A Basic Economic Model for Judging Production Development

Ståhl, Jan-Eric; Andersson, Carin; Jönsson, Mathias

Published in:
Proceedings of the 1st International Swedish Production Symposium

2007

A BASIC ECONOMIC MODEL FOR JUDGING PRODUCTION DEVELOPMENT

Jan-Eric Ståhl, Carin Andersson, Mathias Jönsson

Division of Production and Materials Engineering, LTH, Lund University

jan-eric.stahl@iprod.lth.se

The described technical-economic model clarifies the influence of different production technological factors on the processing cost of a part. The model represents the fundamental theory for the judging of different types of production development. Various influential factors can be weighted against each other, which leads to different production development scenarios and their effects on the processing cost can be studied. This implies a way to generate a basis of decision by which a company can base their production related development goals. The model describes technical factors influence on the manufacturing cost and represents by that the important link between technical development and economy.

Keywords: manufacturing economy, manufacturing analyses, deterministic production development, cost derivatives

1. INTRODUCTION

A majority of all the manufacturing companies are working with production development and improvements to meet the competition from low-wage countries in for example Asia. There are a number of methods and philosophies for working with continuous improvements, where the success of lean production (Womack *et al.*, 1990), is the most widely spread. An important question is if considerations and decisions made regarding investments and development actions are based on correct and adequate knowledge in order to achieve the highest efficiency benefits.

The outsourcing decision has been going on for some time now (Berggren *et al.*, 2005), (Larsson and Malmqvist, 2002). Decisions made about moving production-units to low-wage countries are often based on limited information, giving wages to big influence over the decisions. Existing economic models are inadequate in utilizing estimation of the development potential of a production system and possible development actions.

There are many questions to be asked when considering major improvement changes in a production facility. The most common questions the company management would like to have answered are:

– How much better do we have to be to compete with for example low-wage countries and what and where in the production facility do we have to improve?

– What changes and what research and development actions will give the company the best long term competitive strength?

– What are the bases of decision required to formulate goal functions for production development, and what are reasonable goal functions for the actual production system?

The economic model presented in this article can give answers to some of these questions, if the required data is known.

2. GOALS AND LIMITATIONS

The economic model presented is defined to comprise the direct production cost. The overhead costs are excluded at this level, because they have little to do with developing the production system. Factors tied to the income side of the production are not considered in the model. The model primarily describes batch production with the nominal batch size N_0. The model is summarized to describe one processing step or a so-called planning point. (a planning point is a set of machines and robots where the cycle time is determined by the slowest machine in the line). This simplification enhances the principle of comparing the influence of different cost items on the total production cost. These factors influence on the production cost can therefore constitute the foundation for choosing research and development actions.

The parameters in the model are adjusted to the results from a Systematic Production Analysis (SPA) (Ståhl, 2007), during which the 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

3. LIST OF SYMBOLS

The index of the parameters in the list of symbols are partly tied to the factor groups described above.

t_0	Nominal cycle time per part.	min
t_m	Machine time	min
t_h	Handling time	min
t_{vb}	Tool switch time	min
t_p	Production time per part	min
t_S	Average down time per part	min
t_{pb}	Production time per part for one batch with N_0 parts	min
q_S	Down time rate	-
q_Q	Scrap rate	-
Δq_{S1}	Limited change in down time losses	-
q_{Ssu}	Disturbance rate during set up	-
N	Total amount of required parts to be able to produce N_0 parts	unit
N_0	Nominal batch size	unit
N_Q	Amount of scrap parts in a batch of N_0 parts	unit
N_{av}	Average batch size	unit
n	Rational number > 0	-
T_p	Production time for one batch	min
T_{su}	Set up time	min
∂z	Partial change in arbitrary variable.	
Δz	Change in arbitrary variable	
x_p	Process development factor for the cycle time	-
x_{su}	Process development factor for set up time	-
Δx_p	Limited change in process development factor for cycle time	-
k_i	Part cost of manufacturing case i	Sw.c./unit
k_B	Material cost per part	Sw.c./unit
k_{CP}	Hourly cost of machines during production	Sw.c./h
k_{CS}	Hourly cost of machines during down time and set up	Sw.c./h
k_{Di}	Wage cost for manufacturing case i	Sw.c./h
Δk_{D1}	Limited change in wage cost	Sw.c./h

