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Citation for published version (APA):

Ron, de, A. J. (1993). The transformation factor: a measure for the productive behaviour of a manufacturing process. In *Proceedings International Conference on Industrial engineering and production management, Mons-België, 2-4 juni 1993*

Document status and date:

Published: 01/01/1993

Document Version:

Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

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THE TRANSFORMATION FACTOR: A MEASURE FOR THE PRODUCTIVE BEHAVIOUR OF A MANUFACTURING SYSTEM

A.J.de Ron

To be presented and published during

**Int.Conf.on Industrial Engineering and
Production Management**

2-4 juni 1993

Mons-Belgie

TUE/BDK/FT-9303



Vakgroep Fabricagetechnologie



The Transformation Factor: a measure for the productive behaviour of a manufacturing system.

Ad J. de Ron

Eindhoven University of Technology, Faculty of Industrial Engineering and Management Science, Manufacturing Technology Group, P.O. Box 513, 5600 MB Eindhoven, the Netherlands

Abstract

By using advanced manufacturing processes, production results should increase. Nevertheless managers have their doubts to invest in such processes because of the financial risks and the absence of adequate technical and economical measures which should support their decisions. Measures which contain the advances of sophisticated manufacturing process, like quality and flexibility increase, have not yet been developed.

Starting with the mass balance, a technical measure has been derived, called the transformation factor, which is a measure for the productive behaviour of a manufacturing process. By using data from the production floor as well as from simulations, the practical usefulness of the transformation factor as measure is shown.

1. INTRODUCTION

The decision to invest in advanced manufacturing processes is difficult because of the financial risks, this in spite of the large potential of these processes to gain considerable productivity improvements. Furthermore, indicators which could support investments in such processes are absent as the usual indicators do not contain the advantages of these manufacturing processes, namely the improved quality and flexibility.

A well founded measure does not only support investment decisions but can also be used to compare process design alternatives and for controlling a process.

In literature publications can be found in which an integrated value is given to a combination of the (total)

productivity, the quality and the flexibility of advanced manufacturing processes (FMS, CIM), Son (1987), Son and Park (1988) and Son (1990). However, based upon fundamental laws, such a concept is not right. Not only the quality and the flexibility are expressed in costs, which results in comparing different quantities, but also an economic measure has been obtained while behaviour, quality and flexibility are technical quantities. Therefore it is obvious to use a technical measure which may possibly be expressed in economic values through weighting factors. Besides, we think that the concept of total productivity is misused for the firm level which will be discussed in the next chapter.

2. SOME MEASURES

So many papers can be found in literature about productivity, so few papers are written about measures for process behaviour.

Barbiroli (1989), introduces "the real machine capability" which is a measure for the actual production capacity of a machine as a result of shut-down, reduced production or defaults.

The disadvantage of his description is that it is related to the operational time of the machine and not to the considered time period. Furthermore the produced quantity depends upon the machine velocity which makes a comparison with machines of the same type impossible.

Florentin and Omachou (1991) define three measures: the machine efficiency (ME), the machine use (MU) and the machine productivity (MP):

$$MP = ME.MU \quad (1)$$

The used definitions have a lot of disadvantages. For instance, the machine efficiency depends upon the machine velocity so that it cannot be a measure for comparison. Besides the choice of the word "efficiency" in this definition has to be avoided as the efficiency is defined for the relations at the input of the process (In 't Veld, 1988).

Furthermore the definition for the machine productivity is quite different from the current definitions for the productivity: the ratio between output and input.

The measures mentioned have all a technical base; an economic measure is the productivity. The productivity concept is used at different levels: international, national, industry and firm level. Often the productivity is used to indicate the

labour productivity, but the productivity concept contains more as the productivity is defined as the ratio between outputs and inputs.

Craig and Harris (1972) define three types of productivity:

- * partial: the ratio between the output in monetary value and one of the inputs (e.g. labor or capital)
- * total factor: the ratio between the output in monetary value and the sum of two inputs: the labour and capital costs
- * total: the ratio between the output in monetary value and the sum of the inputs (labour costs, capital costs, material costs and overhead costs)

In practice difficulties are encountered, using the productivity concept: there are problems in labelling the costs as well as in constructing the output when there is a product mix.

