Variety Management in Manufacturing. Proceedings of the 47th CIRP Conference on Manufacturing Systems

Performance measurement of modular product platforms

G. Schuh1, S. Rudolf1, T. Vogels1*

1Laboratory for Machine Tools and Production Engineering (WZL) RWTH Aachen University, Steinbachstraße 19, 52074 Aachen, Germany

* Corresponding author. Tel.: +49-(0)241-8020617; fax: +49-(0)241-80620617. E-mail address: t.vogels@wzl.rwth-aachen.de

Abstract

It is a vital issue for producing companies in high wage countries to maximize economies of scale and economies of scope simultaneously. Many companies nowadays use a modular product platform approach to solve this dilemma. The preservation of the modular product platform over the lifecycle is one of the central success factors of this strategy. Therefore, a performance measurement system for modular product platforms is described in this paper. The approach is based on three steps to evaluate the performance of a modular product platform. In the first step the company-specific objectives for the modular product platform are defined and weighted. Afterwards relevant performance figures are identified and integrated into a balanced scorecard model, which is developed for the performance measurement of modular product platforms. At last an evaluation is done, which performance indicators can be obtained automatically by using data from different IT-systems.

© 2014 The Authors. Published by Elsevier B.V.
Selection and peer-review under responsibility of the International Scientific Committee of “The 47th CIRP Conference on Manufacturing Systems” in the person of the Conference Chair Professor Hoda ElMaraghy.

Keywords: Performance measurement; Standardization; Modular product platform

1. Introduction and motivation

Due to saturated markets and growing competition especially from Asian competitors, producing companies in high wage countries need to solve the dilemma between economies of scale and economies of scope. Therefore, they have to offer innovative and individual products with reasonable prices which suit the needs of customers worldwide [e.g. 1, 2, 3]. One approach to solve this dilemma is the development of modular product platforms [e.g. 3, 4, 5]. Two main challenges have to be solved to successfully implement modular product platforms: Firstly, a modular product platform needs to be developed initially, which requires a reorganization of product development processes as well as a consideration of the whole value chain. Secondly, the conservation of the modular product platform over the lifecycle has to be ensured without limiting the ability for innovation [4, 5, 6, 7].

The following paper introduces a methodology facing the second challenge. Therefore, an approach to develop a performance measurement system for modular product platforms is described in this paper. A main task of the approach is to enable companies to track the fulfillment of given objectives in different dimensions, i.e. not only financial dimensions but also production aspects. In case of modular product platforms it is of special importance to evaluate product changes over the lifetime of the platform to conserve the developed structure. In many cases product variety increases significantly over the lifecycle and therefore decreases economies of scale.

2. Existing approaches addressing the performance measurement of modular product platforms

According to Reichmann [8] the structure of controlling is generally built up from five dimensions:

• Controlling targets
Gleich [9] defines performance measurement as a part of controlling, so that the structure can also be used for the conception of the performance measurement of modular product platforms. Classical controlling is focused on financial aspects [8]. There are various approaches which focus on the evaluation of the financial aspects of modular product platforms or complexity in general [e.g. 15, 17, 21, 24, 25]. However, these approaches do not address all dimensions of the value chain which are affected by the implementation of a modular product platform. Especially benefits which are hard to measure in financial figures or not assessable at all have to be considered [10, 12].

Therefore different approaches use key performance indicators and key figures to evaluate and optimize complexity [e.g. 10, 11, 12, 20 22, 23]. Especially the balanced Scorecard is frequently used [13] as performance measurement system to evaluate and track the long term strategy. From the above mentioned approaches only one focusses on the performance measurement of modular products in special. Junge [10] uses a modular balanced scorecard approach to control modular product families in the automotive sector. He defines the four fields: finance, production, development and marketing/sales. In accordance to the last three fields Schuh et. al [5] define three areas for an integrative assessment model and add a fourth field to the model: the supply chain. The defined fields of action of other works [11, 12] correspond with the mentioned works.

However, these approaches are not developed for the continuous performance measurement of modular product platforms. Especially the ease of use is not focused in the described approaches. Therefore, the following approach focuses on the development of key figures which can be created automatically by using data from IT-systems and should be applicable for manufacturing companies from different branches.

3. Performance measurement of modular product platforms

The approach is based on three steps to evaluate the performance of modular product platforms. In the first step the company-specific objectives for the modular product platform are defined and weighted based on the three generic objectives for a modular product platform: time, costs and flexibility [14]. Target conflicts between partial objectives are identified or newly developed, where needed. Afterwards the partial objectives are structured in a system of objectives. In the second step relevant performance figures are identified or newly developed, where needed.

