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A Performance Measurement System For Global Manufacturing Networks

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Abstract

New developments coming along with globalisation increasingly force companies to realize efficient global manufacturing networks (GMN). Current research offers abundant methods aiming at the configuration of GMNs. However, less attention is paid to identifying the need for adapting existing networks and the comparison of enhanced network configurations. In other fields, like for example logistics, performance measurement systems (PMS) are applied to accomplish these tasks. This paper therefore seeks to support the improvement of network configurations by providing a PMS for GMNs.

In the course of this research existing PMS are reviewed and a multidimensional evaluation is carried out. The system with the best fit is chosen and transferred to the field of GMNs. Subsequently, performance attributes are deduced from a strategic and operational point of view based on a literature review as well as the application of concepts known from life-cycle-management and systems theory. The proposed PMS is validated by an industrial case study.

The results of the multidimensional evaluation show that the concept of selective key figures that is known from the field of logistics has the best fit to serve as a basis for a novel PMS for GMNs. The transferred PMS consists of metrics evaluating the strategic success factors of GMNs like flexibility and delivery reliability on the one hand and possible operational bottlenecks like complexity on the other hand. The validation of the PMS in a real life environment shows that it contributes to overcoming the identified gap in the literature and supports practitioners in the process of enhancing GMNs.

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1. Introduction

1.1. Motivation

Manufacturing companies face increasingly competitive and volatile environments due to the inexorable progress of globalisation during the last decades [1,2]. New developments like the global mobility of people, decreasing communication and transportation costs and the reduction of customs as well as trade restrictions enable companies to realise efficient global manufacturing networks (GMNs) in order to be prepared for the upcoming challenges [3,4].

The network configuration development as a decision process follows the generic sequence of formulating the problem, specifying the target system, investigating the action alternatives, selecting one alternative and making decisions during the implementation phase [5]. While research focusses on the overall network configuration development as well as the single steps of the decision process less attention is paid to the starting point of the configuration of GMNs - the identification of the need for

action or as it is formulated by the Institute of Manufacturing of the University of Cambridge: “Why is it necessary to evolve the manufacturing network?” [6]

The answer to this question necessitates a continuous monitoring of the forecast for the key performance indicators that are used to evaluate the existing manufacturing network. The aim of this research therefore is to support the identification of the need for evolving a manufacturing network by providing a Performance Measurement System (PMS) that is “defined as the set of metrics used to quantify both the efficiency and effectiveness of actions” [7]. As metrics have to be defined individually by each company in order to consider individual requirements [8,9] the PMS shall not be formulated by providing a list of predetermined metrics but by defining relevant evaluation dimensions that need to be covered by individually definable key figures.

1.2. Structure of the Paper

The paper is arranged as follows. The literature review provides an analysis of the state of the art concerning PMS for

GMNs as well as the identified research gap. The third section is used for the description and comparison of existing concepts for PMS as well as the selection of the concept with the best fit for the evaluation of GMNs. Sections four and five contain the deduction of key figures from a strategic respectively operational point of view followed by the resulting PMS in section six. The description of the application of the PMS in an industrial case study and the conclusions close the paper.

2. Literature review

2.1. Structure of the state of the art

Existing literature dealing with performance measurement of GMNs and - in a larger context - of supply chains is vast. The relevant research can be classified in two categories. The first one contains methods to examine performance measurement aspects in the context of the configuration process of GMNs. Models that are belonging to the second category in contrast exclusively focus on performance measurement of GMNs.

2.2. Integrated Performance Measurement Approaches

Relevant integrated performance measurement approaches are provided by Liebeck [3], Varandani [10] and Herm [11]. Liebeck [3] presents a market- and resource-oriented network design model that emanates from the market service of a company with respect to the customers point of view. The cost-side of the company is considered by a process-oriented modelling and monetary evaluation of the necessary production steps. With this approach Liebeck [3] combines the external market view with the internal business-management view.

Varandani [10] proposes a multi-stage network configuration process model starting with a single objective mathematical model that optimizes the total landed costs. By varying the input parameters a set of possible network configuration alternatives is created. These solutions are evaluated with respect to the resulting management complexity of the network in a second step. By this means Varandani [10] expands the strategic point of view of the network configuration by an objective considering the operational practice.

