Implementation of an Economic Model to Simulate Manufacturing Costs

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Abstract
An economic model describing manufacturing costs is implemented within the frame of a case study. The implemented economic model is developed to enable analyses of the cost items and parameters influencing the cost of a part or a batch and also to make simulations for the purpose of investigating the economic outcome of future development activities. The aim of the case study was to identify activities in a production unit that could lead lower manufacturing costs by using the method described in this paper.

Keywords:
Manufacturing Economy; Cost Model; Economic Simulation

1 INTRODUCTION

The globalisation has influenced the manufacturing sector considerably; it has become more important than ever to constantly increase the productivity in the manufacturing plants to be able to meet the increasing competition, especially from companies in low-wage countries. Many companies deal with these circumstances by offshoring or by offshore outsourcing. These types of relocations are solely based on cost reductions, in contrast to relocations based on market aspects for the purposes of getting closer to a certain market for competitive reasons. But to relocate the manufacturing plants to low-wage countries doesn't have to be the only way out to maintain a high competitiveness for companies in countries with high wages. Focusing on the optimal production development regarding organizational issues and production technology can in many cases compensate the higher level of wage costs.

In order to make the right decisions concerning the offshoring based on cost reductions, it is necessary to be able to make correct analyses of the performance in the manufacturing plant from an economic point of view. One approach is to analyse the manufacturing costs of the products produced in the plant. Common methods to calculate the manufacturing costs are the traditional full costing methods and Activity-Based Costing (ABC). Traditional full costing is mostly used for cost-price calculations and is not an equally suitable method to use when seeking detailed and accurate information solely about the manufacturing costs, essentially because of the methods volume based approach. One of the main purposes behind the development of ABC was to in a more accurate way than traditional full costing allocate the overhead costs [1]. A lot of research has been done over the years since ABC was first introduced with the intention of implementing and analyzing the method, for example Thyssen, *et al*. [2].

The model presented in this paper is developed with the purpose of calculating and analysing the part cost associated with the manufacturing. The model has some similarities to ABC, for example when it comes to recognising the cost of unused capacity and the different types of parts individual consumption of the manufacturing resources. The main differences are that the model presented here only describes costs related to manufacturing. The focus of this model is to describe the relations between economy and manufacturing performance. Another difference is that this model allocates batch level activities to the unit level and also allocates cost of unused capacity to products.

Models describing the manufacturing cost can roughly be divided into a micro- and macroeconomic approach according to Tipnis, *et al*. [3]. The macroeconomic models are essentially based on aggregated information while the microeconomic models include process data like cut rate, gas flow, current intensity etc. For example Colding [4], [5], Alberti, *et al*. [6] and Knight and Poli [7] have all described microeconomic models while Groover [8] has described a macroeconomic model.

The model applied below can be described as a macroeconomic model. The applied model differs from the models presented in the previous section by the inclusion of all the production loss parameters; scrap rate, down time rate and production rate.

2 PURPOSE

The performance of a defined production unit that manufactures gearwheels will be analysed, using a manufacturing economic model described in section 6. The purpose was to identify activities in the production unit that can lead to lower manufacturing costs by using the method described in this paper.

3 METHOD

To be able to test the model in real a context a case study at a company was considered as the most appropriate choice of method. The case study was chosen to be limited to one section at the factory in order to make the data collection manageable from a practical perspective and it was also considered sufficient in order to to comply with the purpose of the study. The case study began with a careful study of the chosen production unit to get an understanding about its characteristics regarding the process and function. The accuracy of the economic data obtained by the cost model is dependent on the accuracy of the collected data. Therefore a systematic data collection was made regarding the scrapped parts, down time, production rate and the set up time.

4 SYSTEMATIC PRODUCTION ANALYSIS

The systematic data collection mentioned in section 3 was performed by implementing a method called Systematic Production Analysis (SPA) [9]. The method has been developed to determine the existing production condition. In this method the result parameters downtime rate, scrap rate and production rate are measured for each processing unit involved in the manufacturing of a specific product. The possible downtime, scrapped parts and loss in production rate are related to a factor found in one of the following factor groups: A Tool and tooling system; B Work piece material; C Manufacturing process and process data; D Personnel, organization and outer logistics; E Maintenance and wear tied to A, C, D and G; F Special process behavior/factors; G Surrounding equipment and inner logistics; H Unknown or unspecified factors