4. LITTERATURE REVIEW

Several different models have been developed for the purpose of calculating the manufacturing cost. According to Tipnis, *et al*. (1981), the models can be devided in microeconomic and macroeconomic models. In the microeconomic models specific process parameters influence on the part cost is described. Microeconomic models dealing with machining has been described by Colding (1978, 2003) and Alberti, *et al*. (1985) among others and Knight, *et al*. (1982) has developed a corresponding model for forging. Within the field of machining a microeconomic model can describe how for example the cutting rate, feed or working margin influence the part cost. In a macroeconmic model several parameters are aggregated. An example of a macroeconomic model is when the cost calculations are based on the cycle time and not the factors that influece the cycle time. The fundamental principles for developing macroeconomic models are described by the economists Kaplan and Anderson (2007). The authors have not developed any models that are diretctly applicable to calculate the part cost but leaving these activities to the reader.

Macroeconmic models have priviously been illustrated by Groover (1987). In this model only one production loss parameter is taken into considereation; the scrap rate. Ravignani and Semeraro (1980) has developed a model that combines the micro- and macroeconomic views by noticing both cutting tecnological conditions and the batch size. Any production loss parameters is not regarded.

It can be stated that the microeconomic models are specific for different processing methods. A numerous models has been developed to describe the cutting cost of machining. The models are describing the connection between the cutting rate, the wear rate of a cutting tool and the tool switch time. Preferably you separate maximum production rate and minimum production cost. In these models the tool cost is higly prioritized. Cost for down time and the scrap rate is not taken into consideration.

A cost model for assemblieng is introduced by Teng and Garimella (1998). This model is based on inventory costs, assembly costs and costs associated with diagnostic and rework activities. The model has a high reslution concerning cost for differnet types of equipment in the assembly line. The model is based on average cycle times where also the scrap rate is considered. Boothroyd (1984) is describing a specific cost model for robot assembly which is noticing the down time costs in the assembly line.

Production cost regarding design has been discussed by Locascio (2000), Liebers and Kals (1997) and Shehab and Abdalla (2001). Locascio is assuming that all cycle times of the processing steps is known in advanced. Any specific connection to production loss parameters is not considered. Shehab and Abdalla is describing an interesting model that estimate the manufacturing cost for machining for different choises of material where both the material cost and the precessing cost is taken into consideration.

The model to be descibed below is general and can regarded as a macroeconomic model but with the possibility to consider the micoeconomic parameters. The model is intended to describe the part cost of various specific or aggregated processing methods without any major modifications.

5. MODELLING OF THE PART COST

The nominal processing time (cycle time) t_0 for a part is comprised of machine time, handeling time and tool change time:

$$t_0 = t_m + t_h + t_{vb}$$

(1)

The equation assumes that the events are performed in a sequential order and can be considered as a planning point. The real processing time t_p will be longer than the nominal time due to disturbances and downtime. The rate of the disturbance and downtime can be expressed as the quotient between the downtime t_S and the observed production time t_p described in equation 2. The sum of the downtime and nominal processing time gives the real processing time t_p according to equation 3. Combining equation 2 and 3 the processing time can be determined based on the nominal cycle time and the downtime rate q_S:

$$q_S = \frac{t_S}{t_p} = \frac{t_p - t_0}{t_p}$$

$$t_p = \frac{t_0}{1 - q_S} = t_0(1 + \frac{q_S}{1 - q_S})$$

$$t_S = \frac{t_0 \cdot q_S}{1 - q_S}$$

(2-4)

To obtain N_0 number of correct parts, N number of parts has to be manufactured due to scrapped parts. The rate of scrapped parts is expressed by q_Q:

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

$$N = \frac{N_0}{1 - q_Q} = N_0(1 + \frac{q_Q}{1 - q_Q})$$

(5)

Losses in production rate are a fact when the cycle time has to be increased from t_0 to t_{0v} to maintain the quality level or avoid unplanned downtime. The relative loss in production rate is described as:

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

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

(6)