Herm [11] uses so called business capabilities for the configuration of GMNs. The definition of capabilities results amongst others from the analysis of relevant value-adding processes for the manufacturing of a product. In this respect Herm [11] attributes more value to the product than comparable approaches. For the evaluation of network alternatives Herm [11] comes back to the four main dimensions of business objectives cost, time, quality and flexibility as suggested by De Toni & Tonchia [12].

2.3. Stand alone Performance Measurement Approaches

Besides the integrated consideration of performance measurement, literature provides models focussing the design of PMS relating to GMNs.

Ude [13] postulates that performance measurement approaches need to be independent of the method how a network configuration alternative is generated in contrast to the integrated evaluation models. He proposes a multi-stage procedure that

combines the quantitative evaluation by means of a simulation model and qualitative aspects by the application of the multi-criteria decision analysis method PROMETHEE. The main considered qualitative objectives are costs and throughput time. Furthermore, the approach includes methods to analyse the robustness of possible network configuration alternatives. By applying PROMETHEE supplemented by Monte Carlo simulations and sensitivity analysis Ude [13] shows a clear focus on the preparation of a decision for one alternative by providing an in depth analysis and comparison of possible solutions.

Krebs [14] proposes an approach for the cross-linked site selection with respect to multidimensional uncertainties. The modelling of qualitative uncertainties is carried out by means of fuzzy set theory. The Market Value Added represents the main objective. With the clear focus on site selection Krebs [14] covers one aspect of the holistic evaluation of GMNs in depth.

Chan [15] presents both quantitative and qualitative performance measurements for supply chains. While quantitatively a classification is conducted in cost and resource utilisation the categories quality, flexibility, visibility, trust and innovativeness are distinguished qualitatively. In order to prioritize the performance measures the analytic hierarchy process (AHP) is applied. However, the metrics are a conglomeration that is not integrated in a framework that describes the performance of a supply chain out of multidimensional views. [15]

This shortcoming forms the starting point for the framework for supply chain performance measurement proposed by Gunasekaran et al. [8]. Their framework is spanned by the four major supply chain activities plan, source, make/assemble and deliver on the one hand and the management levels strategic, tactical and operational on the other hand. For each combination of supply chain activity and level of management performance measurement metrics are provided. The proposed framework is a mapping of responsibilities and company departments. Multidimensional perspectives like the financial aspects or the customers point of view that need to be covered by the performance measurement metrics are not considered. [8]

Bhagwat & Sharma [16], Richert [17] and Giese [18] try to overcome this deficit by developing a PMS for supply chains on the basis of the Balanced Scorecard (BSC) concept. Representative for these PMS a closer look is taken at the concept of Bhagwat & Sharma [16]. They assign the proposed metrics of Gunasekaran et al. [8] to the four perspectives of the BSC: financial, customer, internal business and learning & growth [21]. Hereby a comprehensive PMS has been created for the measurement of strategic supply chain performance. The authors recommend future research in order to examine whether the four perspectives of the BSC and the listed metrics are adequate to analyse the performance of a supply chain.

Beamon [19] took a similar approach and developed a PMS for supply chains with the focus on strategy. The performance measurement types resources, output and flexibility are considered. The first dimension contains cost metrics, the second customer service aspects and the third one the ability to change. It needs to be emphasized that this PMS formed the basis for a multi-objective optimisation model for supply chain planning [20]. Hence, a connection between the PMS and supply chain design has been established. However, the developed PMS on the basis of the BSC appear more balanced as they include the dimensions proposed by Beamon and beyond that consider additional aspects.

2.4. Research gap

Each of the mentioned integrated performance measurement approaches comes up with an innovative aspect. Liebeck [3] combines the market and the business management view, Varadani [10] supplements strategic factors with the evaluation of operational aspects and Herm [11] emphasizes the importance of considering the product. However, there is no approach that combines these concepts.

The stand alone performance measurement approaches of Ude [13] and Krebs [14] give insight in relevant performance dimensions as well as sophisticated methods to determine the robustness of various possible solutions. Though, these models are focussed on bringing about a decision. Therefore, these approaches are thought to examine and compare various action alternatives in depth. This comes along with a huge effort that needs to be spent for the application of the proposed evaluation models and contradicts the aspired continuous monitoring of a GMN.

