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Evaluation of performance differences between manufacturing sites

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Abstract

In order to profit from local differences regarding factor costs, ensure proximity to customers and get access to new markets most of today's manufacturing companies established production sites around the world. Usually the performance of these sites differ significantly. Currently companies are not able to explain and evaluate the performance discrepancies since production sites differ in technological equipment, local framework conditions and other aspects. The inability to evaluate performance differences prevents an efficient and effective improvement of the design of production networks. Therefore the aim of this paper is to develop a method to evaluate performance differences between manufacturing sites.

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1. Introduction and challenges in the performance evaluation of production sites

In recent decades many companies expanded their production network on a global scale also frequently by acquisitions to get access to new markets and realize cost advantages [1]. In the course of this progress global manufacturing networks became more and more complex inter alia due to the geographical distribution of sites, a growing product diversity, sophisticated manufacturing processes and many other aspects [2]. This development led to historically grown manufacturing networks consisting of sites which differ from each other significantly in many characteristics, e.g. the product variant diversity, the degree of automatization, produced quantities and environmental influences like labor market conditions [3].

In order to stay competitive companies are forced to optimize their global production networks including each site continuously [4]. One option to identify optimization potentials within production networks is the performance measurement of production sites and furthermore the comparison of the detected site performances [5]. Due to the heterogeneity of production sites, companies are not able to explain and evaluate performance differences between sites. If for instance the productivity of site one differs from the productivity of site two and these two sites differ from each other in aspects like the degree of automatization, the size and other environmental conditions, the management is not able to evaluate the performance difference. The difference could result from site characteristics or from real performance deficits, which refers e.g. to a lack of commitment and employees with a lower productivity at a certain site. Hence companies require an approach which takes the heterogeneity of production sites into account while evaluating the sites' performances.

Beyond the fact that site characteristics are not considered within the performance process, companies struggle with missing standards for the calculation of key performance indicators (KPIs). The lack of a standardized calculation method results in the situation, that KPIs themselves are not comparable [6]. Furthermore many production networks suffer from inconsistent data sources, which leads to an incorrect calculation of KPIs [7].

The incapability to evaluate differences in the performance of sites, prevents an efficient and effective development of production sites in the production network. An effective benchmarking within the network requires the ability to explain and evaluate performance differences [8]. The knowledge about cause-and-effect relations of differences in performance of production sites and location characteristics is necessary in order to implement appropriate measures, to be

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able to transfer knowledge at suitable positions and to enable an effective learning.

If there is for instance a difference concerning the productivity between site one and two due to outdated machinery at site one, a suitable measure would be the purchase of new machinery. If the performance difference is not reducible to any location characteristic, trainings or experience exchanges would be the appropriate measure.

In summary the following challenges concerning the performance evaluation of production sites result:

- Missing standards regarding the performance evaluation of production sites
- Neglecting of location characteristics while evaluating their performance
- Lacking transparency concerning cause-and-effect relations of performance differences

Cause-and-effect relations within production systems are explored within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" in the context of the decision orientated Theory of Production. This paper aims at making a contribution to this topic and focuses on cause-and-effect relations of performance differences of production sites.

2. State of the art

The following section analyzes the state of the art regarding the evaluation of performance differences between manufacturing sites. At the beginning general KPI-systems for the evaluation of performance are surveyed. Secondly KPI-systems, which focus the performance assessment of global production networks are discussed. Finally approaches for the identification of cause-and-effect relations in production networks are examined.

2.1. General KPI-systems

There are already numerous well established KPI-systems, which evaluate the performance of businesses in general [9]. These approaches focus on financial dimensions and neglect idiosyncrasies of globally distributed production sites [10]. In the following section such KPI-systems will be discussed.

The concept of the Balanced Scorecard by Kaplan and Norton is one of the best known methods for performance measurement. A Balanced Scorecard examines a company with regard to the strategy in four perspectives: the financial perspective, the customer perspective, the internal processes and the learning and development perspective. However, it is not focused on specifics of production sites and offers no approach to determine cause-and-effect relations in manufacturing networks [11].

The Du-Pont-System was developed from Du Pont de Nemours and Co. and focuses only monetary variables for evaluating a company and is structured in the form of a pyramid. The return on investment is located at the top of this pyramid. This figure is composed of the product of the profit-turnover ratio and the asset turnover. These figures can be calculated again with other indicators, such as the return on capital, the turnover and the total capital. The Du-Pont-System examines only the financial situation of companies and neglects features that should be considered when measuring the performance of production sites. The approach does not consider the evaluation of performance differences of locations either [12].

