, cause and effect relationship between the production-related KPIs and the strategic KPIs of a corporate strategy become transparent. To this end, this KPI network is integrated into a Performance Measurement and Management (PMM) methodology. This methodology consists of three phases: performance planning, performance improvement, and performance review. For testing the practical suitability, the PMM methodology is applied to the production network of an automotive supplier using a simulation model to estimate the effects of proposed improvement actions of the methodology.

**Keywords** Global production network · Performance measurement · Performance management · Key indicator networks

## 1 Introduction

The increasing globalization of sales and procurement markets results in worldwide competition for manufacturing companies. To survive in this global competition, manufacturing companies have internationalized their production structures. Starting from the export of products and the establishment of independent foreign production sites, production networks have emerged that today span the entire world [1, 2]. A characteristic of the resulting global production networks (GPNs) is a manifold supply and service interdependencies between the individual production sites [3]. Managing the emerging complexity of global production networks is a major challenge for manufacturing companies [4].

For the management of individual production sites, the use of key performance indicator (KPI) systems has proven itself in practice. These KPI systems provide site management with relevant information about the current state of the production site. However, an expansion of such KPI systems from individual production sites to entire production networks is hardly used in industry [5, 6].

In practice, cost savings of up to 45% could be achieved by optimizing production networks. Yet, most companies realize only 10% of this potential. [1] For the realization of such optimization potentials in production networks, transparency about the current and targeted performance is essential. Systematic assessment approaches, which display the performance of entire production networks in a quantitative form using suitable KPIs represent a relatively unexplored field in literature [7]. Besides creating transparency, a quantitative performance assessment of production networks also enables a better alignment of operational processes with the superordinate strategy [7, 8]. With the help of suitable KPIs, quantitative objectives can be set to align the management of production sites [5, 9].

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Currently, in the literature, no suitable KPI network exists for the comprehensive measurement of the performance of GPNs. Therefore, a KPI network for GPNs will be presented in Sect. 4 of this article, which displays the performance of GPNs in four dimensions: efficiency, flexibility, quality, and time. Furthermore, this KPI network will be integrated into a methodology for the strategic management of GPNs. The resulting Performance Measurement and Management methodology consists of three phases: performance planning, performance improvement, and performance review.

## 2 Fundamentals

In the context of this article, the term global production network is defined as a network of production sites, whereby the production sites have a global distribution and belong to the same company [3].

In literature, the tasks for designing and operating such GPNs is divided into three dimensions: the strategy dimension (focusing on the definition of main objectives), the configuration dimension (focusing on the design of the network structure), and the coordination dimension (focusing on the execution and control of the production and transport processes) [10]. The three dimensions are interdependent and are each assigned to different planning horizons [11]. The strategy dimension includes long-term strategic decisions, such as designing an overall manufacturing strategy, a network strategy, and individual site strategies for each production site in the network [4]. The configuration dimension is part of the mid-term tactical planning processes and the coordination dimension focuses on short-term operative decisions [10]. In this article, a methodology for the performance measurement and management of GPNs is developed, which aims to close the gap between the strategic long-term decisions and the short-term operative decisions by including both dimensions into a closed-loop performance management process.

As part of the long-term strategic planning process, the objectives of the overall manufacturing strategy are derived from the corporate strategy. In doing so, differentiation factors are defined for the overall manufacturing strategy of the GPN, based on which the company differentiates its GPN from the competition. The differentiation factors describe the goals for increasing competitiveness from a market perspective [4]. Six differentiation factors of an overall manufacturing strategy can be thereby distinguished [4]: price, quality, dependability, flexibility, innovation, and service. To be able to achieve the goals set from a market perspective for differentiating the GPN, appropriate internal capabilities must be built up. A distinction is made between network and site capabilities, whereby four categories of network capabilities and six categories of site capabilities can be

distinguished [4]. Table 1 summarizes the set of network and site capabilities, for which objectives must be derived while designing the long-term strategies of GPN. Each capability is therefore described with a set of criteria, which help to understand all relevant strategic decisions of the respective capability category.

To define an overall manufacturing strategy for the future development of a GPN's capabilities, transparency about the current performance is necessary. Therefore, a comprehensive KPI system is needed to measure and display the current state of the GPN's capabilities.

In literature, comprehensive KPI networks for displaying a system's performance are often defined as performance measurement approaches. In general performance measurement approaches describe a system's performance with the help of several quantifiable KPIs out of different dimensions [12]. For the development of a fitting performance measurement approach, four basic characteristics must be fulfilled [12]:

- Selection of quantifiable KPIs
- Pursuit of a holistic approach to ensure direct reference to goals and strategy
- A multidimensional approach for the illustration of monetary and non-monetary KPIs
- Consideration of different performance levels

Performance management builds upon performance measurement and supplements it with the aspect of goal-oriented strategy development, planning, and implementation [13]. It thereby consists of three basic phases. The first phase, performance planning, comprises the formulation of the strategy and the definition of success. Subsequently, the strategy is implemented through the performance improvement phase in the form of strategic measures and finally evaluated in the performance review phase [14].

A common tool for managing performance on a corporate level is the Balanced Scorecard (BSC) [14, 15]. For the performance management with a BSC, Kaplan & Norton elaborated four consecutive phases. Starting with defining a strategy out of four perspectives (financial, customer, internal processes, learning & growth) in the first phase, the defined strategy is communicated with all relevant stakeholders and implemented within all divisions by setting quantitative targets using suitable KPIs. These KPIs are structured in a Strategy-Map, which describes the interdependencies between the KPIs and categorizes them into the four strategic perspectives. Finally, in the fourth phase, the strategy is reviewed and revised based on the accomplished performance [16, 17].

In literature, the definitions of performance measurement and performance management overlap to some extent. However, the basis for performance management is always

**Table 1** Capabilities of a GPN [14]

	Category	Criteria	
Network capabilities	Accessibility	Access to markets & customers	
		Access to competitors	
		Access to sociopolitical factors	
		Access to image factors	
		Access to suppliers & raw materials	
	Thriftiness ability	Access to skilled workers	
		Access to cheap labor	
		Access to external knowledge sources	
		Economies of scale	
		Synergies	
	Manufacturing mobility	Avoidance of redundancies	
		Mobility of products, processes and personal	
		Mobility of production volume	
		External learning	
		Internal learning	
Site capabilities	Learning ability	Control of the production inputs (material, labor, overhead)	
		Specification accuracy and high product quality	
		Short delivery times and high delivery reliability	
		Range of products manufactured at the site and their customer-specific adaptability	
		Flexibility to change order quantity size and delivery times	
	Cost	Offering innovative products and processes	
		Quality	
			Availability
	Design flexibility		
		Order quantity flexibility	
			Innovativeness

performance measurement, because, without the measurement and quantification of performance, management is not possible [18]. To illustrate this connection between measurement and management, in the following Performance Measurement and Management (PMM) as a combination of both terms will be used. Section 3 gives an overview of existing PMM methodologies and approaches in the field of GPNs.

### 3 Literature review

In the following section, existing approaches concerning performance measurement and management in global production networks are presented. The PMM approaches are compared regarding the fulfillment of defined requirement criteria, which are derived from the overall objective of this paper.

The objective of this paper is the development of a comprehensive KPI network, which enables users to quantify the performance of a GPN. This KPI network should also be able to identify cause and effect relationships between corporate and production network performance. This objective results in six main requirements (see Fig. 1), which a suitable PMM approach must fulfill.

On the one hand, the scope of the PMM approach has to be on GPNs. The integrated KPI network is intended to

cover all relevant performance levels of a GPN and should also quantify the performance at every level out of different performance dimensions. For the aggregation of the performance, a link between the individual KPIs on the different performance levels are necessary. To ensure that a suitable PMM approach can also be used for the performance management of GPNs in addition to performance measurement, a systematic process for deriving strategies within a GPN is required. The individual strategies must be aligned with the corporate strategy, to support the defined business objectives. To meet the management aspect, the approach should also have a closed control loop that allows several planning rounds to be run to improve performance.