The remaining approaches show a clear advancement that began with lists of metrics [15] that developed to a structured classification of performance measures [8] and ended in strategic PMS based on the concept of the BSC. These models focus entire supply chains and therefore attribute great importance to inter company relationships. The focus of this research however is the configuration of a focal companies' manufacturing network and is therefore one level below and demands an adoption of the proposed concepts in this respect. Beyond that, known concepts are restricted to strategic aspects and leave operational and leave operational aspects unattended.

In conclusion, to the best of the authors' knowledge no coherent PMS for the monitoring of GMNs exists.

3. Determination of the basic PMS concept

3.1. Presentation of mature PMS

The first approaches for PMS trace back to the measurement of financial metrics. By gradually enhancing these models sophisticated PMS like the BSC, the PMS integrated in the Supply Chain Operations Reference (SCOR) model and the Concept of Selective Metrics (CSM) evolved. [17]

The BSC is among the most widespread PMS in the operational practice [22]. The basic idea of this concept is to provide a well-balanced system for the evaluation of the effectiveness and efficiency as well as the capabilities of a company. The BSC is subdivided in the four above mentioned dimensions financial, customer, internal business and learning & growth. In each dimension a set of metrics targeted at the evaluation of the realisation of the company's strategy is provided. [21]

The SCOR model is intended for the description of intra- and inter company business processes [23]. It is subdivided in three hierarchical levels. The first level serves a company to define the individual scope and levels two and three assist to configure and detail the supply chain. Performance attributes describe relevant evaluation dimensions on each level and possible metrics are assigned to each performance attribute. On the first level the processes plan, source, make, deliver and return are distinguished and measured by the five performance attributes reliability, responsiveness, flexibility, costs and asset manage-

ment [23].

The CSM has been developed for the performance measurement in the field of logistics. It does not represent a definite system of metrics but a design approach for compact PMS in three steps. Firstly, the logistics strategy of a company is formulated and strategy conform metrics are deduced. Secondly, metrics evaluating the flow of materials on an operational level are developed. Thirdly, both the operational and strategic level are connected by establishing logical or mathematical relations between the metrics [24]. Figure 1 illustrates the structure of the CSM.

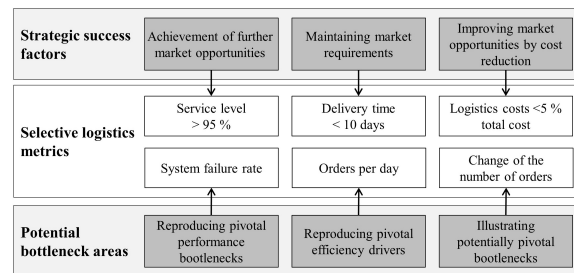


Fig. 1. Concept of selective key figures [25]

3.2. Selection of a basis PMS concept

Lelke [26] developed a coherent catalogue of criteria for the evaluation of PMS consisting of eight evaluation dimensions. Amongst others the aspects problem adequacy, consistency, flexibility, balance and economic efficiency are considered. His comparison of the BSC and the CSM shows that both PMS meet the criteria. An analogue assessment of the SCOR model does also not show deciding shortcomings. This proves the quality of these widely spread PMS. The applicability of the mentioned PMS as a basis for the problem at hand can therefore be taken as granted.

As more specific eligibility criteria the idea of considering a strategic as well as operational view mentioned in section 2 and the transferability of the PMS to the field of GMNs shall be considered.

The SCOR model and the CSM contain strategic and operational aspects while the BSC has a clear focus on strategy. The SCOR model as a hierarchical system represents a top down approach. While the first level shall empower the higher management to draw decisions, levels two and three consider operational aspects. In contrast, the CSM examines the strategic and operational evaluation as equally important performance measurement dimensions.

The BSC has been established in various industries and for an evaluation horizon of whole companies as well as single functional areas. These aspects prove the transferability of the BSC. The same applies to the CSM as it represents a design approach and not a specific PMS. The SCOR model on the contrary is designed for the examination of supply chains. For a transfer to the field of GMNs only the basic idea of structuring GMNs in processes with assigned performance attributes and metrics can be used.