In addition to the concept of the Balanced Scorecard and the Du-Pont-System many other approaches exist that primarily assess the financial situation of companies, e.g. Tableau de Bord, SMART-Pyramid or the Performance Measurement Matrix. A detailed listing of existing approaches can be found for instance at Pekkola[13] or Demartini[14].

2.2. KPI-systems for global production networks

Beyond the numerous approaches addressing the financial evaluation of businesses a few consider performance measurement especially for global production networks.

Liebetrau developed a strategic performance measurement and management system for production networks (SPMMS). The approach focuses the fit of the company’s strategy with the production network’s and production site’s strategy. Beyond that special guidelines are given how to monitor the strategy implementation at every site. During the performance measurement process the author is merely pointing out that only similar locations should be compared in order to identify optimization potentials. However, it is not described according to what criteria the network can be clustered to identify similar locations. No cause-and-effect relations are examined [9].

A model presented by Reichert enables the distribution of additional production volumes to productions sites depending on their technical capabilities and competencies. The author develops the MAE P³ (machinery and equipment - process - product - planning) method, which compares production lines and process chains to identify, which sites are able to produce specific products. If several locations are worth considering, a KPI, which evaluates the process control, is calculated in order to determine the site which has the highest level of competence. Reichert provides an approach which enables the comparison of sites with regard to their process control. Additional performance indicators are not considered. Thus, this approach does not identify cause-and-effect relations of site characteristics and performance differences [15].

2.3. Approaches for the identification of cause-and-effect relations in production networks

Additionally there are two approaches which examine cause-and-effect relations of performance differences.

Chew et al. investigate the effect of management on the network performance. At the beginning the management’s scope of action is analyzed. Then productivity differences between locations of a food producer are examined. At the end the authors provide recommendations how a knowledge-sharing could be organized within the corporate network. In addition to the performance factor productivity no further dimensions to measure location performance are analyzed. Moreover, only locations are compared which produce very similar products with the same production process. It is not examined how heterogeneous sites can be compared [16].

In analogy to the approach of Chew et al., Hayes et al. analyze productivity differences of locations. Again only the measure productivity is examined, although the performance of production sites has more dimensions. Beyond that just very few site characteristics are analyzed and solely very homogeneous production sites with the same product portfolio are compared [17].

The approaches of Chew et al. and Hayes et al. lack a derivation of the most important indicators for assessing the performance of sites as well as the elementary location characteristics which need to be considered while evaluating performance differences. Both of the models only examine productivity differences of homogenous production sites.

3. Evaluation of performance differences between manufacturing sites

Performance differences between manufacturing sites result from influenceable and uninfluenceable location characteristics as well as from the pure site performance (cf. Fig. 1). Influenceable site characteristics are conditions, which can be changed by a network manager, e.g. the technological equipment, the size of the location or the products being produced at the site. Uninfluenceable location characteristics cannot be affected by the company at all, e.g. labor market conditions or tariff regulations. The site performance expresses the performance which is caused solely by the location and not by any other framework conditions. For instance if the site suffers from demotivated employees or a poor plant manager, the site will not perform in the same way like a site with motivated employees and an excellent plant manager will do. Obviously the site performance can suffer due to certain site characteristics, which e.g. can demotivate employees.

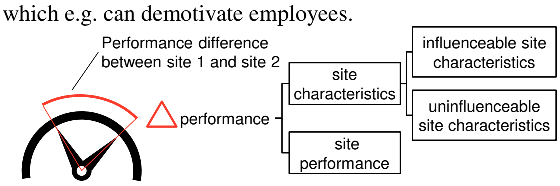


Fig. 1 Sources of performance differences between manufacturing sites

In the following section a method will be described, which enables the identification of cause-and-effect relations which are inevitable to assess performance differences between manufacturing sites (cf. Fig. 2).

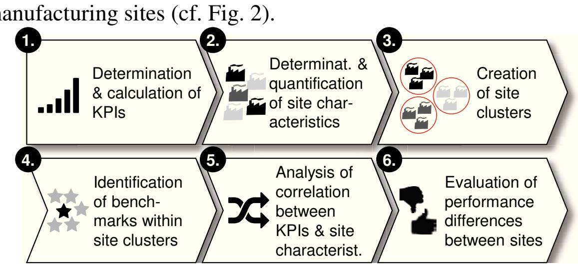


Fig. 2 Method for the evaluation of performance differences

At the beginning the important KPIs for assessing the performance need to be identified and calculated. Following site characteristics have to be determined and quantified. Hereinafter the sites will be clustered on the basis of the site characteristics. Afterwards the benchmark for all KPIs within the site clusters are defined. This step enables the identification of performance differences, which result from the sole site performance. The analyses of the correlation between the site characteristics and the benchmark values for the identified KPIs sheds light on cause-and-effect relations. Finally the performance difference between manufacturing sites can be evaluated. These steps will be described in detail in the following sections.