Table 1 shows a method of presenting a SPA. Q_1 to Q_n describe different quality deviations leading to scraped parts, where every Q has a separate column. Analogous to the quality parameters, S_1 to S_n describe different types of down time losses and P_1 to P_n describe different production rate deviations. The factor groups describe causes leading to the different result parameters. Every factor group contain individual factors, for example factors A_1 to A_n, where every individual factor has a separate row. After an implantation of this method, where every disturbance has been registered in the right place in the table, you can sum up the result for every row and column and then find critical result parameters and factors for the specific processing unit. This method makes it possible to directly get an indication towards which of the result parameters and which of the individual factors that causes losses in the production efficiency. Coupling this to economic parameters it is possible to determine the part cost under the influence of the result parameters. In section 6 it will be shown how these result parameters together with time and batch size parameters and also economic data build up the part cost in a specific processing step.

Table 1: Systematic production analysis.

	Result parameters			
Factor groups	$Q_1,..,Q_n$ (unit)	$S_1,...,S_n$ (min)	$P_1,...,P_n$ (min)	Σ
$A_1,...,A_n$				
$B_1,...,B_n$				
$C_1,...,C_n$				
$D_1,...,D_n$				
$E_1,...,E_n$				
$F_1,...,F_n$				
$G_1,...,G_n$				
H				
Σ				

5 LIST OF SYMBOLS

Table 2: List of symbols used in this paper. The economic parameters is described in the Swedish currency krona (kr).

Parameter	Description	Unit
t_0	Nominal cycle time per part	min
t_m	Machine time	min
t_h	Handling time	min
t_{vb}	Tool switch time	min
N_Q	Amount of scrap parts in a batch of *N* parts	unit
N	Total batch size, including scrap parts	unit
N_0	Amount of correct produced parts in a batch	unit
q_Q	Scrap rate	-
t_p	Production time per part	min
t_S	Average down time per part	min
q_S	Down time rate	-
q_P	Production rate	-
t_{0v}	Cycle time including production rate losses	min
T_{su0}	Nominal set up time	min
T_{su}	Set up time including deviations from nominal set up time	min
q_{Ssu}	Ratio between the nominal set up time T_{su0} and the real set up time T_{su}	-
k	Part cost	kr/unit
k_A	Tool cost	kr/unit
k_B	Material cost	kr/unit
k_{CP}	Equipment cost during production	kr/h
k_{CS}	Equipment cost during downtime and set up	kr/h
k_D	Wage cost	kr/h
x_p	Process development factor for the cycle time	-

x_{su}	Process development factor for set up time	-
κ_c	Equipment cost development factor	-
Δz	Change in an arbitrary variable z	-
k_{VA}	Value added part of the part cost	kr
k_{NVA}	Cost of non value added activities	kr
k_{Tsu}	Costs related to set up	kr
k_Q	Costs connected to the scrap rate	kr
k_S	Costs related to the down time rate	kr
k_P	Costs connected to the production rate	kr

6 ECONOMIC MODEL

The economic model is priviously described in [9]. In this section a summerized description is presented.

The nominal cycle time t_0 in a machine or a line is defined in equation 1, t_m is the machine time, t_h handling time and t_{vb} tool change time.

$$t_0 = t_m + t_h + t_{vb} \tag{1}$$

The scrap rate q_Q is defined in equation 2, where N_Q is the number of scrap parts, N is the batch size and N_0 the number of correct, non scrapped parts of the batch.

$$q_Q = \frac{N_Q}{N} = \frac{N - N_0}{N} \tag{2}$$

The down time rate q_S is defined in equation 3, where t_s is the down time per cycle and t_p the actual cycle time.

$$q_s = \frac{t_s}{t_p} = \frac{t_p - t_0}{t_p} \tag{3}$$

The production rate q_P describes the ratio between the nominal cycle time t_0 and the real cycle time t_v and is defined in equation 4.

$$q_P = 1 - \frac{t_0}{t_{0v}} \tag{4}$$

The downtime rate during set up q_{Ssu} describes the ratio between the nominal set up time T_{su0} and the real set up time T_{su}, see equation 5.