In conclusion, the BSC does not consider the claimed operational aspects and the transferability of the SCOR model to

GMNs is very limited. As the CSM meets both requirements the PMS for GMNs is developed on this basis. In addition, the approach provided by the SCOR model of defining general performance attributes that are to be described by metrics individually by each company is adopted. The next steps therefore consist in deducing strategic as well as operational performance attributes and merging the two views on the GMN.

4. Deduction of strategic performance attributes

The deduction of strategic performance attributes (SPA) emanates from the axiom that producing companies pursue the sustainable maximisation of the profit from selling products to customers. Besides the obvious financial aspect, the product and the customer result as dimensions that need to be considered for defining SPA. The axiomatic deduction of relevant aspects is in line with ideas presented in section 2. Liebeck [3] emphasizes the importance of the market view and Herm [11] uses the product for the selection of metrics. Concerning the third dimension the pivotal question is which challenges arise for a manufacturing network by considering the product. Relevant determinants on a network level are for example the number and location of factories or the overall production capacity. Hence, the challenges do not yield from the construction of a product nor from aspects that determine the difficulty of the production process like the necessary production technologies. The challenges for GMNs induced by products originate from a more superordinate level that becomes obvious by classifying the technology a product belongs to into the technology life cycle. Figure 2 shows the phases of the technology life cycle by Arthur. D. Little [27].

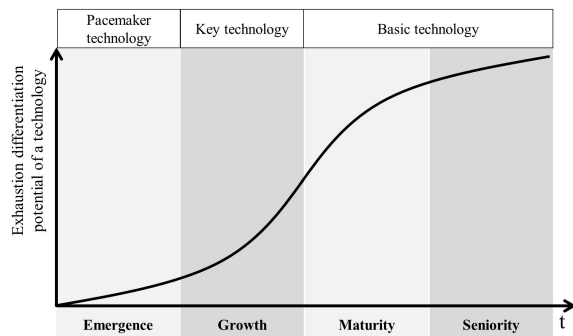


Fig. 2. Technology lifecycle model according to Arthur D. Little [27]

The first phase is affected by research and development and is therefore not crucial for production networks. With the beginning of the second phase rapid extensive growth of demand may begin. GMN for products in this technology life cycle phase therefore need to be responsive in order to be able to cope with an increasing demand. Products that belong to the third phase will no longer experience leaps in demand. The challenge that needs to be met in that phase is to cope with short-term fluctuating demand. Hence, the GMN has to be flexible. On the contrary the demand for products belonging to the last phase may suffer falls in demand. The challenge for GMNs is to avoid residual costs. Table 1 summarizes the challenges

as well as SPAs that are deduced from the classification of a product in the technology life cycle.

Table 1. SPAs deduced from the technology life cycle.

Phase	Dominating Challenge	SPA
1	(not relevant)	(not relevant)
2	adoption to major demand leaps	quantity responsiveness
3	adoption to short-term fluctuating demand	quantity flexibility
4	avoidance of residual costs	residual costs risk

SPAs with respect to the market-view are defined by referring to customer needs. Friedli et al. [28] provide a comprehensive list of customer needs based on a literature review: price, quality, delivery pace, delivery reliability, product range and design flexibility, order quantity flexibility, innovation and service. However, not all of these customer needs can be remarkably influenced by a GMN. Innovation as well as product range and design flexibility are superordinate propositions that have to be met by GMNs. The price is defined by the market as most of today's markets are buyers' markets. Quality has also to be excluded from the SPAs list as identified quality problems will first and foremost not lead to a change of a GMN but to measures on the factory or lower levels. The customer need service can be satisfied all over the world almost independently of the GMN. The remaining customer needs delivery pace, delivery reliability and quantity flexibility represent SPAs for GMNs. The financial aspect is not discussed in detail as it is assumed that financial performance measurement has become firmly established in industry [17]. Financial aspects are therefore incorporated in the PMS as one SPA named business economics.

5. Deduction of operational performance attributes

By measuring operational performance attributes (OPA) the basis for the successful implementation of SPAs shall be assured [24]. For the deduction of OPAs the structure of the considered system needs to be analysed [24]. Weber et al. [24] developed the structure illustrated in figure 3 for this analysis on the basis of systems theoretical approaches.