3.1. Determination and calculation of KPIs for the site performance evaluation

First of all it is important to determine indicators, which are important for assessing the site performance. These indicators can vary of course from company to company and especially in different industries. A consortial benchmarking study which was conducted at the laboratory for machine tools and production engineering showed, that the following KPIs are used to assess production sites most often [18]:

- Adherence to delivery dates
- Quality
- Productivity
- Sales
- EBIT

3.2. Derivation and quantification of site characteristics

The following step focuses on the derivation and quantification of site characteristics. These ones can differ also from company to company and in different industries. At this point it is important to distinguish between influenceable and uninfluenceable characteristics, since improvement measures can just be implemented, if performance differences result from influenceable characteristics. Influenceable site characteristics could be the following for instance:

- Product complexity
- Size of site
- Technological equipment
- Different degrees of automation

For uninfluenceable characteristics the following conditions can be mentioned exemplarily:

- Labor market conditions
- Tariff regulations
- Certain differences in local work force productivities
- Regional wage levels

Subsequently the mentioned site characteristics need to be quantified in order to determine any correlation with performance differences later. The product complexity at a site can be calculated e.g. with the following formula [17]:

$$Product\ complexity = \frac{\#\ Different\ material\ numbers}{Produced\ quantities}$$

A possibility to assess the conditions of the technological equipment could be [16]:

$$Technological\ equipm. = \frac{Gross\ book\ value\ of\ the\ machines}{Net\ book\ value\ of\ the\ machines}$$

3.3. Creation of site clusters with homogenous characteristics

After deviating and quantifying site characteristics, site clusters with homogenous characteristics, will be created. The site clusters should be similar regarding all site characteristics from the previous step. E.g. sites in one cluster should work under similar labor market conditions and should produce with the same level of technological equipment. At this point it might be reasonable to analyze if some characteristics occur always together. In this case these characteristics could be examined together while analyzing the correlation between characteristics and performance differences.

3.4. Identification of benchmarks within the site clusters

Within step four benchmark values for the site clusters are determined. The calculated KPIs need to be plotted within all clusters as pointed out in Fig. 3. The benchmark is always the best value within one cluster for one KPI. It indicates a value which can be achieved by all sites belonging to the certain cluster, since they operate under the same conditions. This step ensures, that self-inflicted performance deficits from sites are filtered out. Subsequently at this point performance differences which result solely from site performances can be identified since the sites within the clusters do have the same characteristics. These performance differences can be antagonized e.g. with best-practice-sharings.

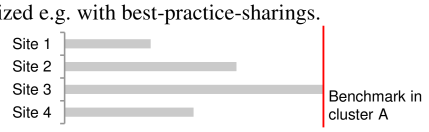


Fig. 3 Determination of benchmark values

3.5. Analysis of the correlation between benchmarks and site characteristics

After identifying benchmarks (BM) within the clusters the values for all clusters should be plotted separately for every KPI like shown in Fig. 4 in order to analyze the correlation between benchmark values and the site characteristics. The statistical analyses can be carried out with the help of a suitable software like Microsoft Excel or SPSS.

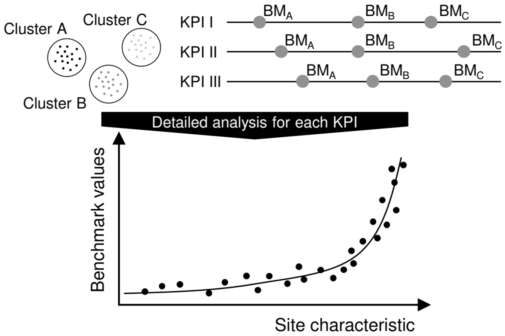


Fig. 4 Correlation analysis

A detailed analysis for each KPI is reasonable to examine the exact correlation. This step enables the identification of cause-and-effect relations between site characteristics and performance gaps. This graph might show for instance the impact of the technological equipment, which can be indicated e.g. as the ratio of the gross book value and the net book value of the machines on the productivity. If the curve would look like drawn above, the management would get an indication how important up-to-date technological equipment is. If no cause-and-effect relation is visible, the technological equipment might have no major impacts.

