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Productivity measurement and improvements: A theoretical model and applications from the manufacturing industry

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Abstract. At many companies, workers associate productivity or efficiency increase with something negative, it is interpreted as an increase in speed and the “sweat factor”. Productivity is not only made up of the speed factor, but these misconceptions and lack of knowledge tend to put “a wet blanket” on all attempts to increase productivity. It is therefore important to clarify what productivity is and especially how it can be improved.

In general, the productivity at shop-floor level can be improved through improving the method, increasing the performance, and increasing the utilization. The design of the products and the amount of scraped products also affects the productivity in both manual tasks as well as work performed by machines. These aspects of productivity will be elaborated in the theoretical model and the industrial applications presented in this article.

Keywords: Productivity, Performance measurement, OEE, KPI.

1 Introduction

Productivity is an important factor to create wealth and well-being at national level as well as creating competitiveness at corporate level. But productivity itself is only a mean to create high standard of living for nations or high profitability for companies [1, 2]. Productivity can in general be defined as output over input. The choice of outputs and inputs are dependent upon the intended application. For example is the standard definition¹ for productivity at national level gross domestic product (GDP) over total amount of work hours for the total population. On a factory level the productivity may be defined as added value per employee and on cell or station level a typical productivity measure is the number of products produced per hour planned production time. Vora [3] has made a study of the industrial use of different productivity definitions at three separate levels in manufacturing companies. The conclusion was that at first and middle manager level the most common productivity measure

¹ See e.g. Eurostat (<http://ec.europa.eu/eurostat>).

used was physical output per labor. Labor can be interpreted as number of people or planned working time.

This article concerns productivity improvement at factory floor level, i.e. at station, cell, or line level. There are many ways to achieve these improvements and people associate different feelings and have corresponding attitudes towards productivity improvements. At many companies, workers associate productivity or efficiency increase with something negative. It is interpreted as an increase in speed and the “sweat factor”. However, the sweat factor is only one way of increasing the productivity, and probably the least desirable one in most situations. Managers at different levels have often a low level of knowledge about productivity measurement and therefore also about its improvement. These misconceptions and lack of knowledge tend to put “a wet blanket” on all attempts to increase productivity in good times and productivity improvements are only discussed in bad times when the company is bleeding and at that time it’s often too late. For these reasons it’s important to clarify what productivity is and how it can be improved. In general, the productivity at shop-floor level can be improved through improving the method, increasing the performance (“the sweat factor”), increasing the utilization, improving the product design, and reducing the scrap. These aspects of productivity will be elaborated in the theoretical model presented in this article.

In order to measure the real productivity potential in Swedish manufacturing companies an assessment method was developed: Productivity Potential Assessment (PPA) [4]. Since 2005, close to one hundred PPA studies have been carried out in the manufacturing industry. The productivity improvement potentials have thus been assessed and measured for a wide variety of companies: large and small companies from different industries. The majority of the studies have been performed at suppliers to the automotive industry. The focus of PPA is on the utilization aspect of productivity, however it is not given that utilization has the greatest impact on the productivity. In most cases it is the method factor, i.e. the selected machines or the manual work method that represent the greatest potential. The potential for improvement in manual work methods is especially interesting, since substantial improvements often can be achieved without or with very limited investments. The manual work methods are often an effect of the production system design (or lack of intended design) or the management of the system. For example, it is common that the manual work is the bottleneck for machine operations; the machines must be loaded and un-loaded by operators, the operators perform the set-up work, and so on. Thus, the machine utilization is heavily affected by the manual work. However, very few companies in the Swedish manufacturing industry acknowledge this fact and actually design and measure manual work tasks in a systematic way. According to the PPA studies merely around 25% of the manufacturing companies are able to carry out work studies and set standard times in reasonably accurate way by using either time studies or a predetermined time system. The vast majority are either using operation times for similar products, set the times based on pre-production runs, or are simply guessing based on experience. The reason for this misconduct is a mix of the work organizations’ and the salary systems’ historical development and the managers’ lack of insight and competence [5].

2 Theoretical productivity increase model

There are many ways to increase productivity. Taylor [6] was the most famous pioneer in the beginning of last century. He emphasized the productivity potentials in improving the methods used by introducing better tools and, more importantly, how the speed of people working could be enhanced greatly by proper motivation. Later were the socio-technical factors for motivation and productivity increase discovered in the famous Hawthorne studies [7]. In the last decades has the productivity been raised through increased automation and by outsourcing labor intensive work to locations with low salary level. The competence to carry out time- and motion studies vanished in the Swedish industry when new salary models and work organizations were introduced in the 1970-80ies. These days when Lean Production is the norm, the lost competence is needed again. Every company that tries to implement a Lean Production system will need standard work procedures and stable operation times at the lowest shop-floor level, as a base for continuous improvement and steady flows. The methods that were invented by Taylor and his followers (e.g. The Gilbreths, Gantt, Segur, and Maynard [8]) are still valid today even though the purpose of using them (to set the salary in piece rate systems) is not the same today.