To changeover the production from manufacturing part A to part B a certain amount of setup time T_{su} is required. The production time for a batch including the setup time:

$$T_p = T_{su} + N \cdot t_p =$$

$$T_{su} + \frac{N_0 \cdot t_0}{(1 - q_Q)(1 - q_S)(1 - q_P)}$$

(7)

The total average production time for manufacturing N_0 number of correct parts is calculated as:

$$t_{pb} = \frac{T_p}{N_0}$$

(8)

In the presented model there are primarily three cost items specified:
k_C = equipment costs
k_D = staff costs
k_B = material costs
Equipment costs for a machine or a production line can be split up into a cost during production k_{CP} and a cost k_{CS} when the machine or production is not running. For the case in question both these cost items include all of the costs that can be related to the equipment as investment cost, local cost, cost of maintenance, tool costs etc.
The cost of wages per hour k_D are presumed to be independent of if the machine is running or not and also presumed to be unchanged during setup.

To study the material cost including scrapped parts and material waste, a material waste factor q_B is introduced:

$$K_B = \frac{N_0 \cdot k_{B0}}{(1-q_B)(1-q_Q)}$$
$$q_B = \frac{m_{tot} - m_{part}}{m_{tot}}$$
(9)

where k_{B0} is the materials cost for the manufactured part and K_B is the materials cost for the batch including scrapped parts and material waste. The material waste factor q_B consider the total consumption of material m_{tot} per part and comprises also material that are machined or cut off as for example chips during turning or milling and retainer surfaces during sheet metal forming. The remaining material in the machined part is denoted m_{part}.

Reduced occupation in a manufacturing system leads to consequences for all manufactured parts. This situation can be considered differently, 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 per batch T_{prod} and planned production time T_{plan}:

$$U_{RP} = \frac{T_{prod}}{T_{plan}};\ T_{plan} = T_{prod} + T_{free}$$
(10)

The extra free capacity $T_{free,b}$ to be added to a specific batch is calculated as in equation 11. The free time can be considered as a setup time at the same time as the equipment is available for manufacturing:

$$T_{free,b} = \frac{1-U_{RP}}{U_{RP}} T_{pb}$$
(11)

The manufacturing costs per part k, including the previously described parameters and assumptions can be expressed as:

$$k = \frac{K_{sum}}{N_0} + \frac{1}{N_0}\left[\frac{k_B N_0}{(1-q_Q)(1-q_B)}\right] +$$
$$\frac{1}{N_0}\left[\frac{k_{Cp}}{60} \cdot \frac{t_0 N_0}{(1-q_Q)(1-q_P)}\right] +$$
$$\frac{k_{CS}}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_P)} \cdot \frac{q_S}{(1-q_S)} + T_{su} + \frac{1-U_{RP}}{U_{RP}} T_{pb}\right] +$$
$$\frac{k_D}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_S)(1-q_P)} + T_{su} + \frac{1-U_{RP}}{U_{RP}} T_{pb}\right]$$
(12)

In some cases it can be necessary to introduce a disturbance factor q_{Ssu} to handle spreading in the nominal setup time.

The cost item K_{sum} in equation 12 comprises different types of costs that are not described separately in the model. There are also cost items that are merged together in the model. For example is the tool costs integrated with the machine costs (k_C). A more complete economic model has a higher resolution and includes more of separate terms that are now included in K_{sum}. A developed model can for example consider tool costs, cost of maintenance, remainder value of waste material, fixture costs, stock/buffer and transportation costs, surrounding equipment, costs arising due to environmental or recycling actions for example eliminating cutting fluids or oils.

6. DETERMINISTIC PRODUCTION DEVELOPMENT

To be able to manage production development efficiently, clear goals has to be established for the development activities. The development activities can be performed in relation to the company's present production conditions or in relation to the competitors and other terms of the market. Example of production development goal functions are reduction of the manufacturing costs with 20 % for a certain part type, a 50 % reduction of setup time or an increase of production rate from 100 to 120 parts per week with unchanged cost parameters.