3.6. Evaluation of performance differences between production sites

Finally all sites and the performance difference between them can be evaluated while taking their heterogeneity into account. First it is reasonable to compare the KPIs with the benchmark values, which were defined within the homogenous site clusters. If there is a big gap between those values, know-how transfers within the clusters should be pursued. With the help of the identified correlation between the site characteristics and the benchmark values it is possible to calculate values for reachable KPIs dependent on the site characteristics. These can be compared with the actual values. KPIs for all sites including possible optimization measures can be illustrated in one table to summarize key findings.

4. Application

The developed method was applied for a company in the mechanical engineering industry which is producing all over the world in 13 different production sites. The locations were renamed in order to ensure confidentiality.

4.1. Determination and calculation of KPIs for the site performance evaluation

The application of the method focuses in a first step on the productivity as a measure to evaluate the performance of the globally distributed production sites. The productivity of the 13 sites were calculated as shown in the formula below [16].

$$Productivity = \frac{\text{Output}}{Input} = \frac{\sum Product\ quantity * product\ value}{Production\ costs}$$

The differing productivities per site are shown in Fig. 5. The graph shows, that sites which supposed to be more industrialized have a lower productivity than sites in emerging countries in some cases. This could be a first hint, that sites with lower wage levels can achieve higher productivities since they might produce with lower costs due to the wages.

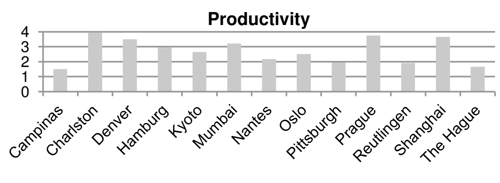


Fig. 5 Differing productivities

4.2. Derivation and quantification of site characteristics

After calculating the productivities for all sites, following criteria were defined for further examination of correlation.

- Product complexity, calculated as the ratio of the number of different products and produced quantities at the site
- Site size, calculated as the total number of machines, since this was the most appropriate measure to calculate the size according to the companies assessment
- Wage level, indicated through an average value of direct and indirect FTE (full-time equivalent) wages in €

4.3. Creation of site clusters with homogenous characteristics

Subsequently site clusters with homogenous characteristics could be created. The defined characteristics product complexity, site size and wage level were clustered in two intervals each. Afterwards all sites were assigned to an interval for each characteristic. Sites which were assigned to the same intervals for all characteristics were allocated in one cluster. Seven different clusters were identified through this process. The characteristics, which occurred most often together were large sites with low complexity and high wage level. Small sites with high complexity and high wage level appeared often together, too.

4.4. Identification of benchmarks within the site clusters

Within the next step benchmark values were identified in all site clusters. The following Fig. 6 shows this process for cluster B (big sites, low complexity, high wage level).

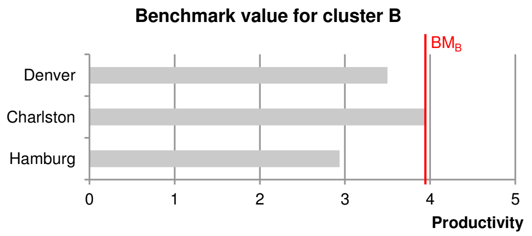


Fig. 6 Benchmark values for clusters with homogenous characteristics

4.5. Analysis of the correlation between benchmarks and site characteristics

The identified benchmark values were plotted hereinafter on one scale in order to get a feeling which site characteristics have a high impact on the productivity. The cluster with big sites having a low complexity and high wage levels showed the highest productivity values (cf. Fig. 7). While looking at the detailed evaluation of the correlations in figure 7, a strong impact of the product complexity on the productivity gets obvious. The size of the site seems to have a significant influence as well. In contrast to that no correlation of the wage level and the productivity is recognizable. The missing correlation shows, that sites with a higher wage level can achieve with fewer employees the same results as sites with lower wage levels and more employees do.