Regardless of method, improvement program, or production philosophy applied to increase productivity, it is important to know what factors that actually affect the productivity. In the following text will a model be presented that has the potential to pedagogically explain what productivity is and at the same time provide a concrete way to calculate a potential productivity increase.

2.1 Productivity model

Productivity can be improved through better methods (M), increased performance (P), and increased utilization (U). This can be expressed in the following equation:

$$Productivity = M \times P \times U \quad (1)$$

Consultants ([9], [10], and [11]) have used this formula or parts of the formula at least since the 1960ies². However, it has not been described or analyzed in an academic context. The model has been developed and previously used for manual work only, but it is actually applicable for all kind of work, even if it's carried out by a machine.

The method factor (M) is defined as the ideal or intended productivity rate. It is the inverse of the ideal cycle time for the specific work task. In order to determine the ideal cycle time for manual work tasks it is necessary to use a predetermined time system. There are a number of available systems and most of them are based on MTM [8]. The MTM systems were in wide use in the Swedish manufacturing industry after WWII until mid-1980ies. At that time, the use was for setting times in piece-rate sala-

² According to Bengt Isaksson who was employed at Maynard's in Sweden in the 1960ies and Shigeyasu Sakamoto who has been employed at JMAC in Japan for a long time.

ry systems. These salary systems have almost vanished now, and with them the competence of using the predetermined time systems. This has resulted in a situation where companies are unable to calculate an ideal cycle time before the work station is up and running. The time for the work task can then be timed with stop watch, but the resulting time will not be the ideal cycle time; it will be affected by the P and the U factor in equation 1.

The performance factor (P) corresponds to the speed the work is carried out at in relation to the ideal cycle time. For manual work the performance factor can be both below and above 100%. The normal speed in MTM is set to be valid for a “normal” person working at this speed for 8 h a day and for the whole working life without getting exhausted or injured. The performance rate is lower for not fully trained workers and for people with disabilities. For machine work can performance by definition never go beyond the ideal cycle time, i.e. 100%.

The utilization factor (U) represents the time that is spent on performing the intended work in relation the total planned time. Utilization can never go beyond 100%. The planned production time is usually defined as the paid working time minus planned stops, like weekly meetings or planned maintenance stops.

2.2 Expanded model

Apart from the three base factors in Equation 1, other factors that affect the productivity are perceivable. The quality rate (Q) or yield affects the productivity if the productivity is defined as the number of quality approved products produced per time unit. All production engineers (and obviously not all product designers) are aware that the product design has a very important impact on the productivity. This can be expressed with a design efficiency rate (D). These two extra factors together with Equation 1 give the expanded model in Equation 2.

$$Productivity = M \times P \times U \times Q \times D \quad (2)$$

The quality factor (Q) is the yield or 100% minus the scrap rate. Yield is common in the electronics industry while scrap rate is normally used in the mechanical products industry. The quality loss is usually very small in comparison to the other productivity losses. However, the scrap rate has other implications as well; such that the errors need to be detected by a quality control system and that the scrap also is a waste of material and energy.

The final factor in equation 1 is the design (D) factor. The factor for improving the design to decrease the cost of manufacturing and assembly is treated in the DFMA (design for manufacturing and assembly) literature. Specifically for assembly, Boothroyd et al [12] have suggested a design efficiency factor. That factor is 100% if the design is ideal from an assembly point of view. The design factor is clearly outside the limitation to the factory floor, and in practice it is very hard for a manufacturing company to affect in many cases. In fact, contract manufacturers have normally little to gain and possibly a lot to lose by suggesting design changes to the customer com-

pany. The contract manufacturer will lose their value adding work since the customer most likely will decrease the price paid because of the design change.

3 Applications

The focus of the applications has been to find and demonstrate how simple, low cost changes, in the production will affect the productivity factors and because of the multiplying effect will provide substantial increase in productivity. The special application to machine work will also be discussed.

3.1 A fictive case based on today's average and best practice

The first application example is fictive in order to demonstrate the three factors in equation 1 and their multiplicative effect. The example is based on an assumed situation with facts based on the average figures in today's industrial practice compared to best practice. The figures are based on previous studies using the PPA method and subsequent improvement studies carried out in Swedish industry [13].

Consider an assembly work station. A specific work task takes 3 minutes or 180 s to carry out according to a well-defined standard work description. However, the worker does not work at standard speed (100%) but rather a bit lower; at 90%. The utilization is 65%, 15% of the time is spent on supporting activities like moving the material to and from the work area, planning and reporting, and cleaning. The remaining 20% of the paid working time is personal time and breaks.

The method can be improved 30% with small means, mainly by putting material closer and minimizing the number of steps. The cycle time decreases to $180\text{ s} - 30\% = 120\text{ s}$. The performance shall always be on 100% if not special conditions apply, e.g. work performed by a not fully trained employee. The utilization can increase to 81% assuming that the personal time and breaks can be lowered to 9% which is a normal agreed level and the supporting tasks can be reduced to 10% using a better method for those tasks as well. The resulting productivity increase can be calculated step by step assuming one hour production of the particular product (table 1).