Considering that a lot of factors, isolated or in cooperation, influence the cost for a specific part, different changes in these factor can lead to same cost effects. To be able to separate the influence of these different factors on the part cost, different development factors are introduced. These development factors operate on different parameters in equation 12.

$$k = \frac{K_{sum}}{N_0} + \frac{1}{N_0}\left[\frac{k_B \cdot N_0}{(1-q_Q)(1-q_B)}\right] +$$
$$\frac{1}{N_0}\left[\frac{\kappa_C \cdot k_{Cp}}{60} \cdot \frac{x_p \cdot t_0 N_0}{(1-q_Q)(1-q_P)}\right] +$$
$$\frac{\kappa_C \cdot k_{CS}}{60N_0}\left[\frac{x_p \cdot t_0 N_0}{(1-q_Q)} \cdot \frac{q_S}{1-q_S} + x_{su} \cdot T_{su} + \frac{1-U_{RP}}{U_{RP}} T_{pb}\right] +$$
$$\frac{k_D}{60N_0}\left[\frac{x_p \cdot t_0 N_0}{(1-q_Q)(1-q_S)} + x_{su} \cdot T_{su} + \frac{1-U_{RP}}{U_{RP}} T_{pb}\right]$$
(13)

In equation 13 the development factor x_p operates on the cycle time and enables therefore analysis of changes in cycle time. The development factor x_{su} operates on the setup time and enables therefore studies of changes in setup time. The cycle time and setup time are the most important parameters describing the capacity and flexibility in setup of a production system. A development factor given a value less than 1.0 result in a reduction in cycle time and setup time, if the factors are given for example the value 0.5, the production time and setup time has been reduced to half of the original size. The development factors can therefore be regarded as improvement variables in a goal function.

A cost development factor κ_C is introduced to describe an investment cost that can be connected to a change in cycle time. The cost factor operates on the equipment costs k_{CP} and k_{CS}. This factor 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. For example does κ_C = 1.20 corresponds to an increase in equipment cost with 20 %.

7. COST DERIVATIVES

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 as:

$$\Delta k_i = \frac{\partial k_n}{\partial z} \cdot \Delta z$$

(14)

The error obtain by the simplification in equation 14 is deceased by using Taylor formula, which is built up by a polynomial where the coefficients are the derivatives of the function up to the chosen order. Being able to consider the effects of derivatives of higher order, gives the possibility of determining the value of the function even for larger changes in the variable. Figure 1 and Figure 2 is examples of a production case, where the error or Lagranges residual term for polynomial with order 1 and 2, with changes in downtime Δq_S and scrap rate Δq_Q. The errors in Figure 1 and 2 have the character of the first of the neglected term of order, which in the actual case is a function of the second and third degree.

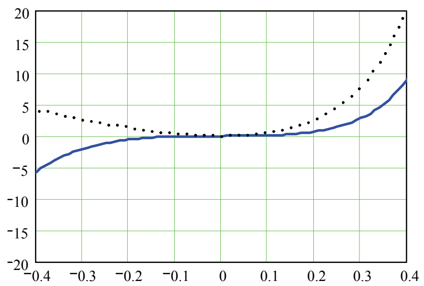

Fig. 1. Example of errors made when estimating the part cost under influence of a changes in downtime Δq_S with a polynomial of order 1 (dotted graph) and 2 (continuous graph).

The below described relations are mainly based on the first derivative (first order), which leads to approximate results with errors in the same magnitude as illustrated in figure 1 and figure 2. In the case when the first derivative is constant and the second derivative equals zero, the correct value of function is obtained by assigning the actual variable *z* the value of $z+\Delta z$. This is the case with for example the development factor x_p and the cost development factor κ_C. The second derivative of the part cost with respect to both of these variables is accordingly zero.

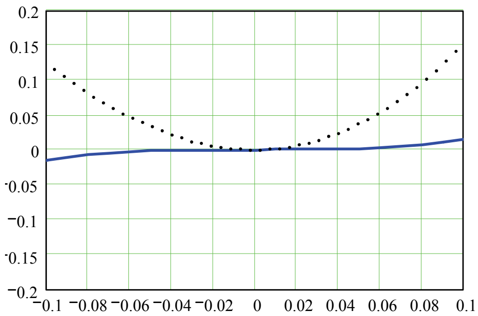

Fig. 2. Example of errors made when estimating the part cost under influence of changes in downtime Δq_Q with a polynomial of order 1 (dotted graph) and 2 (continuous graph).