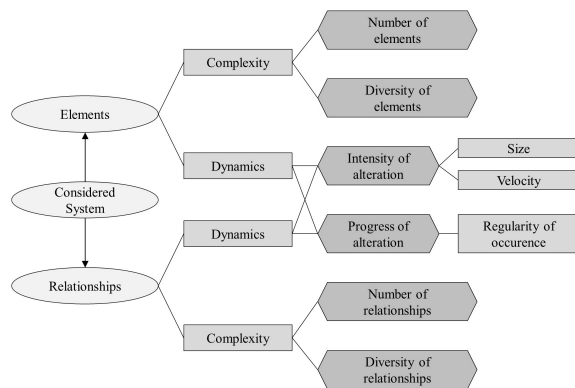


Fig. 3. System analysis by Weber et al. [24]

The system is divided in elements and relationships between the elements that are described in the dimensions complex-

ity and dynamics. While the former results from the number and diversity of elements and relationships the latter arises from their alteration which in turn is subdivided in intensity and progress. Intensity is specified by the size and velocity of changes and progress by the regularity of occurrence. [24]

This structure can be transferred to manufacturing networks and be further elaborated. The elements and relationships of a GMN are nodes and edges. The nodes are represented by production lines. However, a complete description of GMNs requires the definition of sources and sinks. Herm [11] defines the sources as supplier markets and the sinks as sales markets respectively customers. Although these nodes are not within the production network itself they have to be considered as relationships to the network exist. Physical exchange relationships in the form of the flow of material between nodes define the edges of GMNs. In addition to the structure the evaluation dimensions proposed by Weber et al. [24] need to be transferred to GMNs. Referring to complexity the characteristic dimensions can be conclusively converted. The number and diversity of nodes appear as appropriate OPAs. The description of dynamics in the form of intensity and progress is however not suited for a direct transference. Instead of the progress of changes with the metric of regularity the frequency of changes is decisive for the dynamics of GMNs. The measurand intensity of a change proposed by Weber et al. [24] that is specified by size and velocity can be interpreted as impact of a change in the context of GMNs.

6. Formation of an integrated PMS

Figure 4 illustrates the resulting structure of the PMS with exemplary metrics for each SPA and OPA.

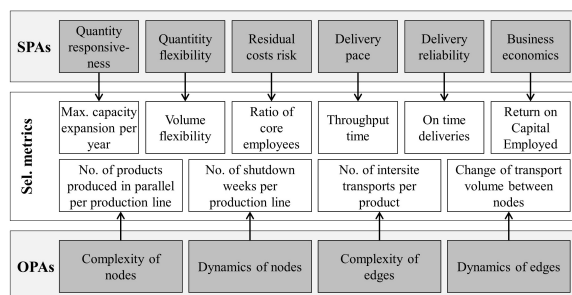


Fig. 4. Structure of the PMS for GMNs

In analogy to Weber et al. [24] the final step following the deduction of SPAs and OPAs is to merge and connect the two views on the GMN. The purpose is to identify interdependencies of SPAs and OPAs. Adverse effects of SPAs on OPAs are of particular importance as in this case a trade-off between the achievement of strategic objectives and operational disadvantages is necessary. For this analysis the complexity and dynamics of nodes respectively edges is pooled as the dynamics represents the temporal change of the complexity and an isolated consideration would therefore not yield different insights.

Realising a GMN at optimal cost has to be based on the utilisation of site specific cost advantages for each value-added step and will therefore result in a dispersed network. The emerging supply relationships lead to a high complexity of edges. This

effect does not occur if transport costs are pivotal as a cost optimisation approach will result in a world factory concept. General negative consequences of a cost-effective network design on nodes cannot be identified.

Striving for a high network flexibility in contrast requires the ability to manufacture one product on different production lines or to increase the installed capacity. As this comes along with an increasing number of production lines and products manufactured by one production line as well as a growing number of production paths, a high flexibility will be at the expense of rising complexity of nodes and edges. The responsiveness of a GMN as an expansion to flexibility in contrast goes beyond the limits of the existing system. General negative effects on existing production lines or flow of materials cannot be identified.