The PMM approaches presented in this chapter are only an extract of all already existing PMM approaches in the literature. However, the approaches presented here are those which cover best the defined requirements. Each of the five presented PMM approaches below excels the other approaches in certain areas, but none of the approaches is complete without shortcomings (see Fig. 2 at the end of this chapter).

Hon developed a performance measurement framework for manufacturing systems, which contains several KPIs from five performance dimensions (cost, time, quality, flexibility, and productivity). The framework is divided into the performance levels machine, cell, line, factory, and network.

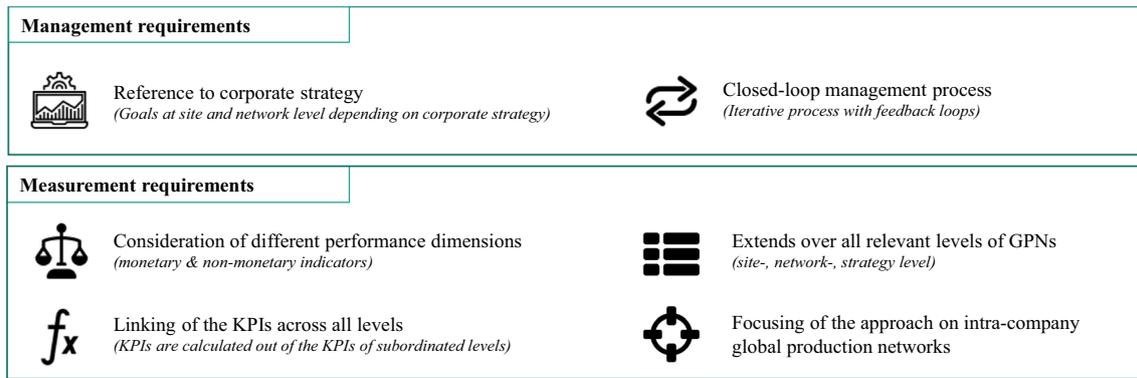


Fig. 1 Requirements for a PMM approach for GPNs

Requirements for a PMM approach for GPNs		PMM approaches				
		PMM-Framework by Hon	PMM-System by Sager et al.	PMM-Process by Ferreira & Fleury	SC Scorecard by Gleich & Daxböck	SC Scorecard by Zimmermann
	Focusing of the approach on intra-company global production networks	●	●	●	○	○
	Extends over all relevant levels of GPNs (site-, network-, strategy level)	◐	◐	◐	○	◐
	Consideration of different performance dimensions (monetary & non-monetary indicators)	●	●	●	●	●
$fx$	Linking of the KPIs across all levels (KPIs of a level are calculated out of the KPIs of subordinated levels)	○	○	◐	◐	◐
	Reference to corporate strategy when defining goals (Goals at site and network level depending on corporate strategy)	○	◐	◐	◐	○
	Closed-loop management process (Iterative process with feedback loops)	○	○	●	●	○

Fig. 2 Comparison of the presented PMM approaches for GPNs

In total, 442 KPIs are used to quantify the performance out of the five dimensions on the five levels. The focus of the framework lies entirely on GPNs, nevertheless, the framework's purpose is limited to the measurement of performance [19].

Sager et al. also developed a performance measurement approach for GPNs, which is designed to evaluate the need to adjust the network configuration by quantifying the production network's performance. The performance dimensions are divided into two levels. On a strategic performance level, the performance dimensions "quantity responsiveness", "quantity flexibility", "residual costs", "delivery pace", "delivery reliability" and "business economics" are considered. On the second level, the operational performance level,

the basis for the implementation of the strategic performance capabilities of the production network is evaluated from a system theory perspective. A production network is seen as a set of nodes and edges. Both the set of nodes and the set of edges are evaluated concerning their complexity and dynamics. The approach of Sager, Hawer & Reinhart was also developed as a performance measurement system and is therefore not suitable as a management approach. Furthermore, the authors do not assign key figures to quantify the performance dimensions and levels [20].

The performance assessment process model for GPNs of Costa Ferreira Junior & Fleury quantifies the performance of a GPN from three performance dimensions (costs, flexibility, innovation) on two performance levels (site and

network level). In total, 12 KPIs are proposed to quantify the performance. The model also includes a performance management process for the application of the model, which consists of five steps. In the first step, the mission for the production network is defined and quantified. The options available are global competitiveness, potential exploitation, market presence, dynamic responsiveness, resource availability and capability development. By selecting the production network’s mission, the performance dimensions are prioritized. This step is carried out by the headquarters on the network level, which defines objectives in quantitative form for the KPIs. The performance targets are disaggregated in the second step and individual quantitative targets are set for each production site in the network. Once the targets have been set for the individual sites, the third step involves collecting the necessary data at the sites and calculating the actual KPIs. In the fourth step, the collected data of the sites is aggregated again by the headquarters on the network level. In the final fifth step, the headquarter evaluates the performance achieved [7].

In addition to the PMM approaches of Hon, Sager, Hawer & Reinhart, and Costa Ferreira Junior & Fleury, which have focused on internal company GPNs, there are several PMM approaches with the goal of performance evaluation of inter-company supply chain networks.

One of these approaches is the Supply Chain Scorecard by Gleich & Daxböck. Based on the Balanced Scorecard framework, the Supply Chain Scorecard with the supplier perspective includes a fifth perspective in addition to the classic four perspectives. This fifth perspective enables the inclusion of a company’s suppliers in the definition of strategic objectives. In the practical application of the Supply Chain Scorecard, Gleich & Daxböck follow the procedure for creating a BSC. Based on the vision and mission, strategic objectives are defined for the five perspectives. To quantify the strategic objectives, Gleich & Daxböck also provide a selection of KPIs for each perspective [21].

Another PMM approach for supply chain networks is the Supply Chain Balanced Scorecard by Zimmermann. In contrast to Gleich & Daxböck’s Supply Chain Scorecard, Zimmermann avoids the pre-selection of KPIs for performance measurement and the introduction of a fifth perspective. Zimmermann focuses on the development and implementation process. Starting with the definition of a supply chain vision and strategy, strategic goals are set and communicated within the supply chain. After that, strategic measures for achieving the defined goals are identified and their implementation is planned by setting time milestones. In the last step of this process model, a supply chain strategy review takes place to evaluate the success of the planned strategy. The findings of the strategy review are integrated into the next management cycle [22].

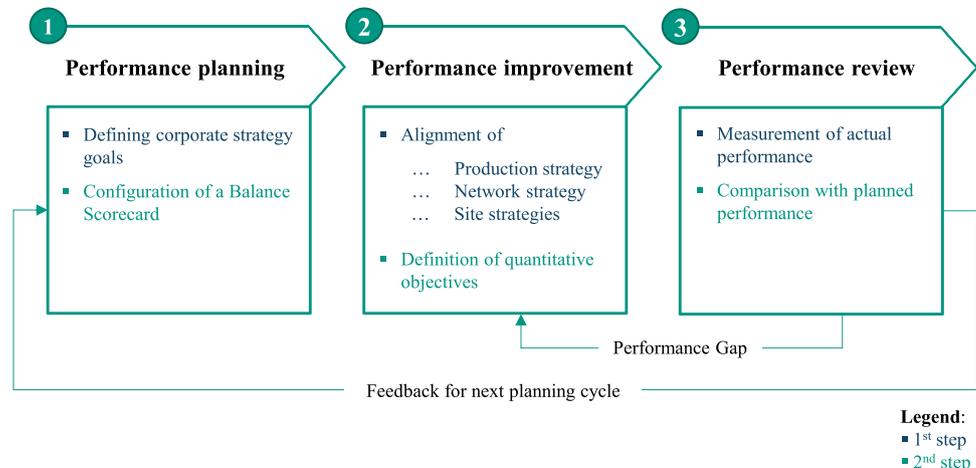
The aforementioned approaches show that the performance measurement and management of GPNs is a relevant field in the context of global production research. Nevertheless, a comprehensive approach, which covers all the defined managements and measurement requirements, lacks in research and practice. Figure 2 summarizes the comparison of the presented PMM approaches for GPNs.