$$q_{Ssu} = 1 - \frac{T_{su0}}{T_{su}} \tag{5}$$

The production time for a batch including the setup time can then be defined as in equation 6:

$$T_{pb} = \frac{T_{su0}}{(1 - q_{Ssu})} + \frac{N \cdot t_0}{(1 - q_S)(1 - q_P)} \tag{6}$$

Reduced occupation in a manufacturing system leads to consequences for all manufactured parts. This situation can be considered in different ways, hence the free production resource can be considered both as an economic asset and a disadvantage depending on the situation. In a long term view the manufactured parts must carry the costs for the over capacity. The over capacity time can be distributed over all the batches in relation to their production time T_{pb} by introducing a degree of occupation U_{RP}, calculated as the quotient between real production time T_{prod} and planned production time T_{plan} according to according to equation 7 and 8. T_{free} is the time for the free, non occupied production time.

$$T_{plan} = T_{prod} + T_{free} \tag{7}$$

$$U_{RP} = \frac{T_{prod}}{T_{plan}} \tag{8}$$

The extra free capacity $T_{free,b}$ to be added to a specific batch is calculated according to equation 9. The free time can be considered as a setup time at the same time as the equipment is available for manufacturing:

$$T_{free,b} = \frac{1 - U_{RP}}{U_{RP}} T_{pb} \tag{9}$$

With these parameters together with economic data, the cost of production per part can be calculated. The economic parameters included in the model is the following :

- Tool cost k_A
- Material cost k_B
- Equipment cost during production k_{CP}
- Equipment cost during down time and set up k_{CS}
- Wage cost k_D

The cost of production per par can then be calculated using equation 10.

$$\begin{aligned} k = {} & \frac{k_A \cdot N}{N \cdot (1 - q_Q) \cdot (1 - q_P)} + \frac{k_B \cdot N}{N \cdot (1 - q_Q)} + \\ & \frac{k_{CP} \cdot t_0 \cdot N}{60 \cdot N \cdot (1 - q_Q) \cdot (1 - q_P)} + \\ & \frac{k_{CS}}{60 \cdot N \cdot (1 - q_Q)} \cdot \frac{t_0 \cdot N}{(1 - q_P)} \cdot \frac{q_S}{(1 - q_S)} + \\ & \frac{k_{CS}}{60 \cdot N \cdot (1 - q_Q)} \left(\frac{T_{su0}}{(1 - q_{Ssu})} + \frac{1 - U_{RP}}{U_{RP}} T_{pb} \right) + \\ & \frac{k_D}{60 \cdot N \cdot (1 - q_Q)} \left(\frac{t_0 \cdot N}{(1 - q_S) \cdot (1 - q_P)} \right) + \\ & \frac{k_D}{60 \cdot N \cdot (1 - q_Q)} \left(\frac{T_{su0}}{(1 - q_{Ssu})} + \frac{1 - U_{RP}}{U_{RP}} T_{pb} \right) \end{aligned} \tag{10}$$

To be able to simulate the effect of an improvement of the production process, a number of factors are introduced. The development factors are x_p, x_{su} and the cost factor κ_c, where x_p describe the improvement in cycle time that is achieved due to the development of the process. Likewise, x_{su} describes the improvement in set up time. κ_c is used to model changes in costs in primarily existing equipment, and can be used to determine the limit of investment justified to for example a decrease of the downtime rate to a certain value.

The manufacturing economic model including development and cost factors is described in equation 11.

$$k = \frac{k_A \cdot N}{N \cdot (1-q_Q)\cdot(1-q_P)} + \frac{k_B \cdot N}{N\cdot(1-q_Q)} + \frac{\kappa_C \cdot k_{CP} \cdot x_P \cdot t_0 \cdot N}{60 \cdot N \cdot (1-q_Q)\cdot(1-q_P)} + \frac{\kappa_C \cdot k_{CS}}{60\cdot N\cdot(1-q_Q)} \cdot \frac{x_P \cdot t_0 \cdot N}{(1-q_P)} \cdot \frac{q_S}{(1-q_S)} + \frac{\kappa_C \cdot k_{CS}}{60\cdot N\cdot(1-q_Q)}\left(\frac{x_{su}\cdot T_{su0}}{(1-q_{Ssu})} + \frac{1-U_{RP}}{U_{RP}} T_{pb}\right) + \frac{k_D}{60\cdot N\cdot(1-q_Q)}\left(\frac{x_P \cdot t_0 \cdot N}{(1-q_S)\cdot(1-q_P)}\right) + \frac{k_D}{60\cdot N\cdot(1-q_Q)}\left(\frac{x_{su}\cdot T_{su0}}{(1-q_{Ssu})} + \frac{1-U_{RP}}{U_{RP}} T_{pb}\right) \quad (11)$$