In order to realise a low residual costs risk it has to be ensured that the capacity of each site is sufficiently utilised. This requires the ability to manufacture one product at different sites in order to be able to balance product specific slumps in demand. In analogy to the explanations concerning flexibility this results in negative effects on the complexity of nodes and edges. The ability to balance demand fluctuations has positive effects on the delivery reliability as breakdowns of sites can be compensated. Therefore the negative interdependency between a low residual costs risk and the complexity of nodes and edges can be transferred to the SPA of a high delivery reliability. The remaining SPAs delivery pace do not yield obvious negative consequences on OPAs.

7. Industrial Case Study

The applicability and benefit of the proposed PMS has been evaluated in a real life environment. The object of investigation has been the GMN for combustion engines of an automobile manufacturer. For reasons of confidentiality all presented information is alienated. Accordingly, the provided results only serve as an illustration of the proposed concept. In the course of the case study the three steps of determining relevant SPAs and associated metrics, determining relevant OPAs and associated metrics and consolidating the SPAs and OPAs have been ran carried out.

The first step of applying the proposed concept is to classify the considered product technology in the technology life cycle. Combustion engines belong to the third phase. As a consequence the SPA flexibility needs to be examined while the responsiveness and the risk of residual costs can be neglected as neither remarkable demand growth nor extensive demand losses are to be expected. Quantity flexibility, delivery pace, delivery reliability and business economics formed the SPAs in course of the case study. As the OPAs do not depend on case-specific parameters they were applied without restrictions. The definition of metrics specifying the various performance attributes has been carried out in close coordination with the responsible specialist departments in order to meet the individual requirements of the company.

The considered GMN is characterised by manifold supply relationships for components between different sites. The measurement of flexibility was therefore a challenging task that could not be accomplished by one but three metrics. Firstly, the volume flexibility on the assumption of a constant product mix, secondly the possible exchange flexibility of diesel and gaso-

line engines and thirdly the volume flexibility of each engine type. In contrast to measuring flexibility the quantification of the delivery pace has been interpreted as the average throughput time per engine. The metrics referring to delivery reliability provided by literature are in general oriented towards the past like for example the monitoring of the percentage of on time delivered orders. An early identification of the need for action requires a future oriented metric. Therefore, the maximum possible capacity loss per year without an impact on the order fulfilment has been calculated for each production line. For the evaluation of the financial performance the metrics one-time-spending per year and the temporal progress of the current expenses have been chosen. Other well known metrics like for example the return-on-capital-employed (ROCE) were considered as too complex and too high-level for a continuous monitoring of a network. For measuring the OPAs one metric per OPA has been defined:

- Complexity of nodes: number of products that are manufactured in parallel on a production line
- Dynamics of nodes: predicted change of the production rate of each production line from month to month
- Complexity of edges: number of possible combinations of production lines that can be used to produce an engine
- Dynamics of edges: predicted change of the transport volume per edge from month to month

In the last phase of developing a PMS for the GMN for combustion engines possible negative interdependencies between the metrics describing SPAs and OPAs were analysed. As not all of the defined SPAs have been included in the developed PMS only the following negative interdependencies were identified: financial metrics - complexity of edges, flexibility metrics - complexity of nodes and edges and delivery reliability - complexity of nodes. The consolidation of the used SPAs and OPAs turned out to be helpful for the interpretation of the metrics. For reasons of confidentiality no details concerning the recording of the defined key figures and the identified need for action are allowed to be presented.

8. Summary and conclusions

The inexorable progress of globalisation during the last decades forces companies to produce in GMNs. The starting point for this article is formed by the widely unregarded identification of the need to change the configuration of a GMN by research. To overcome this gap a PMS on the basis of the CSM is proposed for the continuous monitoring of a GMN. The PMS includes the measurement of strategic as well as operational performance attributes. The applicability of the developed approach has been proved in an industrial case study. Further research is necessary to integrate the evaluation of uncertainty in the PMS. However, the complexity of the PMS needs to remain on a manageable level as the intended use of the PMS is the continuous monitoring and not a non-recurring evaluation of a GMN. The application of the PMS revealed that literature provides numerous metrics for evaluating the defined SPAs. Operational aspects in contrast are less considered. In order to examine and improve the proposed PMS the application in other industries is recommended.

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