#### 4 Methodology for the performance measurement and management in global production networks

Since no existing PMM approach can fully meet the defined requirements, a newly developed PMM approach for GPNs is presented in this section. In the development of this approach individual aspects of already existing approaches were taken up again (e.g. in the definition of relevant performance dimensions or the design of the individual management steps).

The developed PMM methodology is divided into three phases (see Fig. 3). First, the performance goals are planned

Fig. 3 Overview of the methodology for the performance measurement and management in GPN



by defining a corporate strategy. Second, all strategies within a GPN (see Sect. 2) are aligned to support the goals of the corporate strategy, and quantitative objectives are defined for all entities of the network. Third, the success of the planned strategies is measured and evaluated with the help of a comprehensive KPI network for GPNs. If the measured and the planned performance of the GPN match, the planned strategies are successful, and the next planning cycle is initiated. In case of a mismatch of planned and measured performance, the strategies within the GPN should be revised to close the existing performance gap. The different text colors are used in order to have a transparent mapping with the respective elements of Fig. 9 in the application of the PMM methodology.

In the following subchapters, guidelines for configuring a corporate strategy (Sect. 4.1), for improving the GPN's performance by aligning all strategies (Sect. 4.2), and for the review of the archived GPN performance (Sect. 4.3) are presented.

#### 4.1 Performance planning

The objectives for a GPN's performance are derived from the company's corporate strategy. In phase one, performance planning, alternative options for designing a corporate strategy are developed using the Balanced Scorecard Framework. From the Balanced Scorecard, KPIs for quantifying the corporate strategy are derived, which are then put into cause-and-effect relationships in the form of a strategy map. For the four perspectives of the Balanced Scorecard, alternatives for the objectives of the respective perspective are presented, and KPIs for quantifying the objectives are discussed. The focus is on elements of the Balanced Scorecard that are directly related to the company's production network or whose performance is significantly dependent on the production network.

From a financial perspective, the strategy for achieving long-term financial success is defined. In a market-based economic system, companies strive for profit maximization as their primary objective. By aligning all activities in the company to this top objective, the value of the company is to be increased in the long run [23]. From the shareholder's point of view, the value of a company rises through an increase in shareholder value. In general, shareholder value can be improved by two basic financial strategies: the growth strategy and the productivity strategy [24]. The growth strategy looks for ways to increase sales. The productivity strategy, in turn, aims to improve productivity within the company.

After the financial strategic objectives of the corporate strategy have been defined, the next step focuses on the strategic objectives from the customer perspective. This involves describing from the customer's perspective of how

the company wants to differentiate itself from the competition by offering a unique customer value proposition. The customer value proposition is defined by designing the product characteristics (price, quality, time, selection) and by offering complementary services for the customers [24]. Companies align their customer value proposition by pursuing a differentiation strategy. According to Kaplan & Norton [24], the differentiation strategies pursued by successful Balance Scorecard users can be summarized into three general strategies: operational excellence, customer intimacy, and product leadership. Depending on the chosen differentiation strategy, the customer value proposition focuses on specific aspects. The definition of the desired product characteristics has a decisive influence on the requirements for production. The aspect of selection for example determines the number of product variants that a company wants to offer and hence also has to produce. The desired market price in turn determines which budget is available for production. The desired quality level is crucial for quality management processes. The time, in which the product is supposed to be delivered to the customer, results in organizational requirements for the production and distribution processes. When applying this configuration approach, companies choose one of the three generic differentiation strategies presented.

Once the desired customer value proposition has been determined from the customer's perspective, the next step is to align internal processes. For this purpose, strategic measures and objectives for the production and distribution processes are developed. Depending on the industry and the characteristics of the product portfolio, the requirements for the production processes differ. A consumer goods manufacturer who produces millions of units per year has to organize the production processes differently than a special machinery manufacturer. These characteristics are independent of the chosen differentiation strategy or financial objectives. For the internal production processes, therefore, different ideal-typical structures are presented. The discussed ideal types are derived from a combination of the morphology for the classification of order processing structures by Schuh et al. [25] and the differentiation strategy chosen from the customer perspective. In total, seven ideal types of production companies are distinguished:

- Engineer-to-order manufacturers produce highly customized goods, whereby each product is designed according to customer requirements.
- Strategic suppliers produce highly customized products, which are designed for each customer individually. Customers' relationships are defined in a framework agreement, which is detailing order quantities and order lead times. Production processes are aligned with customer requirements.

- Standard component suppliers offer a cost-efficient product portfolio. Customers order a certain number of products within a framework agreement, which is detailing order quantities and order lead times. Offered products are customer independent.
- Innovative suppliers offer an innovative product portfolio. Customers order products of the innovative supplier within a framework agreement because of the superior product characteristics.
- Make-to-order manufacturers produce on customer order (small order quantity, no supplier relationship) a customized product, which the customer can configure out of several standard components.
- Innovative manufacturers produce innovative products (small order quantity, no supplier relationship). Customers choose the products because of superior product characteristics.
- Standard component manufacturers offer a range of cost-efficient products, which are bought by customers because of their value for the money.

Figure 4 shows an example of the resulting Strategy-Map of a strategic supplier. Out of the internal perspective, the maximization of the number of on-time-deliveries and capacity utilization are key for successful corporate strategy implementation. Also, the production processes should be flexible to produce a wide range of customized products in high quality to minimize customer complaints. Furthermore, additional KPIs in the strategy map can be derived directly from finance department (financial perspective) where there is no KPI in the network performance KPI list. The idealistic

Strategy-Maps of all the above mentioned production companies are displayed in the appendix.

After Sect. 4.1 dealt with the design of overall corporate objectives and thereby seven ideal types of production companies were identified, the following chapters deal with their realization by deriving suitable functional strategies.

### 4.2 Performance improvement

In the second phase of the PMM-methodology for GPN, the implementation of the defined objectives out of the internal perspective is focused. All strategies within a GPN are aligned for the execution of the designed corporate strategy of the performance planning phase. In GPN, three strategies are distinguished, the overall production strategy and the supporting site and network strategies [4]. Figure 5 summarizes the steps to align these strategies with a respective corporate strategy as input.

The process of aligning the GPN strategies with the corporate strategy starts with prioritizing the network and site capabilities (see Table 1 in Sect. 2). Therefore, the site capabilities are categorized into Order-Winner- and Market-Qualifier-Factors based on the defined customer differentiation strategy. The order-winner factors are the decisive factors for the successful implementation of the corporate strategy. These factors are therefore the key aspects in the design of the strategic measures. The objectives of the site capabilities are defined by elaborating on an overall production strategy. On the network level, the production management should specify quantitative target values using a set of network performance indicators.