As the productivity does not result in the right economical measure of the process behaviour, mainly because the quality and the flexibility are not considered, Son (1987) has described a method which includes these effects.

Son considers the cost of quality and flexibility (mainly, opportunity costs) and defines:

- * total quality: the ratio between the output in monetary value and the sum of the process and product quality costs
- * total flexibility: the ratio between the output in momentary value and the sum of the machine, product, process and demand flexibility costs.

The total productivity (PT), quality (QT) and flexibility (FT) are transferred into one measure, the "Integral Manufacturing Performance" (IMP):

$$\frac{1}{IMP} = \frac{1}{PT} + \frac{1}{QT} + \frac{1}{FT} \quad (2)$$

Son does not give an explanation which justifies eq. (2). He only thinks that the productivity will decrease if quality and/or flexibility increase.

In practice the Son method does not result in the right conclusions, as is shown by the next case:

- output in monetary value = 139 MNLG
- the sum of capital, labour, material and overhead costs = 103 MNLG
- total flexibility costs = 44 MNLG
- total quality costs = 0,84 MNLG

Then:

$$PT = 1,35$$

$$QT = 164$$

$$FT = 3,15$$

$$IMP = 0,94$$

The change of the IMP as a result of a change of one of the measures results in the influence of this measure to the IMP. These are:

$$\frac{\partial IMP}{\partial PT} = 0,48 \quad \frac{\partial IMP}{\partial QT} = 0,00 \quad \frac{\partial IMP}{\partial FT} = 0,09 \quad (3)$$

Based on these values, increasing the quality (decreasing quality costs) does not make sense while increasing the flexibility does give hardly any result. Nevertheless, the flexibility costs are approx. 30% of the total costs, so a decrease of the flexibility costs will certainly result in better overall results!

The conclusion is, that the IMP should not be used as a measure to compare process behaviour or to support decisions.

From the described measures it is concluded that at least two measures have to be derived, both including the effects of quality and flexibility:

- * a measure of the *technical* behaviour of a manufacturing process to compare and to control these processes.
- * a measure of the *economical* behaviour of a manufacturing process to compare and to control these processes.

3. THE TRANSFORMATION FACTOR

To arrive at measures which are based upon basic science, first we will inspect what is understood by a technical manufacturing process. Bekker (1988) defines: "a collection of ... transformation processes which .. have the aim to produce industrial products".

Boer and Krabbendam (1989) give the following description: "transforms inputs to desired outputs", while Propst (1989) writes: "transforms inputs to more valuable outputs".

Important terms in these descriptions are: transformation process, desired outputs, more valuable outputs.

Based upon the given descriptions, we define a technical manufacturing process as a transformation process where at least one of the outputs is desired, and has an added value compared to the inputs.

This definition involves that there has to be a product flow (the desired output) and these products have to have an added value compared to the material and/or component flow at the input.

With this description of a manufacturing process, it follows (Propst, 1989) that:

- a process that transforms materials into more valuable products, only adds value to the materials and not to machines, people, capital, methods or surroundings,
- value is only added to machines, people, capital, methods or surroundings if these are inputs which are transformed.

For instance, people during a sales training are the input of a transformation process, as they become more valuable after this training (transformation).

This system description differs completely from the productivity concept where material (costs), capital (costs) labour (costs) and overhead (costs) are considered as inputs.

The given definitions and descriptions show that it is basically wrong to use machines, people, capital and overhead as inputs of a technical manufacturing process as these are not transferred and therefore do not attain any added value; they are the *necessary conditions* to be able to transform.

In fact, also the energy flow is an input as the energy is transformed to another more valuable energy form. As we are interested only in the transformation of materials, the energy flow is not considered.

Based upon the mass flow, De Ron (1992) has derived an equation for the ratio between the quantity products manufactured during a time period and the maximum quantity which can be manufactured during the same period; this ratio will be called the *transformation factor* (TF):

$$TF = U \cdot A \cdot E_{av} \quad (4)$$

where U is the utilisation factor of the process, A the availability factor of the process which is a measure for its flexibility and E_{av} the average effectiveness of the process which is a measure for its quality.