The changes in part costs can in equation 15 be calculated with respect to different parameters as for example changes in wage costs, share of downtime Δq_{Si}, process development factor Δx_{pi} or cost development factor $\Delta\kappa_{Ci}$. Equation 15 is exemplifying changes in part costs due to changes in different governing parameters.

$$\Delta k_i = \frac{\partial k_i}{\partial k_{Di}} \cdot \Delta k_{Di} + \frac{\partial k_i}{\partial q_{Si}} \cdot \Delta q_{Si}$$

$$\Delta k_i = \frac{\partial k_i}{\partial \kappa_C} \cdot \Delta \kappa_C + \frac{\partial k_i}{\partial x_{Pi}} \cdot \Delta x_{Pi} + \frac{\partial k_i}{\partial x_{sui}} \cdot \Delta x_{sui}$$

(15)

Cost neutral changes in each variable can be studied by putting the change in part costs $\Delta k_i = 0$. Equation 15 is written in a cost neutral form in equation 16, describing the size of the reduction in downtime share required to compensate for a change in wage costs.

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

(16)

$$\Delta \kappa_{Ci} = \frac{-\left(\dfrac{\partial k_i}{\partial x_{pi}} \cdot \Delta x_{pi} + \dfrac{\partial k_i}{\partial x_{sui}} \cdot \Delta x_{sui}\right)}{\dfrac{\partial k_i}{\partial \kappa_{Ci}}}$$

(17)

Equation 17 describes a corresponding connection between cost development factor and changes in process development factors. The cost development factor in equation 17 indicate to what extent the equipment costs can be changed, if any or all of the other parameters are changed, without an increase in part cost.

The influence of a specific variable can be studied by calculating cost derivatives. A change in a variable giving a large influence on the part cost also gives large cost derivative values. It is hazardous to uncritically compare different cost derivatives with each other since the possibility of changing each variable is different. A weighting of the cost derivative can be made by multiplying the cost derivative with its functional value. A weighted cost derivative is a better indication of the impact each variable has on changes in the cost derivatives. All changes Δz in the variable z becomes relative with respect to the absolute value of the variable. By introducing a relative variable $\Delta z_0/z_0$ the changes expressed as a percentage for a specific variable can be compared with changes expressed as a percentage for another variable. This principal is expressed in equation (18).

$$\Delta k = \frac{\partial k(z_0)}{\partial z} \cdot z_0 \cdot \frac{\Delta z_0}{z_0}$$

(18)

The quota $\Delta z_0 \cdot 100/z_0$ describes a change expressed as a percentage in the variable z in the point z_0.

8. MODEL EXAMPLE

The costs for two different production cases can be studied by introducing an index i tied to the parameters and variables in equation 13 in order to separate them. In the following the part costs k_1 and k_2 are calculated for the presumption valid for each case. Two process development factors x_{pi} and x_{sui} have been introduced in equation 13 to study the consequences of a changed process time respectively a changed set up time. The process development factors x_{pi} and x_{sui} describes a change in the process time t_0 and the set up time T_{su}. When the factors are set to for example 0.5, the process time and set up time have been halved. Below the developed model is exemplified by inserting technical and economic data.

Table 1 Economic data for the model (Sw.c. = Swedish crowns)

t_0	10	min
T_{su}	100	min
k_{Cp}	1000	Sw.c./h
k_{CS}	700	Sw.c./h
k_{D1}	200	Sw.c./h
k_{D2}	50	Sw.c./h
k_B	20	Sw.c./part
q_B	0	-
K_{sum}	0	Sw.c./batch

Figure 3, 4 and 5 illustrate the part cost according to equation 13 under various conditions. In case 1 (dotted graph) is the wage cost k_{D1} = 200 Sw.c./h and in case 2 (unbroken graph) is the wage cost k_{D2}= 50 Sw.c./h. Figure 3 illustrate the influence of the wage cost only.