The total productivity improvement by going from the average level to the best practice level identified in the PPA studies is over 100%. This example, based on realistic improvement levels, clearly demonstrates the importance of the multiplicative effect of the small improvements in each factor.

Table 1. Calculation of productivity increase step by step for 1 h = 3600 s production (p/h = products per hour).

Factor	Productivity before	Productivity after
Method improvement	$3600/180 = 20\text{ p/h}$	$3600/120 = 30\text{ p/h}$
Performance improvement	$20 \times 0,9 = 18\text{ p/h}$	$30 \times 1 = 30\text{ p/h}$

Utilization improvement	$18 \times 0,65 = 11,7$ p/h	$30 \times 0,81 = 24,3$ p/h
Actual productivity	11,7 p/h	24,3 p/h
Total improvement = $(24,3 - 11,7)/11,7 = 108\%$		

3.2 Improvement of manual assembly

This application is from a manufacturer of heat, ventilation, and air condition (HVAC) units for vehicles like buses and trucks. The production is highly customized and the products are manufactured and assembled in relatively small batches, typically around 10 units in each batch. The study was a part of a government supported program to suppliers to the automotive industry and it was carried out by professional consultants.

The study commenced with a PPA study of the factory's general productivity potentials. The final assembly area was selected for the work sampling study and that revealed that the utilization rate (U) for carrying out the actual assembly work was 60%. The remaining time was split equally on supporting (necessary) activities, e.g. fetching material from the warehouse and reporting, and personal time. To formally measure the method improvement potential is not a part of the PPA study. However, while the work sampling is conducted it usually becomes obvious to the experienced analyst if the method potential is large. After the initial PPA study a total of 10 consultancy days were spent on analyzing the method in detail and involving the operators in the work to improve the assembly area's productivity.

The analysis was delimited to the assembly of the factory's volume products; two varieties of ventilation units. The performance factor (P) was measured to be close to 100%. The productivity was 0,27 units/h and 0,44 units/h for the two products before the improvements. The present assembly was conducted at stations and in batches, where the worker assembled several units in parallel. A lot of time was wasted on walking to and from the material storage areas. The improvement was to transform the station assembly into a simple flow, where the work was divided into three parts and corresponding workstations were designed. The workers were involved in the design and they constructed some simple material racks out of scrap material from the production. The new work method was documented in work instructions and the assemblers started to work according to the new standard. Virtually no investment apart from workers' time was needed.

The productivity for the two products was improved to 0,37 units/h and 0,68 units/h respectively. This corresponds to a productivity increase of 37% and 54%. The improvement was verified in running production. The performance rate was most likely 100% afterwards as well. The utilization was not measured afterwards, but it is likely that it improved slightly due to less external material handling. The personal time and break time was probably not changed at all since that was a matter of culture and old habits. In other words; almost all of the productivity increase was thanks to the method improvement. That confirms what has been concluded from similar studies [13]: It is much easier to improve the M factor than trying to improve the U factor,

even though the potential is considerable in that factor. The U factor is affected by the company culture and the management of the production. That takes a lot of time to change compared to involving the operators in method improvements.

3.3 Improving machine work productivity

The theoretical model can be applied to machine work as well, but the definitions are a bit different to that of manual work activities. The M factor is defined as the inverse of the ideal cycle time. Ideal cycle time is the fastest time either recorded or simulated for a particular job in the machine. In practice it is hard to determine the ideal cycle time for a running production, especially if manual tasks are a part of the work cycle. The prepared times (e.g. from a CAM simulation) can be used in many cases, but it is not certain that used machine programs are optimal and “ideal”.

The ideal cycle time is important for calculating OEE (Overall Equipment Effectiveness) [14]. The OEE ratio is commonly used in the Swedish manufacturing industry and it is included as one parameter in PPA. The basic definition of OEE is the ratio between the time that was spent on producing a certain amount of quality approved products and the planned production time. OEE can be calculated by multiplying the availability (A) which is the planned production time minus larger stoppages and break-downs, the operation efficiency (O) (including both small stops and speed reductions), and the yield (Q):

$$OEE = A \times O \times Q \quad (3)$$

The OEE figure is not a productivity measure, there is no M factor. The A factor plus the small stops of the O are the same thing as U losses and the speed reduction part of O is the same as P losses. That gives the following relations:

$$M \times OEE = M \times P \times U \times Q \quad (4)$$

$$OEE = P \times U \times Q \quad (5)$$

Equation 4 and 5 explains the applicability of Equation 1 (and 2) to machine work.

4 Conclusions

The presented productivity model has great practical importance for industry. There is a need in industry too understand what productivity is and how it is defined and measured. The equation is simple, yet it pedagogically describes the important factors that can be improved in order to increase the productivity. The model is well founded on the experiences from the PPA studies and it has been validated through applications by academics and consultants.

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