The performance figures are integrated into a balanced scorecard model, which is developed for the performance measurement of modular product platforms. Depending on the company specific system of objectives, a sub-set of the identified performance figures has to be chosen. Due to the effort, which is needed to collect the data for the performance figures, the implementation of many scientific validated performance measurement systems fail in reality [9]. Therefore, an evaluation is done in step three, which performance indicators can be obtained automatically by using data from different IT-systems. If the needed data for chosen performance indicators is not available, alternative solutions are derived. On the other hand the need to adapt and augment the available data from IT-systems will be discussed and solutions will be described. (see fig. 1)

3.1. System of objectives

The three generic objectives of modular platforms are:
- Shorter time to market
- Cost reduction and
- Higher flexibility (variety) for customer requirements

Modular platforms should fulfill all three objectives at the same time but in reality each company has a different focus: e.g. mass producers focus more on cost savings in the production area, while small series producers focus more on customer specific solutions and therefore flexibility and variety. Very innovative companies e.g. in the field of electro motors are mainly interested in a shorter time to market since this is their unique selling point. Therefore, the three objectives need to be weighted according to the company specific strategy.

The objectives can be detailed into partial objectives, which enable the companies to derive practical measures. These partial objectives again need to be weighted. In combination with the weighting factor for the shorter time to market, each partial objective gets an overall weighting factor.

The targets presented below are an example for machinery and plant engineering companies.

Partial objectives for a shorter time to market are e.g.:
- Reduction of development time
- Reduction of iterations in the prototype testing
- Reduction of ramp-up time

Partial objectives for cost reduction are:
- Less effort for part maintenance by reduced part numbers
- Reduction of investment for tools and machines
- Reduction of stored material
• Reduction of assembly and manufacturing time by standardization
• Reduction of assembly errors

Partial objectives for higher flexibility for customer requirements:
• Quick adjustments for customer specific requirements
• Fulfillment of customer requirements
• Shorter delivery time

The interdependencies between the partial objectives can be visualized in a cause and effect network. Target conflicts can be solved in advance by the weighting factor for each partial objective. The weighing factors can be either developed in workshops based on expert knowledge or by analytical methods (e.g. analytical hierarchy process AHP, utility analysis). Anyway, the results should be discussed with all relevant stakeholders like development, product management, production etc.

3.2. Performance figures and balanced scorecard

The performance measurement of modular product platforms demands the fulfillment of specific requirements.

1. At first they need to be related to the system of objectives. Therefore, the objectives namely reduction of time to market, reduction of costs by economies of scale and fulfillment of customer requirements should be evaluated by the key figures.

2. Furthermore the automated creation of the key figures is of the utmost importance like explained in chapter 1. This requirement will be discussed in chapter 3.3.

3. The third requirement for the key figures is the continuous evaluation of the modular product platform. Since the performance measurement should be done on a regular basis, only key figures which can be created and compared at different times should be used.

4. Since the modular product platform has an impact on the whole value chain, it is important to control all relevant areas.

The effects of modular product platforms affect the whole value chain [e.g. 3, 4, 15]. Therefore, all areas of the value chain need to be considered. Schuh et. al [5] developed an integrative assessment model for complexity based on the theories of Malik [16] and Kaiser [17] whereby complexity can be differentiated into internal and external complexity. The second dimension they used is described by Wiendahl and Scholtesek [18] and divides complexity into a product and a production type.

In addition Junge [10] uses in his balanced scorecard concept the financial aspect for the controlling of modular product platforms. These five dimensions are used as constitutive framework for the performance measurement of modular product platforms (see fig. 2).

The required key figures have to be derived for each company based on the specific system of objectives. The key figures presented below are an example of machinery and plant engineering companies. There are different key figures which apply to the different company specific targets. However the chosen key figures were discussed with experts from all relevant fields and chosen with regard to their ease of use for the mentioned companies. Note that there might be other better suited key figures for companies with a different background.

![Fig. 2 Constitutive framework for the performance measurement of modular product platforms](image-url)

In the field of Product Program there are four key figures which are shown in table 1.