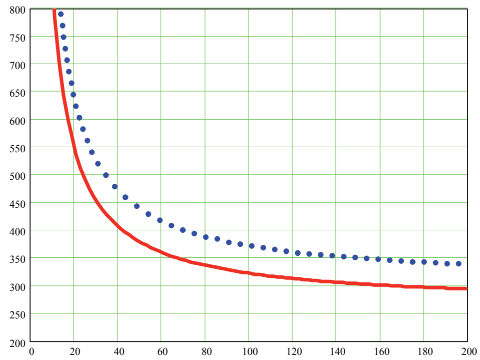

Fig. 3. The part cost of the production cases 1 (dotted graph) and 2 (continuous graph) as a function of the nominal batch size N_0. In both case 1 and 2 is q_Q = 5 % and q_S = 40 %, x_p and x_{su} is 1.0.

In figure 4 has production case 1 a decreased down time loss from q_S = 40 % to q_S = 35 % and the process development factor x_{p1} has decreased from 1.0 to 0.95. By these changes the difference in part cost between the two cases has more than halved, even if it differ a factor 4 in wage cost.

In figure 5 below the down time factor q_{S1} has been further decreased with 5 % to 30 % and the process development factor x_{p1} is reduced to 0.80. In this situation the part cost of case 1 has been reduced so it becomes 30 crowns lower than of case 2 for batches larger than 100 parts.

In figure 6 the cost change Δk_1 is illustrated in crowns as a function of change in down time loss Δq_{S1} and change in relative wage cost $\Delta(k_{D1}/k_{D1})$. In the figure you can observe that a increase in part cost by 40 crowns can either be received by increasing the down time loss 10 % or the wage cost by 70 %. In this linear model the corresponding decrease applies in the described variables.

In figure 7 the cost neutral changes are shown, which illustrate the balance for a change in wage cost and down time loss and also a change in wage cost and process development factor. In the figure it can be established that a wage increase by 40 crowns per hour i.e. 20 %, corresponds a cost neutral improvement i the process development factor Δx_p by about 4 % or a decrease in down time losses Δq_S by almost 3 %.

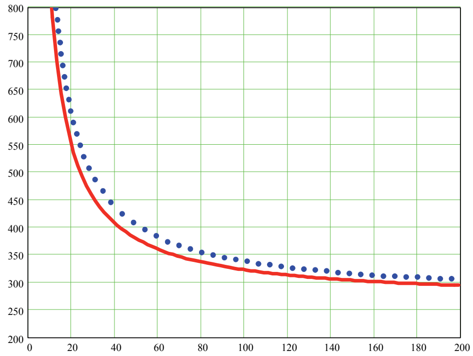

Fig. 4. The part cost of the production cases 1 (dotted graph) and 2 (continuous graph) as a function of the nominal batch size N_0. In both case 1 and 2 is $q_Q = 5$ % and $q_S = 40$ % for case 2 and 35 % in case 1, x_p is 1.0 in case 2 and 0.95 in case 1.

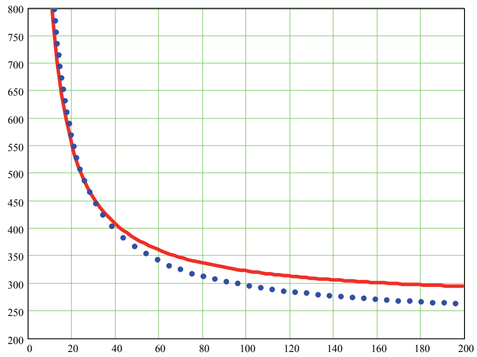

Fig. 5. The part cost of production case 1(dotted graph) and 2 (continuous graph) as a function of the nominal batch size N_0. In both case 1 and 2 is $q_Q = 5$ %. $q_S = 40$ % for case 2 and 30 % in case 1, x_p is 1.0 in case 2 and 0.80 in case 1.

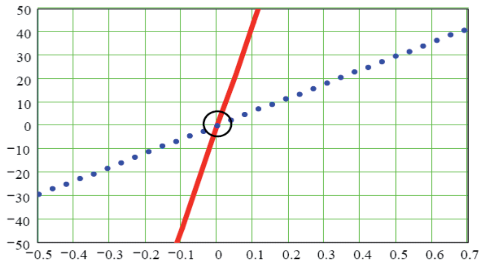

Fig. 6. The relationships between the cost change Δk_1 and change in down time loss Δq_{S1} and change in relative wage cost $\Delta k_{D1}/k_{D1}$. In this case is $q_Q = 5$ % and $q_S = 40$ %, x_p and x_{su} is 1.0, the batch size 200 parts.