By using this transformation factor we are able to compare and qualify the productive behaviour of production systems. It is also possible to use the transformation factor as a measure to qualify a production unit as a component of a production process.

There is an interaction between the utilisation factor U and the availability A .

If $U = 1$, which means that there has been production during the complete period that the production process was available, it follows that $A < 1$ as a result of stoppages, tools exchange, etc. However if $U < 1$, the changing of tools can be done in the non-productive time so that the shut-down time will be less and A larger. If in this situation the shut-down time is only determined by the time needed for changing tools, $A = 1$, then the shut-down time can be kept outside the considered (time) period.

4. SOME APPLICATIONS OF THE TRANSFORMATION FACTOR.

A metal-ware firm has a large number of presses to punch components. The presses have a low utilisation factor. Changing tools can be done in the non-productive periods; there is no further shut-down time, which means $A = 1$. The results are given in Table 1. From this table it can be seen that the values of the TF are good if the presses are used for 100%; the low utilisation results in a very low TF.

Table 1
Value of TF for various presses.

Punch no.	T(min)	T_u (min.)	U	TF
10	110.700	66.620	0.602	0.57
11	109.350	35.742	0.327	0.31
12	109.350	37.278	0.341	0.33
13	109.350	49.818	0.456	0.43
20	111.150	78.312	0.705	0.67
21	109.350	57.510	0.526	0.50
22	109.350	79.692	0.729	0.69
30	109.350	40.962	0.375	0.35
31	109.350	38.772	0.355	0.34
40	109.350	42.402	0.388	0.37
50	109.350	31.698	0.290	0.27
51	109.350	9.714	0.089	0.08

For this firm the TF also has been determined for the complete production floor. Again $A = 1$ as changing tools can be done in the non-productive hours. Furthermore $E_{av} = 0.94$ while the average utilisation factor is 0.60, so that $TF = 0.56$.

It is obvious that this transformation factor is (too) low because of the low utilisation. Increasing the effectivity (a measure of the quality) or the availability (a measure of the flexibility) does not result in a better performance.

The transformation factor has been determined also for a distillery firm. It resulted in: $A = 0.70$, $U = 1$ and $E_{av} = 0.995$, so that $TF = 0.697$. These figures show that increasing production can be done by increasing the availability, that means increasing the flexibility to decrease the time consumed by changing liquids.

Increasing the effectiveness is not sensible because this quantity already has a very good value.

Finally we apply some simulations to study the transformation factor. In case tasks executed in a job shop situation are done by a flexible manufacturing process, the results are ($U = 1$):

	<u>job shop</u>	<u>FMS</u>
A	0.808	0.863
E_{av}	0.954	0.995
TF	0.771	0.859

From these figures it can be derived that in this situation not only the availability has increased by using the flexible manufacturing process, but also effectiveness. The increase of the TF is approx. 11%.

These examples of transformation factor application show that this factor is useful measure to quantify the productive behaviour and to compare machines and systems.

5. THE COST FUNCTION

The transformation factor influences the production costs. If we divide the production costs into fixed costs C_p and current costs C_v , these costs depend upon production volume and, as a result, upon the transformation factor. The fixed costs include the capital costs.

To be able to compare various manufacturing processes, we start from an equal quantity of products: the maximal production volume in the case that $TF = 1$; in this case the material flow is transformed completely into a product flow, without scrap, rejected products and/or shut-down losses (100% transformation). The corresponding current costs are called $C_{v,max}$.

If a manufacturing process with a $TF < 1$ should produce this maximum production volume, then the current costs are $C_{v,max}/TF$.

If we define a cost function C which shows the costs for a maximum production volume, then:

$$C = C_p + \frac{C_{v,max}}{TF} \quad (5)$$

So the cost function depends upon TF , not only because the current costs depend upon TF , but also because the fixed costs are related to the transformation factor. If TF is increased as a result of more investments, capital costs will increase and so will the fixed costs.