Table 1: Key figures for the field Product Program

<table>
<thead>
<tr>
<th>Dimension and Equation</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product-Sales-Balance-Index ( PSBI )</td>
<td>( V_{GA} ) Overall number of sold variants of the product platform, ( V_{GS} ) Number of sold variants, which made 80% of the revenues</td>
</tr>
<tr>
<td>Product Platform Range ( PPP )</td>
<td>( P_{POA} ) Overall number of sold products of the product platform, ( P_{PP} ) Number of sold variants of the product platform</td>
</tr>
<tr>
<td>External Variety ( EV )</td>
<td>( X_{MO} ) Num. of obligatory variants of module m, ( X_{MV} ) Num. of optional variants of module m</td>
</tr>
<tr>
<td>Explainability at Point of Sale ( EF_{poS} )</td>
<td>( V_{GS} ) Number of sold variants, which made 80% of the revenues</td>
</tr>
</tbody>
</table>

The Product-Sales-Balance-Index [11] gives an overview over the distribution between standard and exotic models. This key figure is related to the objective of offering more variants within the platform. The External Variety [10] gives an overview how many standard modules are used for a variant and how many optional modules are used. This key figure refers to two objectives: to offer more variants and to reduce the part maintenance effort. At last the explainability at Point of Sale [12] gives an overview how good the offered variants can be explained and therefore sold by sales persons. This refers to the target of offering more variants.

The derived key figures for the machinery and plant branch in the field Product Architecture are shown in table 2. The Flexibility [12] gives an overview how the distribution of components is set between standard components and exotic components. This refers to the objectives in the two areas cost...
reduction and shorter time to market. The Commonality Index \cite{11} indicates how much costs are deduced by special parts. This refers to cost reduction in the development and manufacturing of parts. The Cycle-Time-Efficiency \cite{10} gives an overview of the needed development time for special variants and therefore refers to the objectives reduction of development, prototype testing and ramp-up time. The Interface-Efficiency-Index \cite{11} gives an overview of the number of interfaces. It is related to the objectives reduction of assembly time and reduction of assembly errors.

Table 2: Key figures for the field Product Architecture

<table>
<thead>
<tr>
<th>Dimension and Equation</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility (FFP) ( F_{pp} = \left( \frac{U_i}{U_{standard}} \right)^{1/n} )</td>
<td>( U_i ) Sales volume realized with variant ( i ), ( U_{standard} ) Realized sales volume by standard variant ( i ), ( n ) Number of standard variants</td>
</tr>
<tr>
<td>Commonality Index (CI) ( CI = \left( \frac{MC_{standard}}{\sum_{p} MC_{standard,p}} \right)^{1/n} )</td>
<td>( MC_{standard} ) Amount of manufacturing costs for special parts of the product line</td>
</tr>
<tr>
<td>Cycle-Time-Efficiency (CCE) ( CEC = \left( \frac{\sum_v T_{R&amp;D,v}}{\sum_v T_{R&amp;D,basis,v}} \right)^{1/n} )</td>
<td>( T_{R&amp;D,v} ) R&amp;D-time for variant ( v ), ( T_{R&amp;D,basis,v} ) R&amp;D-time for basis variant ( v=1 ), ( n ) Overall number of variants</td>
</tr>
<tr>
<td>Interface-Efficiency-Index (IEI) ( IEI = \frac{M}{X} )</td>
<td>( M ) Overall number of modules of a product line, ( X ) Number of Interfaces of the modules of a product line</td>
</tr>
</tbody>
</table>

In the field Supply Chain the following key figures are identified for the machinery and plant industry (see table 3).

Table 3: Key figures for the field Supply Chain

<table>
<thead>
<tr>
<th>Dimension and Equation</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sourcing Variety Index (SVI) ( SVI = \frac{L_{di}}{N_{di}} )</td>
<td>( L_{di} ) Number of different supplier for the used parts, ( N_{di} ) Number of different parts</td>
</tr>
<tr>
<td>Value-Add-Index (VAI) ( VAI = \frac{MC_{bought,di}}{MC_{OA,di}} )</td>
<td>( MC_{bought,di} ) Manufacturing costs for bought in part, ( MC_{OA,di} ) Overall manufacturing costs for all parts of a product line</td>
</tr>
<tr>
<td>Supply chain capital efficiency ( KEC )</td>
<td>( KEC = \max(1 - \frac{U_{i}}{V_{i}}) )</td>
</tr>
<tr>
<td>Supply chain effectiveness ( LEC )</td>
<td>( LEC = \sum_{i} M_{EQ,i} \left( \sum_{i} M_{OA,i} \right)^{-1} )</td>
</tr>
</tbody>
</table>