Figure 8 exemplifies a corresponding balance between a change in cost factor and a change in Δq_S and Δx_p In table 2 below the weighted cost derivative among others are shown for various variables with data from table 1. As expected a decreased cost (minus sign) is obtained when the batch size and the degree of occupation increase. The down time derivative is the largest in this case.

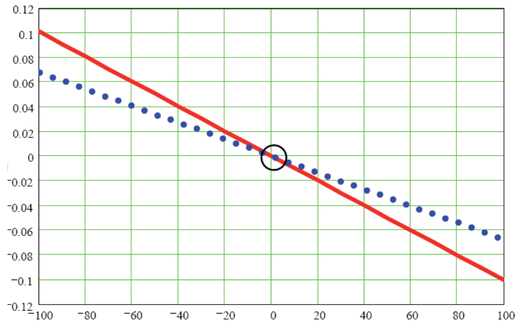

Fig. 7. Cost neutral changes in wage cost and in down time losses (dotted graph) and also in wage cost and process development factor (continuous graph). In this case is $q_Q = 5$ % and q_S 40 %, x_p and x_{su} is 1.0 and batch size $N_0 = 200$ parts.

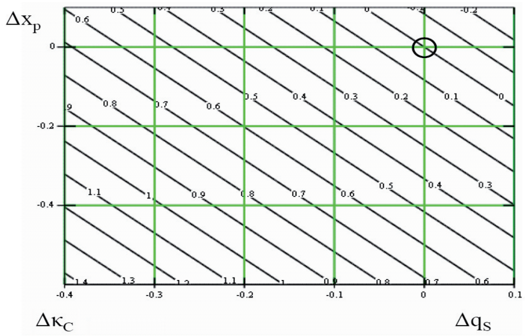

Fig. 8. Exemplification of cost neutral changes between an increase in cost factor $\Delta\kappa_C$ and reduction of relative cycle time x_p and a decrease in down time losses q_S.

Table 2 Cost derivatives

Parameter, starting value and description.			Cost derivative, type and weighted cost derivative		
N_0	200	Batch size	-0.025	Sw.c./ unit	**-5**
q_Q	0.05	Scrap rate	356	Sw.c.	**18**
q_S	0.40	Down time rate	487	Sw.c.	**195**
k_D	200	Wage cost	0.30	h/unit	**59**
x_p	1.0	Development factor	327	Sw.c.	**327**
x_{su}	1.0	Development factor	5	Sw.c.	**5**
U_{RP}	1.0	Degree of occupation	- 297	Sw.c.	**-297**
κ_C	1.0	Investment factor	273	Sw.c.	**273**

9. DISCUSSION AND CONCLUSIONS

The developed model enable analyze and estimation of various technical and organizational development alternatives. The example shown in figure 7 illustrates for example how a higher wage cost can be compensated by technical and organizational improvements. Through studies of cost derivatives different alternatives related to production development can be judged. High cost derivatives shows the strength of a certain variable. The example described in table 2, shows that the development factor x_p and down time loss q_S are two parameters with great influence on the part cost in this case. These parameters should be the basis for the choice of production development activities. Further it can be established that the degree of occupation U_{RP} has a great influence on the part cost. In table 3 below the two production cases previously exemplified in charts are compared. The investment cost in research and development necessary to reduce x_{p1} from 1.0 to 0.80 and q_{S1} from 0.40 to 0.30 can for instance be weighted against alternative costs. The theoretical and practical possibilities to realize the necessary development for example in the case above must of course be estimated in each specific case. The conditions are highly governed by the present level of development and the belonged remaining development potential.

Table 3 The part cost for various technical and organizational circumstances for the nominal batch size N_0 = 200 parts.