Changes in part cost caused by a limited change in an arbitrary variable *z,* is calculated by partial derivative, and is described in linear form in equation 12.

$$\Delta k_i = \frac{\partial k_n}{\partial z} \cdot \Delta z \quad (12)$$

Cost neutral changes in each variable can be studied by putting the change in part costs $\Delta k_i = 0$. Equation 12 is written in a cost neutral form in equation 13, describing the size of the reduction in downtime share required to compensate for a change in wage costs.

$$\Delta q_{Si} = -\Delta k_{Di} \cdot \frac{\dfrac{\partial k_i}{\partial k_{Di}}}{\dfrac{\partial k_i}{\partial q_{Si}}} \quad (13)$$

7 THE CASE STUDY

The implementation of the method SPA resulted in data connected to a number of products produced at the factory at the choosen manufacturing unit. This paper will present an analysis of one of these products, called product x. Besides as an analysis of this product, this case study presentation also can be viewed as an example of how you can apply the cost model described in equation 11, when an SPA has been made and other necessary production data is available.

From the data collection phase of the case study, including a systematic registration of scrap, down time and production rate according to the method described in section 4, the values of the parameters in equation 10 was obtained and is presented in Table 3. In this case study the cost of reduced occupation has not been considered and there is no data for the deviation from the nominal set up time for this product. Inserting the values of the parameters in Table 3 into equation 10, the cost of production per part *k* equals 386,8 kr, which implies that this processing step adds 144,27 kr to the cost of the product.

Table 3 : Calculated values of the parameters in the economic model

q_Q	q_S	q_P	q_{Ssu}	T_{su0}	t_0
0.0230	0.4273	0	0	120	7.2
N_0	k_A	k_B	k_{CP}	k_{CS}	k_D
1000	13.7	242.53	420	420	150

During the analysis of the collected data, new ways to present the costs was developed. This was done by starting out from equation 10 and then divide the cost *k* into the different parts that add costs in the chosen processing step. The chart in Figure 1 below shows the part cost *k* together with k_B and these new cost items; k_{VA}, k_{NVA} k_{Tsu}, k_Q, k_S, and k_P, where *k* equals the sum of k_B, k_{VA}, k_{NVA} and k_{Tsu}, see equation 14.

$$k = k_B + k_{VA} + k_{NVA} + k_{Tsu} \quad (14)$$

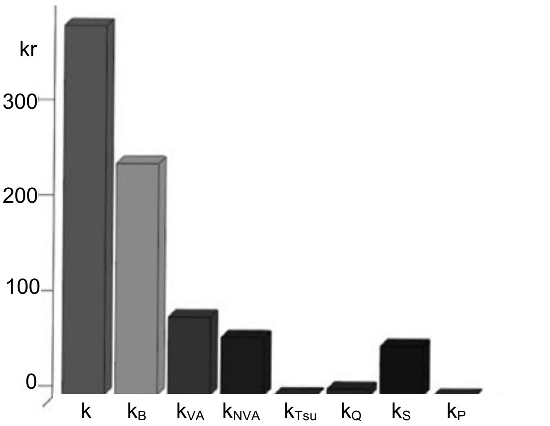

Figure 1: The part cost *k* and different parts of *k*.

k_{VA} is the value added part of the cost and is defined in equation 15. k_{VA} describes the cost added in this processing step, without considering q_Q, q_S, q_P and T_{su}.

$$k_{VA} = k_A + (k_{CP} + k_D)\cdot t_0 \quad (15)$$

k_{NVA} is the cost of non value added activities and constitutes of all costs related to the loss parameters q_Q, q_S and q_P, and is defined in equation 16.

$$k_{NVA} = k_Q + k_S + k_P \quad (16)$$

k_{Tsu} constitutes of the costs related to set up and is defined in equation 17.

$$k_{Tsu} = \frac{k_{CS} + k_D}{60 \cdot N \cdot (1-q_Q)} \cdot \frac{T_{su0}}{(1-q_{Ssu})} \quad (17)$$

By dividing the part cost *k* into k_B, k_{VA}, k_{NVA} and k_{Tsu} you get a quick overview of the cost condition of the product. The size of k_{NVA} indicates the potential cost reduction by decreasing the disturbances in the production. k_{NVA} make up 42.3 % of the total cost added in this processing step, or 61.0 kr per part. Correspondingly, k_{VA} make up 56.9 % of the total cost added, or 82.1 kr expressed in cost per part. k_{Tsu} is calculated to 1.2 kr per part. The combination of a large batch size and a long cycle time makes k_{Tsu} relatively insignificant regarding the part cost of product x at this chosen processing step.