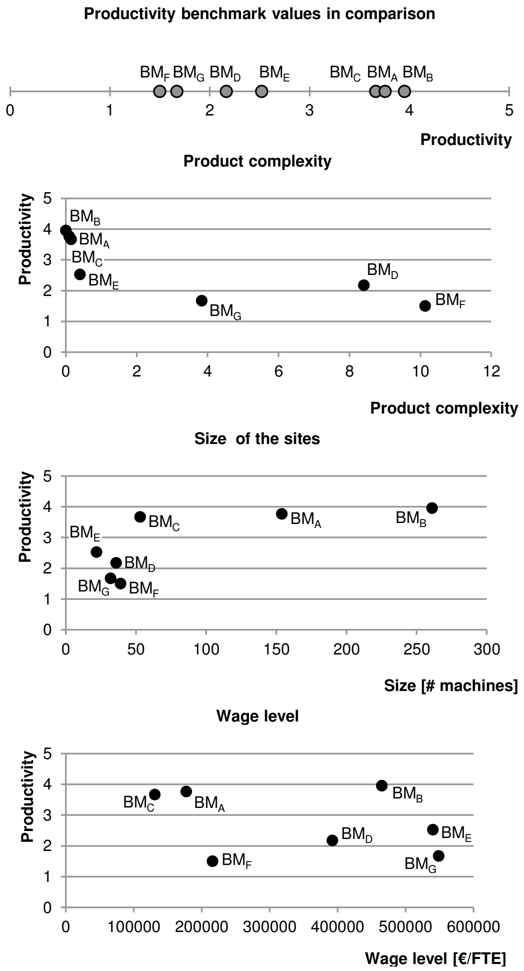
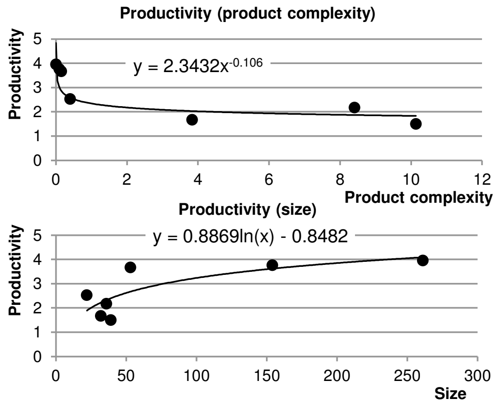


Fig. 7 Correlation between productivity and different site characteristics

4.6. Evaluation of performance differences

Finally the performance of all sites can be evaluated and appropriate measures derived. Since no distinct correlation between the wage level and the productivity could be identified, this site characteristic is not considered while evaluating performance differences.

First of all know-how-transfers within the homogenous clusters should be carried out, if there are distinct performance differences between the benchmark of the corresponding cluster and the site. Beyond that the mathematical correlation between benchmarks and site characteristics can be described if a trend line is drawn in the correlation graphs as shown in Fig. 8. On this basis achievable productivity values depending on the site characteristics can be calculated. If sites show a big gap between achievable and real productivities, they should go for know-how-transfers with the sites, which exceed their goals. Since there is a clear correlation between productivity and product complexity respectively size, there is always the option to reduce complexity or increase the size in order to achieve better productivity values.



Site	P_{real}	BM	P(C)	P(S)	Optimization measures
Campinas	1.5	1.5	1.8	2.4	KHT with Prague/Shanghai, less C, more S
Charlston	4.0	4.0	4.8	4.1	KHT with Prague/Shanghai, less C, more S
Denver	3.5	4.0	3.2	4.0	KHT with BM
Hamburg	2.9	4.0	2.7	3.9	KHT with BM
Kyoto	2.6	3.7	2.4	2.9	KHT with BM
Mumbai	3.2	3.8	2.1	3.3	KHT with BM
Nantes	2.2	2.2	1.9	2.3	KHT with Prague/Shanghai, less C, more S
Oslo	2.5	2.5	2.6	1.9	KHT with Prague/Shanghai, less C, more S
Pittsburgh	2.0	2.2	1.8	2.2	KHT with BM
Prague	3.8	3.8	3.0	3.6	Less C, more S
Reutlingen	1.9	2.5	2.3	3.1	KHT with BM
Shanghai	3.7	3.7	2.9	2.7	Less C, more S
The Hague	1.7	1.7	2.0	2.2	KHT with Prague/Shanghai, less C, more S

P_{real}: Productivity in reality
BM: Benchmark of the corresponding cluster
P(C): Achievable productivity, depending on complexity
P(S): Achievable productivity, depending on size
S: Size
C: Complexity
KHT: Know-How Transfer

Fig. 8 Evaluation of site performance

5. Summary and further research

Summarized the presented approach enables the evaluation of performance differences between manufacturing sites. The method consists of six steps. First major KPIs for assessing the performance are defined. Afterwards site characteristics are derived and quantified. Thereupon site clusters with homogenous characteristics and the benchmark values within these are identified. The correlation between the site characteristics and performances is examined subsequently. Finally all sites and their performance differences are evaluated and appropriate measures are derived.

Future research should extend this examination to further KPIs and site characteristics as well as the analysis of the interdependencies between the single site characteristics. Beyond that the identification of corridors, where the site characteristics are significant for the site performance, should be pursued in order to be able to evaluate from which point of time a site characteristic has a significant influence on the site performance. Furthermore the method should be applied with more KPIs and site characteristics to other companies.

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