Example figure	Case 1 Part cost	Case 2 Part cost
1.	***339 Sw.c./part*** k_{D1} = 200 Sw.c./h x_{p1} = 1.0 q_{S1} = 0.40	***294 Sw.c./part*** k_{D2} = 50 Sw.c./h x_{p2} = 1.0 q_{S2} = 0.40
2.	***305 Sw.c./part*** k_{D1} = 200 Sw.c./h x_{p1} = 0.95 q_{S1} = 0.35	***294 Sw.c./part*** k_{D2} = 50 Sw.c./h x_{p2} = 1.0 q_{S2} = 0.40
3.	***262 Sw.c./part*** k_{D1} = 200 Sw.c./h x_{p1} = 0.85 q_{S1} = 0.30	***294 Sw.c./part*** k_{D2} = 50 Sw.c./h x_{p2} = 1.0 q_{S2} = 0.40

The difficulties of using the described model are that the model demands accurate input data. A Systematic Production Analyze (SPA) made under representative circumstances is highly necessary to be able to estimate the parameters q_Q, q_S and q_P and other parameters such as the set up time. From experience the equipment costs represent though the greatest difficulties. These problems are dealt with by Ståhl (2007) among others.

REFERENCES

Alberti, N., S. Noto La Diega and A. Passannanti (1985). Interdependence Between Tool Fracture and Wear, *Annals of the CIRP*, **34**, 61-63.

Bengtsson, C., L. Berggren and J. Lind (2005). *Alternativ till outsourcing*, Liber AB, Malmö.

Boothroyd, G. (1984). Economics of General-Purpose Assembly Robots, *Annals of the CIRP*, **33**, 287-290.

Colding, B. (1978). Relative Effects of Shop Variables on Manufacturing Cost and Performance, *Annals of the CIRP*, **27**, 453-458.

Colding, B. (2003). *Tids- och kostnadsanalys vid skärande bearbetning – Optimering för synkront detaljflöde*, Colding International Corporation, Stockholm.

Groover, M.P. (1987). *Automation, Production Systems, and Computer Integrated Manufacturing*, Prentice-Hall Inc, Englewood Cliffs, NJ.

Kaplan, R.S. and S.R. Anderson (2007). *Time-Driven Activity-Based Costing; a simpler and more powerful path to higher profits*, Harvard Business School Publishing Corporation, Boston.

Knight, W.A. and C.R. Poli (1982). Design for Economical Use of Forging: Indication of General Relative Forging Costs, *Annals of the CIRP*, **31**, 159-163.

Larsson, J and C-G Malmqvist (2002). *Outsourcing – erfarenheter av outsourcing i svenska företag,* Olle Sjöstedt information AB. Västerås

Liebers, A. and H.J.J. Kals (1997). Cost Decision Support in Product Design, *Annals of the CIRP*, **46**, 107-112.

Locasio, A. (2000). Manufacturing Cost Modelling for Product Design, *The International Journal of Flexible Manufacturing Systems*, **12**, 207-217.

Ravignani, G.L. and Q. Semeraro (1980). Economics of Combined Lot and Job Production with Consideration for Process Variables, *Annals of the CIRP*, **29**, 325-328.

Shehab, E.M. and H.S. Abdalla (2001). Manufacturing cost modeling for concurrent product development, *Robotics and Computer Integrated Manufacturing*, **17**, 341-353.

Ståhl, J-E (2007). *Industriella Tillverkningssystem,* Division of Production and Materials Engineering, LTH, Lund University, Lund.

Teng, S-H and S.S. Garimella (1998). Manufacturing Cost Modelling in Printed Wiring Board Assembly, Journal of Manufacturing Systems, **17**, 87-96.

Tipnis, V.A., S.J. Mantel and G.J. Ravignani (1981). Sensitivity Analysis for Macroeconomic and Microeconomic Models of New Manufacturing Processes, *Annals of the CIRP*, **30**, 401-404.

Womack J.P., D.T. Jones, D. Roos (1990). *The machine that changed the world*, Rawson Associates, New York.

ACKNOWLEDGMENT

The present work has been performed within the scope of the SSF ProViking project SIMUFORM and ShortCut. It has also been partly financed by the EU project TANGO-Verkstad and VINNOVA project TESSPA and Lean Wood Engineering.