A division of k_{NVA} can be made into k_Q, k_S and k_P, with the purpose to find out the specific costs contributed by each result parameter q_Q, q_S, q_P. k_Q describes the costs connected to the scrap rate q_Q and is defined in equation 18.

$$k_Q = \frac{N \cdot q_Q}{N \cdot (1 - q_Q)} \cdot \left(k_A + k_B + \frac{k_{CP} \cdot t_0}{60} + \frac{k_D \cdot t_0}{60} \right) \qquad (18)$$

The largest part of k_{NVA} consists in this case of costs related to the down time rate q_S. This cost is named k_S and is defined in equation 19. k_S was calculated to 52.7 kr per part and constitutes 86.3 % of k_{NVA}.

$$k_S = \frac{k_{CS} \cdot t_0 \cdot N \cdot q_S}{60 \cdot N \cdot (1 - q_Q) \cdot (1 - q_S) \cdot (1 - q_P)} + \frac{k_D \cdot t_0 \cdot N \cdot q_S}{60 \cdot N \cdot (1 - q_Q) \cdot (1 - q_S) \cdot (1 - q_P)} \qquad (19)$$

k_P describes the costs caused by q_P and is defined in equation 20 and was calculated to 0.7 kr per part.

$$k_P = \frac{k_A \cdot N \cdot q_P}{N \cdot (1 - q_Q) \cdot (1 - q_P)} + \frac{k_{CP} \cdot t_0 \cdot N \cdot q_P}{60 \cdot N \cdot (1 - q_Q) \cdot (1 - q_P)} + \frac{k_D \cdot t_0 \cdot N \cdot q_P}{60 \cdot N \cdot (1 - q_Q) \cdot (1 - q_P)} \qquad (20)$$

The size of k_{NVA} for this product at this production unit implies that there is a substantial amount of money to be saved if k_{NVA} can be reduced, if the total annual volume of the product is considered. The annual volume of product x is estimated to 9300 units by the company. If assuming that the value of k_{NVA} is intact over a year, the theoretical cost reduction becomes roughly: $k_{NVA} \cdot 9300 = 61 \cdot 9300 = 567300$ kr.

To reduce k_{NVA} you have to know the result parameters and the factors connected to these parameters that together constituting the value of k_{NVA}. When combining the result from the SPA and the parameters calculated from this data, it will be possible to obtain the influence on the manufacturing cost of every result parameter and factor registered in the SPA. In Figure 2 the factors having the largest effect on the part cost of product x as a result of the performed SPA are shown as their cost per part. The figure illustrates that apart from the tool factor A2, the major factors behind the size of k_{NVA} are related to the process C and organizational issues D.

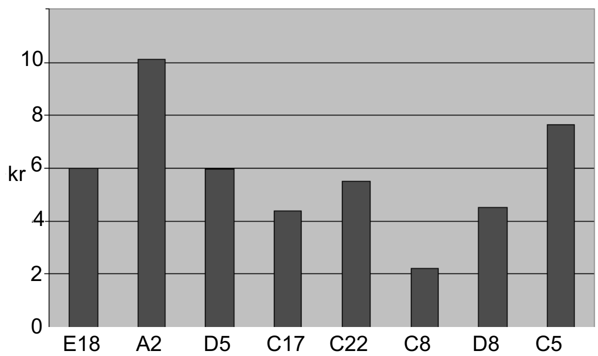

Figure 2: The factors having the largest effect on the part cost of product x

After quantifying the cost of the production disturbances and the factors in the different units or cells of the manufacturing plant, it will be possible to compare different disturbances influence of the manufacturing cost and thereby for example be able to make priorities between different development projects concerning the manufacturing process.