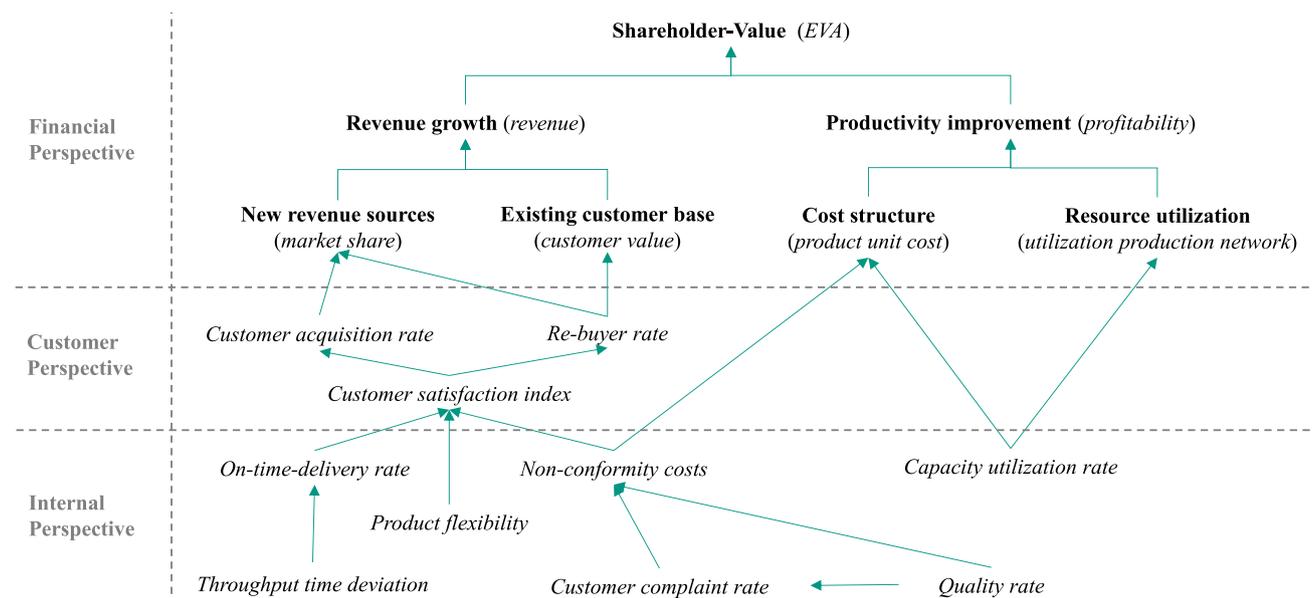
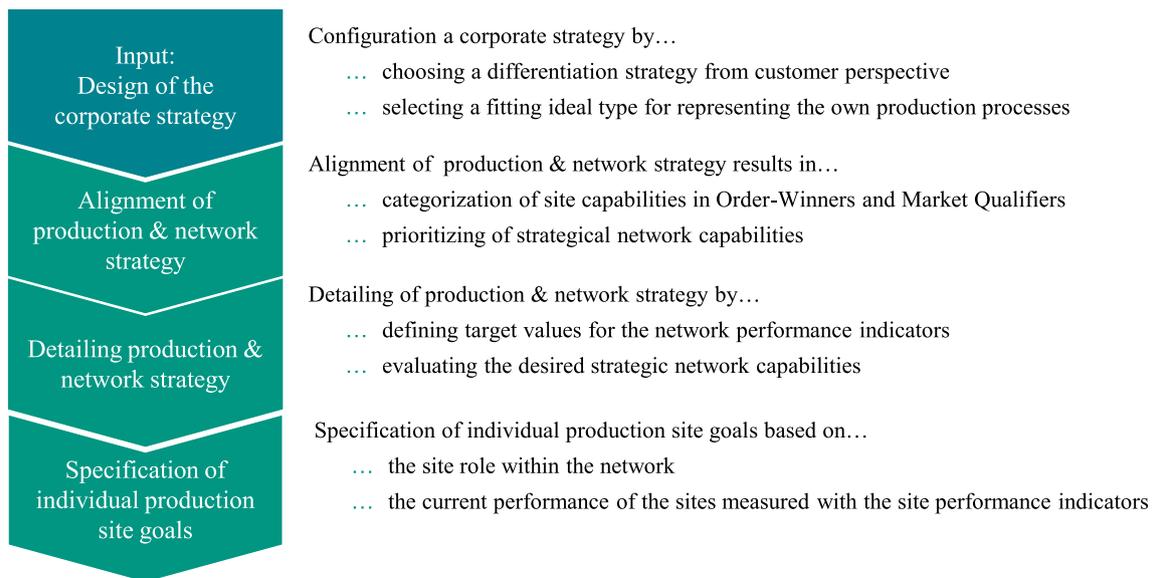


Fig. 4 Strategy-map of the strategic supplier



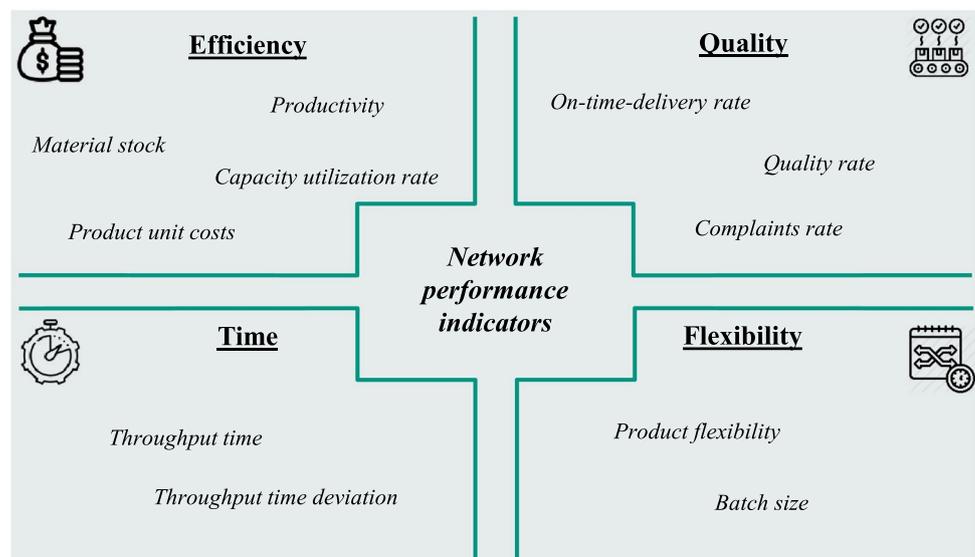
**Fig. 5** Process for implementing a corporate strategy in a GPN

After defining the quantitative objectives on the network level, in the next step individual goals for all sites within the network are deployed. Therefore, the strategic role of the production site should be considered. Depending on the role of a site, each site has a specific strategic advantage compared to sites with different roles. Ferdows [26] distinguishes the strategic advantages “access to low-cost production”, “access to knowledge and skills” and “proximity to market”. Based on these strategic site roles, different KPIs can be used and weighted depending on the strategic site advantage. Exemplary one can state, that quality KPI aims for a lead factory are higher than for simple source factory. Nevertheless, this framework gives an

overview of different directions for KPI weightings across a production network.

Considering the requirements for measuring performance formulated in Chapter 3, the network performance indicators should be multidimensional and linked with corresponding KPIs on site level. The key performance dimensions and indicators are based upon the work of Rittstiegl [27]. The author focuses on the performance of production plants in global production networks. Based on this, the performance dimensions efficiency, time, quality, and flexibility were identified for measuring the performance of a GPN. Figure 6 shows the set of KPIs assigned to these dimensions. The same set of KPIs and

**Fig. 6** KPIs for quantifying performance on site and network level



performance dimensions is also used to quantify the performance on the site level. For the calculation of the site performance indicators, a comprehensive KPI network within the production sites is crucial. In practice, this collection of KPIs is not limited and it might be extended to the company's needs and aims. Unger mann, Jacob et al. [28] presented an exemplary site internal KPI network. Based on their site internal KPI network, the necessary data for the calculation of the presented set of site performance indicators can be collected. For the aggregation of the KPIs on site level to the network level, the network structure (see Sect. 2) should be considered in the aggregation logic.

For quantifying target values of the network capabilities, a five-tier scale can be used. As described in literature, a detailed and quantitative measurement of network capabilities is not possible for production networks [4]. Therefore, we developed the five-tier rating scale in order to realize a qualitative measurement of network capabilities and to have a visualization for network managers. With such a scale, the importance of the individual network capabilities can be weighted in the strategy finding process, and thus the network structure can be designed in a goal-oriented way. Figure 7 shows the rating of the network capabilities for a GPN, in which thriftiness and access to suppliers, skilled workers, and cheap labor are of high importance for the successful implementation of the corporate strategy. Based on the quantified evaluation of the desired network capabilities, the structure of the GPN can be adjusted according to the strategies. Therefore, a strategy-oriented network structure can be visualized for different idealistic production companies. The rating of the network capabilities gives an overview over the weighting of KPIs that are similar to the network capabilities. E.g. economies

of scale might weigh the importance of KPIs in the field of efficiency.

### 4.3 Performance review

In the final phase of the PMM methodology, the success of the planned strategies is reviewed. For this purpose, the planned performance goals are compared with the realized performance.

At the site level, the measures for achieving the specified site objectives are evaluated using the site performance indicators. By comparing the achieved site performance with the targeted site performance, the need for further action at the respective site becomes apparent. The network management has, for example, the possibility to support sites with performance issues by knowledge transfer within the production network.