The Sourcing Variety Index \cite{11} gives the relation between number of suppliers and number of parts. This key figure is related to the objective reduction of assembly errors, since the supplier variety is a main factor for assembly errors in the current state. The Value-Add-Index \cite{11} gives the relation between costs for bought-in parts and manufacturing parts. It is related to the objectives reduction of development time and reduction of assembly time. The Supply chain capital efficiency \cite{12} gives an overview of how much money is bound for stored parts and creates a relation to the overall revenues. This key figure is related to the objective reduction of stored material. The last key figure in this field is the Supply chain effectiveness \cite{12} which gives an overview over the orders delivered in time and therefore is coupled with the objective shorter delivery time.

In the field of production the following four key figures can be used (see table 4). The Process commonality \cite{12} gives an overview of the standardization of processes and is therefore related with the objective reduction of manufacturing time. The same applies for the key figure Resource utilization. The key figure Differentiation-Point-Index \cite{11} gives an overview how many assembly variants exist in each assembly step. It is related to the objectives reduction of ramp-up time, reduction of stored material and reduction of assembly errors. At the same time it is related to the objective of quick adjustment for customer requirements. The Manufacturing Platform Efficiency \cite{10} gives an overview over the investment for a specific variant in comparison to basic variants. This key figure is related to the objective reduction of investment for tools and machines.

Table 4: Key figures for the field Production

<table>
<thead>
<tr>
<th>Dimension and Equation</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process commonality (PKP) ( PKP = 1 - \frac{r}{R_{max}} )</td>
<td>( r ) Number of used process sequences, ( R_{max} ) Theoretical max. of sequences</td>
</tr>
<tr>
<td>Resource utilization (PU) ( PU = \frac{1}{T-\tau} \frac{1}{\tau} \sum_{i=1}^{n} \frac{ti}{n} )</td>
<td>( T ) Duration of underlying period, ( \tau ) Process time of resource ( i ) within time span, ( n ) Number of available resources</td>
</tr>
<tr>
<td>Differentiation-Point-Index (DPI) ( DPI = \sum_{i} (p \cdot V_{OA})^{1} )</td>
<td>( V_{OA} ) Overall number of product variants in process step ( i ), ( n ) Overall number of process steps</td>
</tr>
<tr>
<td>Manufacturing Platform Efficiency (MPE) ( MPE = 1 - \frac{1}{V} \sum_{i} (V_{OA} - \frac{V}{n})^{1} )</td>
<td>( V_{OA} ) Absolute investment in production for the basis variant ( v=1 ), ( V ) Total amount of variants</td>
</tr>
</tbody>
</table>

The last file is the field finance. The key figures are not directly related to the given objectives but they give an overview how successful the modular product platform is. The key figures are shown in table 5.

Table 5: Key figures for the field Finance

<table>
<thead>
<tr>
<th>Dimension and Equation</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net-Present-Value (NPV) ( NPV = \sum_{t} \frac{CF_{t}}{(1+i)^{t}} )</td>
<td>( CF_{t} ) Net-Cash-Flow in period ( t ), ( i ) Required rate of return</td>
</tr>
<tr>
<td>Platform-Revenue (PR) ( PR = \sum_{v} X_{v} \cdot p_{v} )</td>
<td>( X_{v} ) Sales quantity for variant ( v ), ( p_{v} ) Price for variant ( v )</td>
</tr>
<tr>
<td>Price-Cost-Ratio (PCR) ( PCR = \frac{1}{V_{OA}} \sum_{v} \frac{p_{v}}{k} )</td>
<td>( V_{OA} ) Overall number of variants, ( p_{v} ) Price for variant ( v ), ( k ) Prime costs for variant ( v )</td>
</tr>
</tbody>
</table>

The first key figure Net-Present-Value \cite{10} gives an overview over the cash flow in relation to the defined return rate of the modular product platform. The Platform-Revenue \cite{10} gives an overview over the sales of each variant and allows therefore to identify standard products and exotic products. The Price-Cost-Ratio \cite{10} gives the relation of price
to costs for the modular platform and allows to track the profitability.

The key figures will be collected in regular intervals. The development over time can be shown and also need for action can be identified by using statistical methods like control charts. This enables the companies to measure the performance of the modular product platform and enables them to identify fields of action e.g. in the area of production. The interpretation of each value should be conducted in order to the strategic long-term targets. The controlling of the development of each key figures allows to identify trends or differences between the as-is and should-be value and allows an early identification and definition of countermeasures. To better compare the different values and aggregate them into one comprehensive KPI it is useful to standardize the values of each key figure from 0 – 1. The aggregation into a single comprehensive KPI is one focus of further research.