At this stage, when the critical parameters and factors connected these losses are obtained and economically quantified, then cost derivatives can be used to analyse different development scenarios. Figure 3 illustrate the cost neutral relationship between a change in the development factor $\Delta\kappa_C$ and a change in downtime rate Δq_S for product x. The figure shows for example that if the down time rate can decrease by 0.15, you get $\Delta\kappa_C$ to 0.35. This means that the equipment costs, k_{CS} and k_{CP}, can be increased by up to 35 % without increasing the part cost if the decrease in q_S can be accomplished.

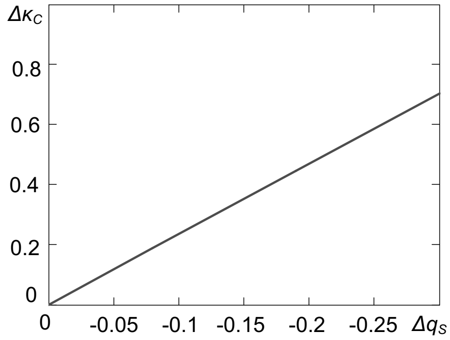

Figure 3: Cost neutral change between an increase in equipment cost factor $\Delta\kappa_C$ and reduction of down time rate Δq_S.

As Figure 2 illustrates, the largest cost factor for product x is A2, which is a factor connected to the tools in the machine. Figure 4 shows the cost neutral relationship for product x between an increase of the tool cost Δk_A and a decrease of the process development factor Δx_P. This relationship illustrates the maximum cost increase of improved tooling capable of reducing the cycle time to a certain level. The dotted graph shows the relationship when new but more expensive tools enables a decrease in x_P, but at the same time causes an estimated increase in the scrap rate q_Q by 0.01. The continuous graph shows the relationship without any increase in q_Q.

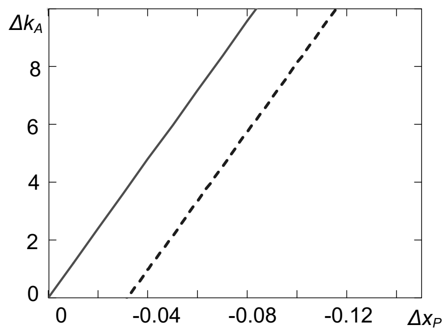

Figure 4: Cost neutral changes between an increase in tool cost Δk_A and reduction of the development factor Δx_P (continuous graph) and an increase in Δk_A plus a 0.01 increase of q_Q and a reduction of Δx_P (dotted graph).

This analysis is made for a single product in a processing step where several other products is produced. These other products and the costs connected to them must of course be taken into consideration to get a general picture of the costs in this processing step.

8 DISCUSSION AND CONCLUSIONS

To sum up the analysis described in the previous section, the high value of q_S is making a significant impact on the manufacturing cost of this product at this processing step. This case study shows that there is a potential in analysing the manufacturing performance of today and alternative simulated scenarios with the method described in this paper. An important prerequisite for these analyses to be reliable is the accuracy of the input data and how detailed this data is. If the model is implemented at every unit or cell at a factory it will then be possible to obtain which cost items that builds up the total manufacturing cost of a part or a group of parts and size of these items. Figure 5 shows the division of the part cost *k* made in section 7. This division makes it easy to get a clear view of the costs added in a processing step. Having this detailed information accessible for products in all processing steps would enabeling a greater insight and understanding about where in the manufacturing process there is the highest potential to lower the costs and thereby function as a basis for prioritys concerning production development activities.

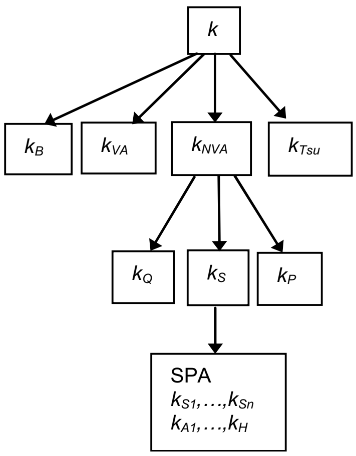

Figure 5: The division of *k* made in the presented case study analysis.

By combining production data and economic data into this economic model it is also possible to establish manufacturing economic development goals. A development goal could for example be to reduce the cost of manufacturing per part with 10 % for a product or a group of products. By the implementation of this model a plan to reach that goal could be established.

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