As part of the review of the production strategy, the network management will compare the achieved network performance with the planned network performance. In particular, the performance review of the production strategy focuses on the capabilities identified as "order-winning" factors. If there is a performance gap between achieved and targeted performance, measured by the network performance indicators, for example, network-wide efficiency improvement programs can be initialized.

In the context of the performance review of the network strategy, the targeted network capabilities are compared with the realized network capabilities. This makes it clear whether the decisions made on the design of the network structure and site role distribution led to the desired network capabilities.

The corporate strategy is also subjected to a performance review. With the help of the strategy map, KPIs can be assessed whether the strategic goals have been achieved.

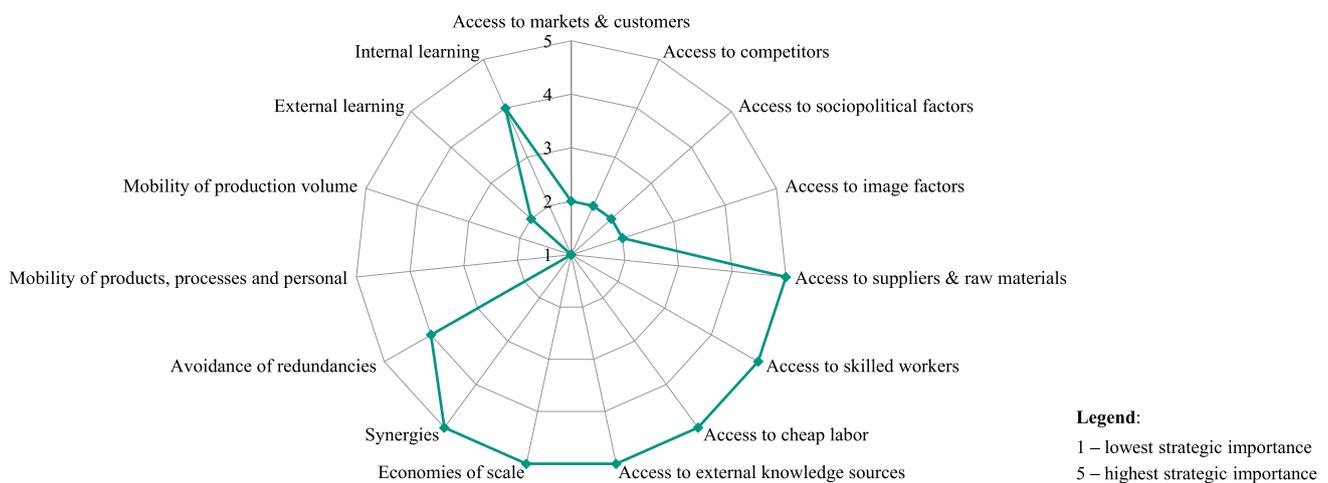


Fig. 7 Five-tier rating scale for network capabilities [4]

By presenting the logical relationships within the strategy map, cause-and-effect relationships can be analyzed. This allows, for example, the reasons for failing to meet set targets for productivity to be broken down into the areas of cost structure and resource utilization. By showing the decisive influencing factors from an internal process viewpoint, this causal research can be further deepened, whereby the influence of the production network performance can also be examined with the help of network performance indicators. By completing the performance review of the corporate strategy, the next planning round is initiated and the performance management process is again carried out from the very beginning. Figure 8 summarizes the procedure for the performance review.

### 5 Application to industrial use case

The methodology for the goal-orientated PMM in GPNs has been applied exemplary to a leading Tier 1 enterprise in the automotive supplier industry. The production program of the enterprise includes cost-efficient plastic components, which are categorized into three product groups (wheel trim, body & interior trim, branding). The company develops all products individually for each customer and produces the customer-specific products in designated plants near the customer location. The company's GPN consists of nine production sites located in Europe, Asia, and Central America. In the following, the application of the presented PMM methodology in cooperation with the network management at the company's headquarter is described. In the scope of this cooperation, the PMM methodology for GPN (see Fig. 3) was practically applied to define quantitative performance goals for the GPN as a whole and the individual

sites within the GPN. Therefore, the calculation logic of the presented set of KPIs (see Fig. 6) was adjusted to the company's needs. The following sections will have a deeper insight into the phases of the PMM methodology in the use case (see Fig. 9).

In phase 1 of the PMM methodology for GPN, the appropriate ideal type was determined by classifying the characteristics of the company's production processes and the differentiation strategy pursued. The considered automotive supplier is categorized as a strategic supplier, because of the company's highly customized product portfolio and the alignment of production with customer needs. As a strategic (automotive) supplier, the company's customers have high requirements for the on-time-delivery of components to the assembly plants. The variation in internal throughput times of production orders must therefore be minimized from an internal process perspective. The company is also facing strong competition, which is why the cost and quality of the components are also crucial. Due to the high number of customer-specific variants with partly only small annual production quantities, the company's production resources must be flexible and adaptable to produce different variants.

In phase 2, the alignment of the GPN to the requirements of the company's corporate strategy takes place. The network management at the headquarters of the company is pursuing a market-oriented network and production strategy. In the course of the market-oriented production and network strategy, customer-specific products are to be manufactured at production sites close to the customer. The network management considers the networking capability "access to customers and markets" to be crucial for success. Also, the network capabilities "economies of scale", "synergies" and "access to cheap labor" are in focus to be able to offer cost-efficient products. From the set of site capabilities, the