3.3. Available data in IT-systems

For the ease of use of the performance measurement it is of the utmost importance, that all relevant key figures can be created with very low or without effort and that the results can be repeatedly created and compared. Therefore, the needed data should be delivered automatically by the existing IT-systems. Nowadays the IT-landscape is very heterogeneous [19] and consists of many different systems. Eigner [19] describes four levels of a state of the art PLM (Product-Lifecycle-Management) system: author tools like CAD, CAM or Office where the data is created are assigned to the lowest level. On the second level so called TDM (Team-Data-Management) systems where the data from the author tools is handled are aggregated. The third level is the so called PLM backbone. The data gets transferred from the different TDM systems into this backbone and is aggregated over all different systems and functions. Functions like configuration management, change management and simulation should be done on this level. The last level is the ERP (Enterprise Resource planning) system where the actual planning of production, purchasing, logistics and so on should be done [19]. For the performance measurement of modular product platforms it is necessary to consider data from all four levels depending on the chosen key figures.

However, in the industry this IT architecture is often made up of many different systems and the synchronization between these systems is nowadays often problematic and the structure is very company specific. Therefore, it is necessary to check for each set of key figures, which data is available and in which IT-system.

If the data is not available in the IT-systems there are different ways to handle the problem. At first it should be examined, if there are different key figures available, which give a similar information based on different data. In the example for the machinery and plant companies the chosen key figure for the product commonality cannot be created automatically. The reason is that it is not possible to identify automatically the parts which are only used for a specific product. Therefore, a different key figure for evaluation of the commonality in the product can be used [2]:

\[
CI_A = \frac{1}{k} \sum_i w_i \cdot \frac{Abs_i}{Abs_{ges}}
\]

\(k\): Number of overall components
\(w_i\): Value of component \(i\) of overall value of product architecture
\(Abs_i\): Sales of component \(i\)
\(Abs_{ges}\): Overall sales

In the mentioned example the number of overall components can be delivered by the PDM system, while the cost value of each component and the sales figures of the specific components and the overall sales figures can be delivered by the ERP system. Therefore, the requirement of automated data preparation is fulfilled. If there is no other key figure available which delivers the same data, it can be considered to create a new key figure based on the data available in the IT-systems. Important for this bottom up approach is the fulfillment of the objectives which are related to the original key figure.

The second way to solve the problem is to adjust the IT-systems to make the needed data available. This step usually creates more effort than the change of key figures, hence the first option should be considered at first. However, there might exist some cases where no alternative key figure is available or where it is useful to have the information in the IT-systems. In the example for the machinery and plant branch the DPI was such a key figure. To evaluate the differentiation point in the production it is necessary to identify the number of assembly variants for each production step. Therefore, it was necessary to structure the production process into several steps and implement a logic to implement the information in the PDM system. Afterwards each product variant got an assembly variant assigned for each of the defined production steps. This enables the PDM system to deliver the needed data for the key figure DPI.

All key figures were checked in this manner and got linked to the IT-systems which contain the needed data. The shown adaptions give an example how the key figures and IT-systems can be adjusted to fulfill the requirement of automated data preparation.

4. Conclusion

In order to measure the performance of modular product platforms it is necessary to develop a controlling system which considers the company specific objectives, allows an automated data creation for the ease of use, considers the effects on the whole value chain and can be used continuously over the lifecycle. Therefore, a method to derive a company specific performance measurement system is presented in this paper. The development is based on three steps. At first the objectives of the modular product platform need to be identified and afterwards structured in a system of objectives. In the second step the objectives need to be linked to key figures which allow an evaluation of the objectives. The key figures are implemented in a constitutive framework. In the third step the automated creation of the required data for the
identified key figures is ensured. Therefore, the companies need to check if the needed data is available in their IT-systems. If they are not available there are two approaches to tackle the problem: the adaption or change of the key figures based on the available data or the adaption of the data available in the IT-systems.

The paper shows examples from the machinery and plant production branch to give an idea how the development of a performance measurement of modular product platforms can be done.

Acknowledgements

The presented results have been developed at the WZL and have been validated with different companies in the machinery and plant industry. The author's sincere thanks go to the companies who supported in the verification of the performance measurement model.

References