In figure 1 the dependence of the cost function upon the transformation factor is shown.

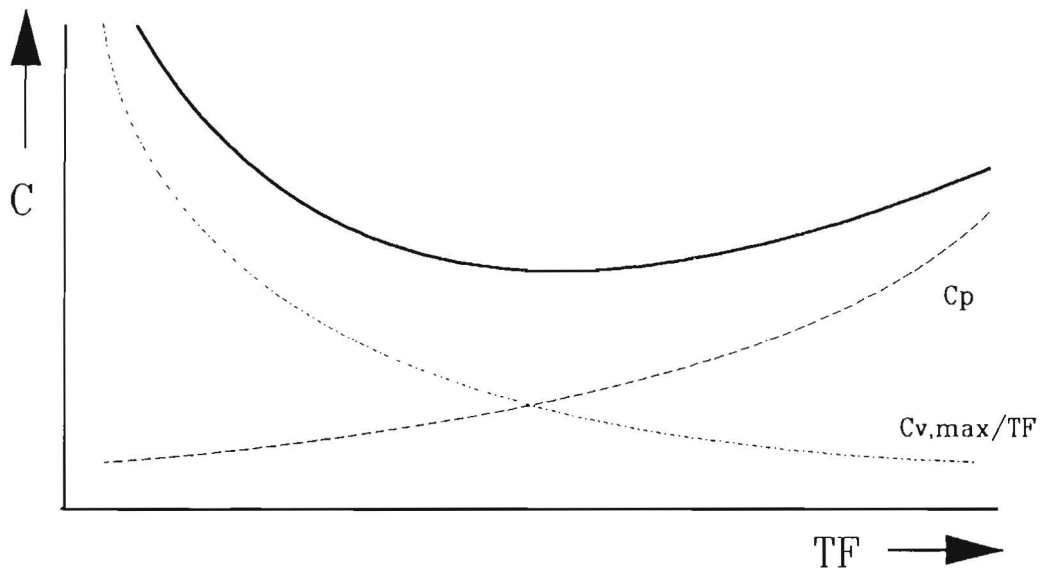


Figure 1: The dependence of the cost function upon TF .

The cost function shows an optimal value at a certain value of TF , which means that this value of TF should be the optimal value to design the process to.

This minimum value of the cost function is reached when:

$$\frac{df}{dTF} = \frac{C_{v,max}}{(TF_m)^2} \quad (6)$$

between where f shows the function which represents the relationship C_p and TF , while TF_m is that value of the transformation factor where the cost function value is minimal. If, for instance, the fixed costs depend linearly upon TF , then: $C_p = C_{p,o} + \gamma \cdot TF$, and the minimum value of the cost function will be:

$$C_m = C_{p,o} + 2\sqrt{(\gamma \cdot C_{v,max})} \quad (7)$$

where $C_{p,o}$ is that part of the fixed costs that is independent of TF .

This minimum value occurs if:

$$TF_m = \sqrt{(C_{v,max}/\gamma)} \quad (8)$$

These exercises show that the cost function will increase if the availability (flexibility) and/or effectiveness (quality) are too large, which is the case if the minimum value of the cost function has been passed. This all as a result of too large sacrifices to reach higher values of the availability and effectivity.

The influence of the TF upon the cost function results in knowledge concerning the cost development by designing or redesigning manufacturing processes. The cost function can be useful in comparing and/or controlling the economical behaviour. An important advantage of the cost function compared to the productivity concept is that the output does not have to be measured.

6. CONCLUSIONS

Well-known measures do not result in adequate description of the advantages of advanced manufacturing processes, like quality and flexibility.

The derived transformation factor contains these quantities and seems to be useful as technical measure for the behaviour of processes as has been shown by examples from practice and simulations.

The influence of the transformation factor has upon the cost function results in having an optimal value of the transformation factor for a minimum value of the cost

function. It is shown that a too sophisticated automation will result in higher costs compared to the optimal value of the transformation factor.

A further application of the transformation factor in practical circumstances should show the usefulness of the transformation factor as a measure to support decisions and to compare processes.

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