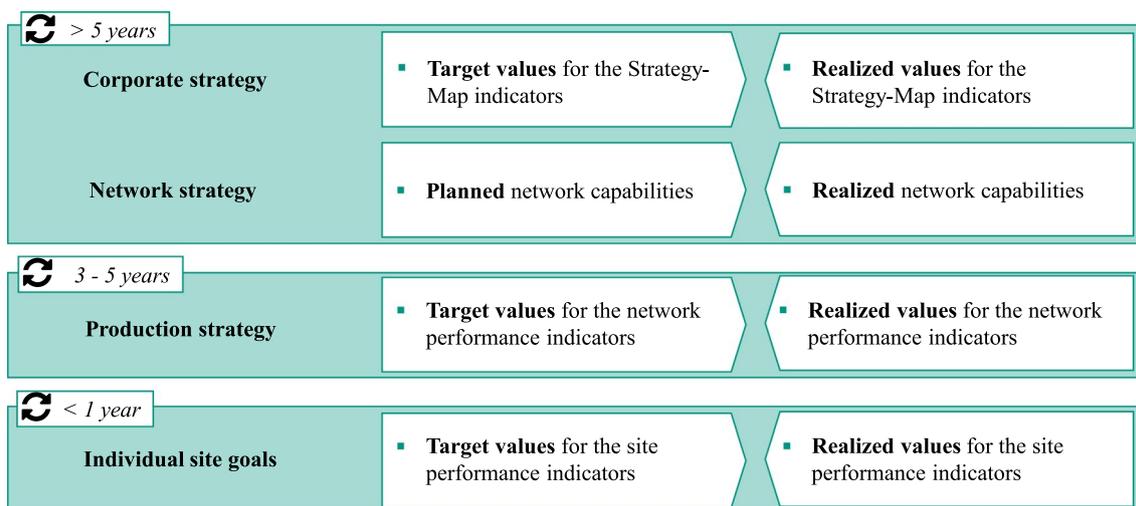


Fig. 8 Systematic performance review

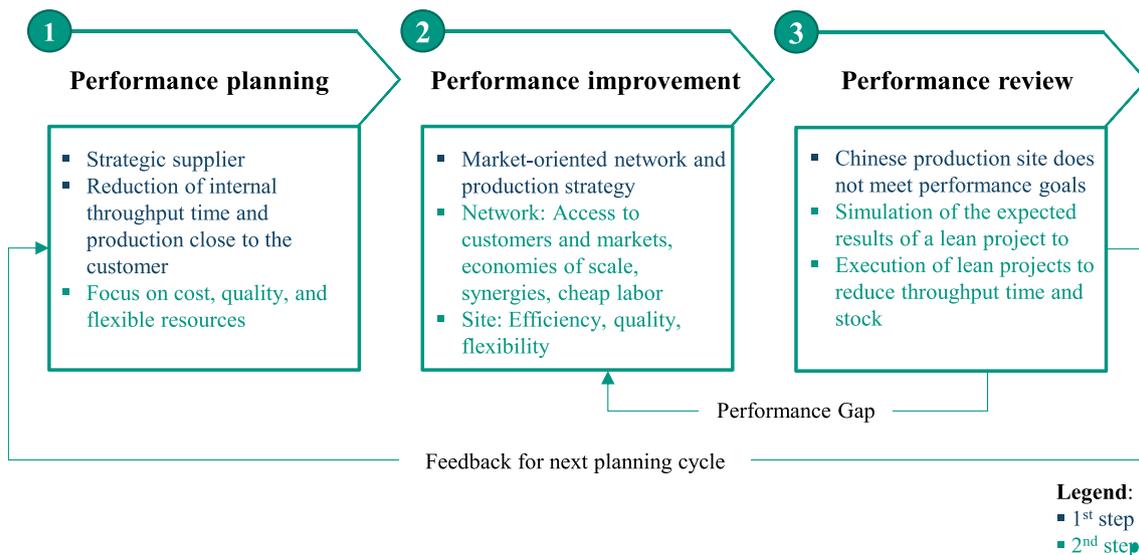


Fig. 9 PMM methodology for the automotive supplier

market-oriented production strategy classifies the capabilities of the categories “efficiency” (costs, resource utilization, and material stock), “quality” (product quality and quality of the distribution processes), and “flexibility” (product flexibility of production resources) as order-winning factors.

Based on the market-oriented network and production strategy, the network management defined quantitative target values with the help of a set of network performance indicators from the developed methodology. The network management disaggregated the targets from the network level to the site level in the next step. In doing so, quantitative target values for all production sites within the GPN were set.

In phase 3, after planning the performance on the corporate level and aligning all strategies of the GPN by setting quantitative targets, the network management reviewed the performance in the next step. The review of planned and accomplished performance revealed that the Chinese production site did not yet meet the set performance goals. To close the identified performance gap, network management-initiated performance improvement projects. The elaboration and implementation of performance improvement measures at the Chinese production site lie within the responsibility of the site management. The Chinese site management defined lean improvement measures to shorten throughput times and to reduce material stocks. To convince the network management of the planned improvement measures, a process centric simulation model of the production lines in the Chinese site was set up to show the impact on the site performance. The process centric simulation model was implemented using AnyLogic©.

For the simulation model, historical demands of the last 18 months, a demand forecast of the next 12 months, machine cycle and change-over times and capacity limitations were used as input information. Based on the historical demand frequency and variation, the inter-arrival times of future customer orders were calculated assuming a normal probability distribution. The order amount is thereby calculated by the historical order volume variation and the forecasted demand plan. The production capacities were simulated by considering the already available machines and tools, the cycle times for each product variant as well as a change-over matrix.

Based on this input information, various alternatives for scheduling work orders were simulated. The current production planning and scheduling approach, which is based on a fixed monthly forecasted plan for the production quantities and sequence, served as the baseline. As alternatives, different production planning and scheduling approaches were simulated, whereby the customer decoupling point was placed at different stages in the production process and the minimum lot sizes per variant of the subsequent production processes were varied for each alternative.

For the simulation model, a process centric simulation approach was chosen. In a process centric simulation model, single blocks represent the production resources (e.g. machines) and entities, which run through the process, represent work orders. Each entity has a defined size (the quantity of the work order) and certain product-specific characteristics (e.g., required cycle time for each of the process steps). For the simulation model three main KPIs were

tracked: Weighted average through-put time, utilization rate and material stock.

Depending on the individual properties of an entity and the number of entities in the entire process, the entity's throughput time results. The average lead time of all entities within a period is determined by a weighted average, using the size of the work order as a weighting criterion.

The utilization rate of the production resources in a period is calculated by the ratio of idle times of the individual resources and active (a block is busy) times.

The Work in Process Stock (WIP) is calculated from the number and size of the entities that are in the process at a given time. The Finished Good Stock is derived from the difference between work order size and sales order quantity for make-to-order variants on the one hand, and from the holding times between work order completion and sales order incoming (simulated by a probability distribution based on the historical sales orders) for make-to-forecast variants on the other hand.

The output of the simulated production planning and scheduling alternatives was compared using these three KPIs. In Fig. 10 the best identified simulation alternatives is compared against the current situation and the defined goals by the network management. The overall enhancement in the utilization rate were minor. Based on the simulation model, it was shown that clustering the product variants into A, B and C parts, each with individual production planning and scheduling strategies, enables greater flexibility due to shorter throughput times with simultaneously low inventories and only minimally lower capacity utilization.

Backed by these simulation results, the Chinese site management convinced the network management of the planned improvement measures.

In the scope of the application of the PMM methodology for GPN, in this industrial use case, the network management of the automotive supplier was supported in defining quantitative performance goals for the GPN and revealing existing performance gaps. The PMM

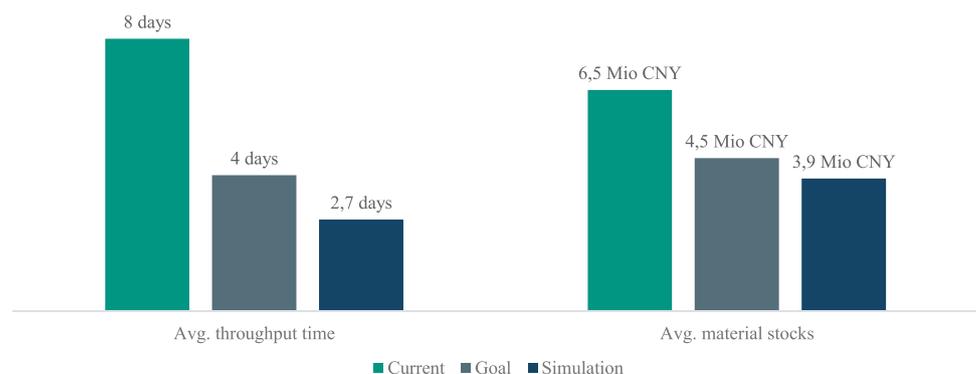
methodology also enabled network management to evaluate site performance improvement measures. In total, the comprehensive PMM approach enabled the network management to align the strategies and goals within the GPN.

## 6 Conclusion

This paper presents a practice-oriented methodology for performance measurement and management in GPNs. The methodology is divided into three phases: performance planning, performance improvement, and performance review. The novelty of the methodology lies in the integrated consideration of a performance measurement approach and a methodology for the management of performance in GPNs. The methodology for aligning the strategies of the GPN was shown and a comprehensive KPI network for managing performance on site and network level was introduced in a use case in the automotive supplier industry. In the use case, the performance of a Chinese production site was improved, considering the corporate strategy and the production strategy of the company. Based on the KPI network and adaptations to requirements and boundary conditions of a specific company, the PMM methodology for GPN has the potential to better align a GPN with the corporate strategy. By doing so, the harmonization of corporate strategy and production network footprint can be enhanced.

Based on the current approach, cultural differences should be reviewed and integrated in the KPIs. Further limitations are apparent in the high level of abstraction of the presented approach. Therefore, only limited practicability is given. A further deep dive into more specific KPIs is needed for detailed root cause analyses. Future research may implement different site roles of the described types of production companies in order to sharpen the needed KPIs for the management of production networks. Furthermore, future research may focus on the mathematical connection of the network KPI level with the respective strategy map of a company.

**Fig. 10** Comparison of selected KPIs at the Chinese production site



## Appendix

The following figures show an overview of the idealistic Strategy-Maps of the seven kinds of production companies presented in the main body of the paper (Figs.

11, 12, 13, 14, 15 and 16). Note, due to nearly the same structure and aims of the “standard component supplier” and “standard component manufacturer”, these two companies share own common idealistic Strategy-Map (see Fig. 13).

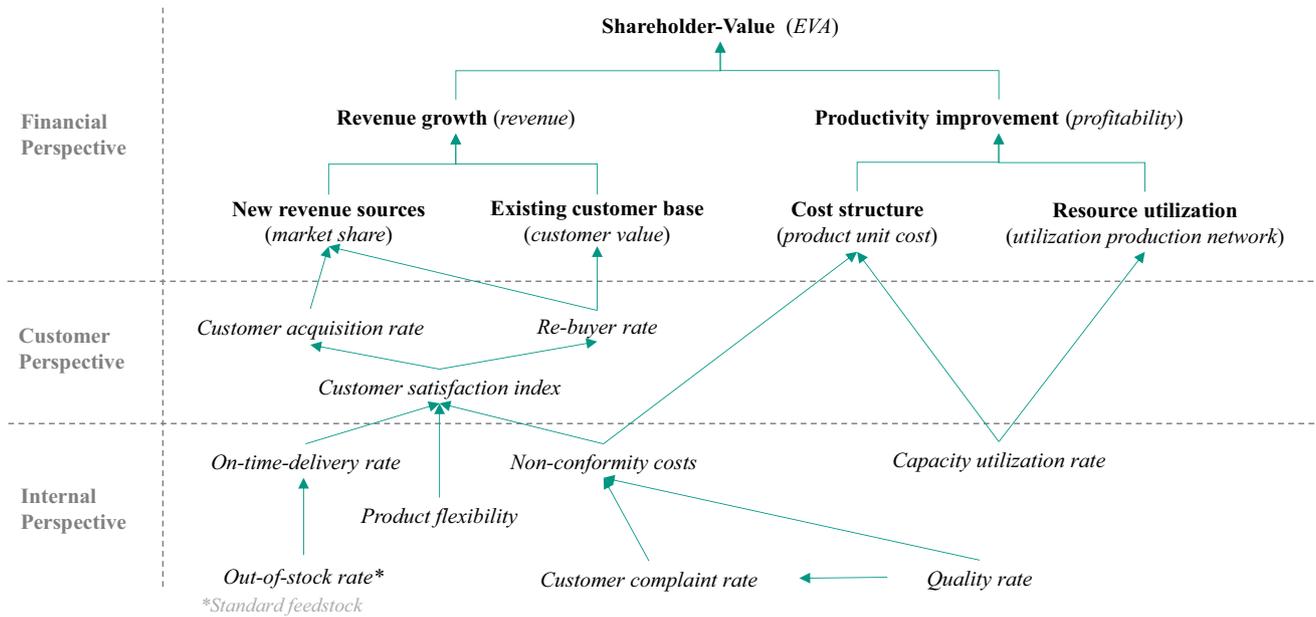


Fig. 11 Strategy-map of the engineer-to-order manufacturer

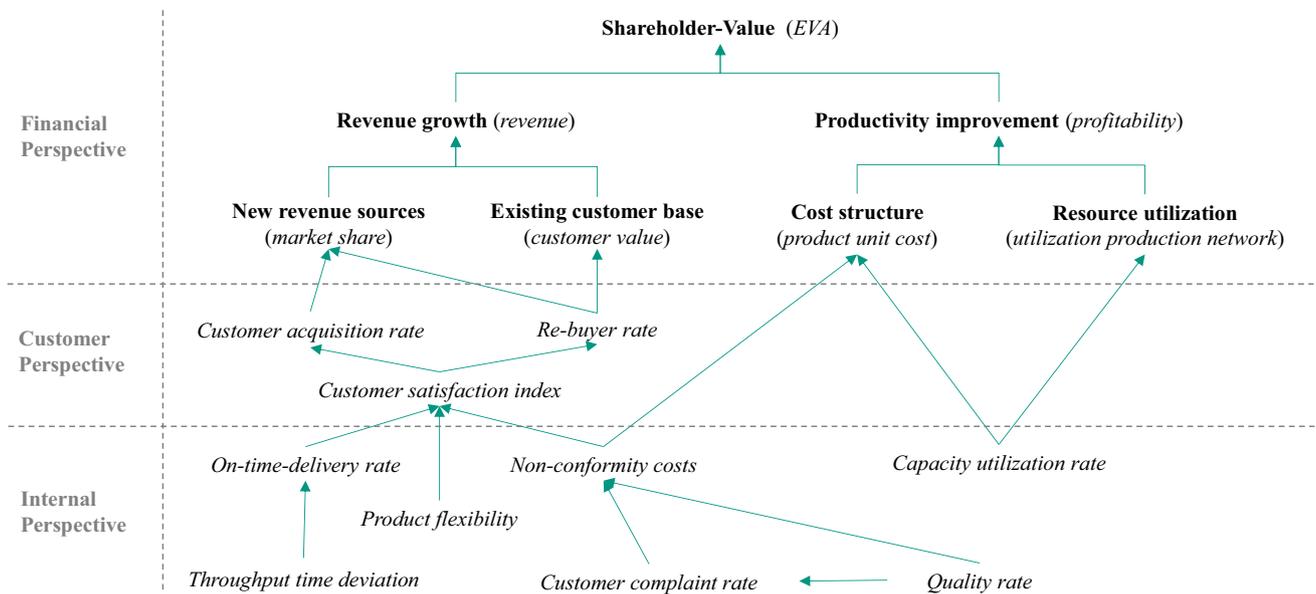


Fig. 12 Strategy-map of the strategic supplier

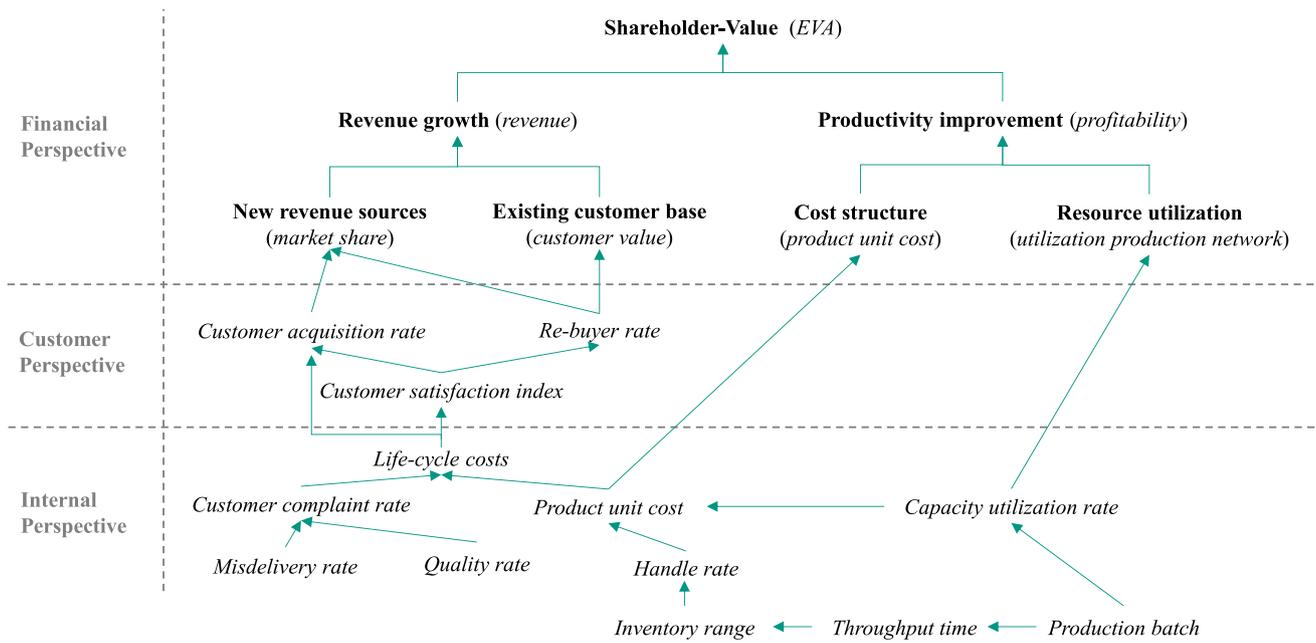


Fig. 13 Strategy-map of the standard components supplier and standard component manufacturer

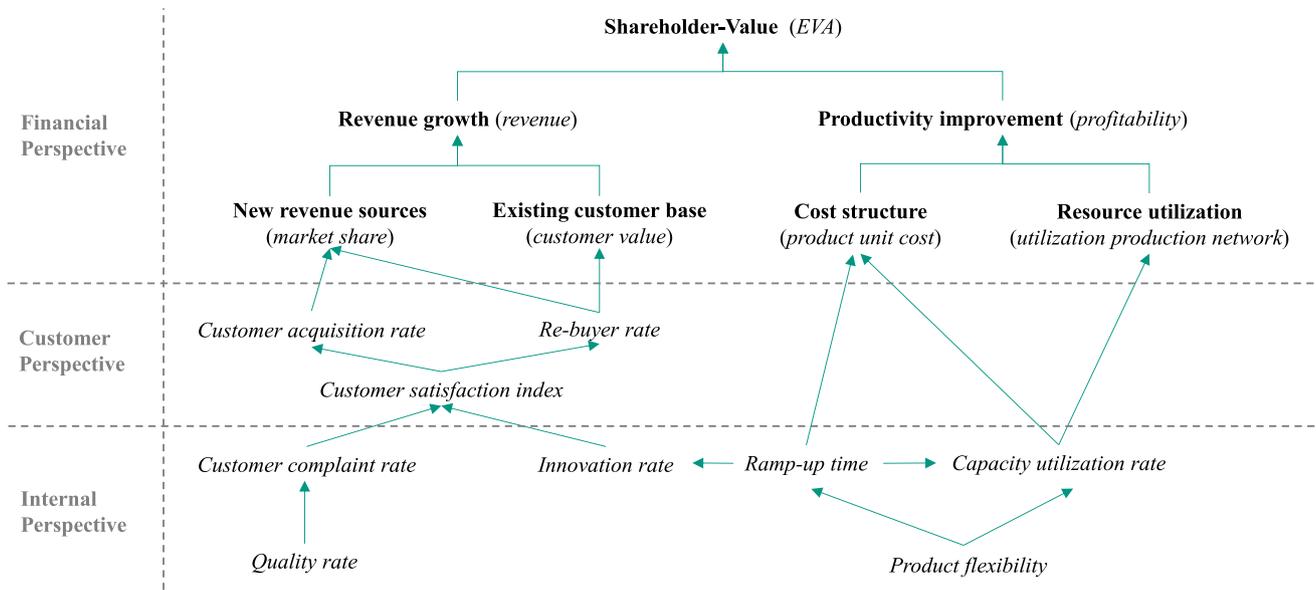


Fig. 14 Strategy-map of the innovative supplier

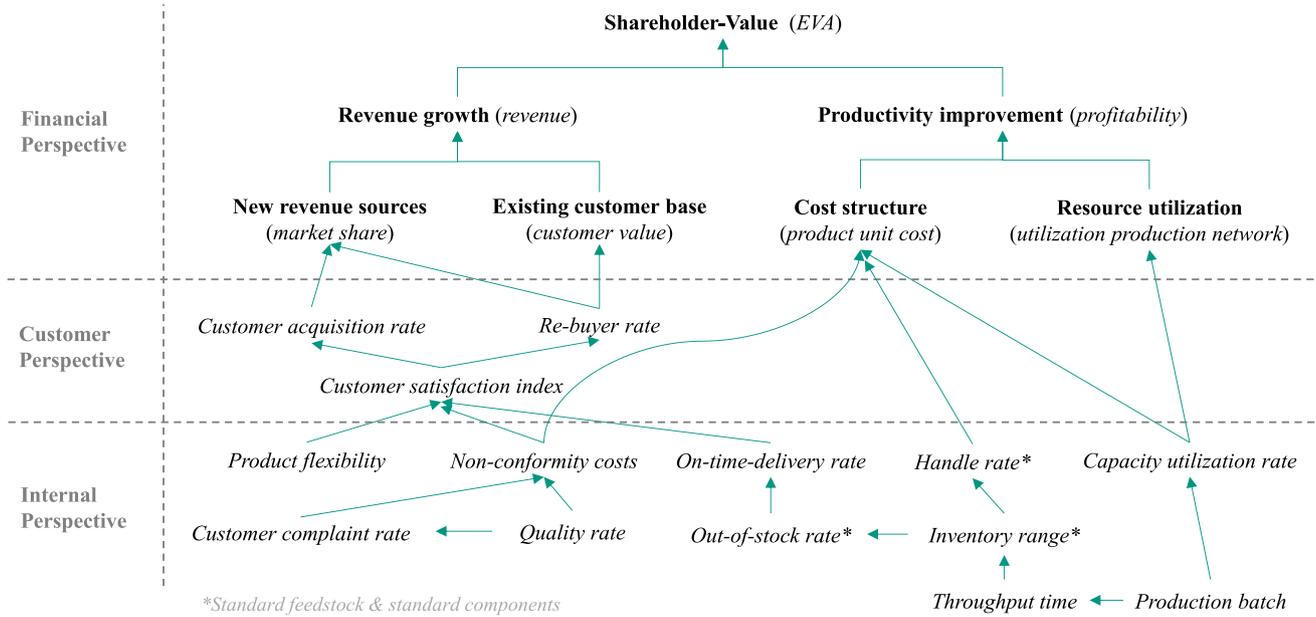


Fig. 15 Strategy-map of the make-to-order manufacturer

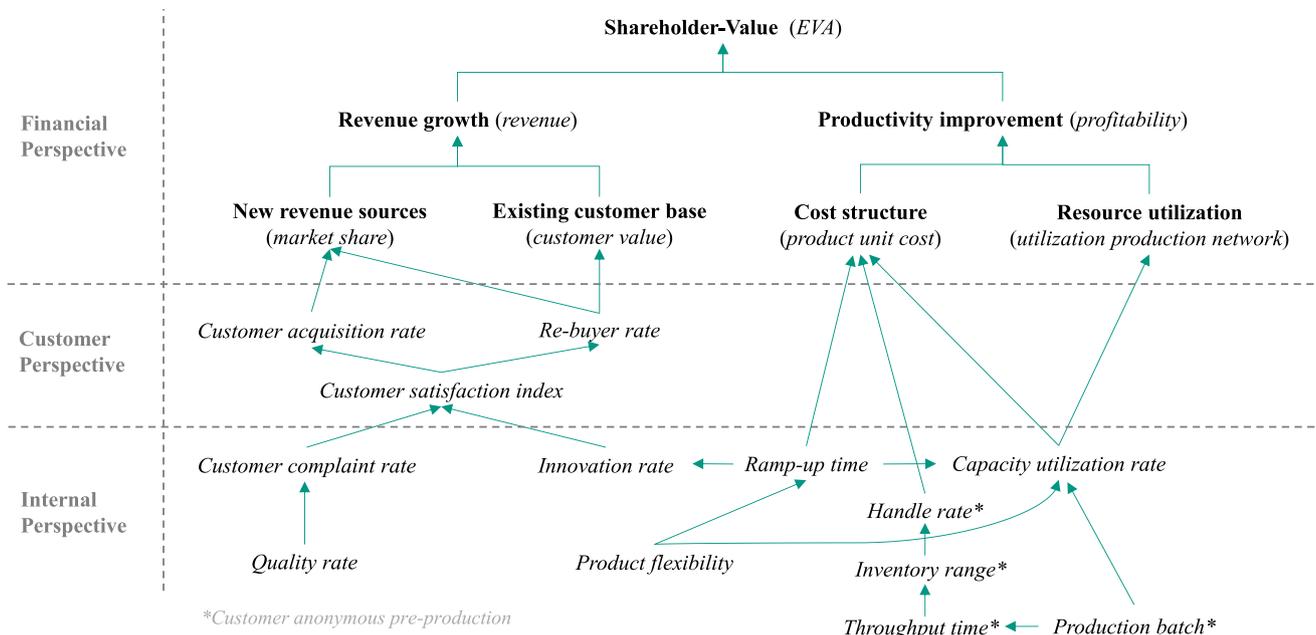


Fig. 16 Strategy-map of the innovative manufacturer

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