

Martina KORTIŠOVÁ\*, Milan GREGOR\*\*

## **MODEL PROPOSAL FOR TOTAL PRODUCTIVITY MEASUREMENT AND EVALUATION IN A SMALL AND MEDIUM MANUFACTURING ORGANISATION**

### **1. INTRODUCTION**

The question of total productivity measurement in SMEs is still not realised in a complex form. The methods of productivity measurement and performance evaluation used lie in partial productivity ratios or main economic indicators only. Because of that, this paper deals with the proposal of a methodology and a model for productivity measurement and performance evaluation in a manufacturing organisation of small and medium size. The main focus of the paper is on the core of a transformation process and analyses the individual production steps in detail. Except the flow of material throughout the system, the work is capable of cost analysis, which evaluates a manufacturing company's performance within a present period of time or the comparison of individual activities over time. The essential part of this productivity measurement and evaluation tool is a benchmarking module that creates the conditions for the comparison of internal and external productivity and performance ratios with company's benchmarks.

### **2. MEASUREMENT APPROACHES**

The theoretical background of this work goes out from the basic ratios of productivity computations and the so called *Onion model of productivity measurement and evaluation*, developed by the Slovak Productivity Centre (see the following Fig. 1).

Performance metrics, mainly focused on outputs, are used in order to specify as to what a company is doing. Next, diagnostic metrics are implemented to specify as to why a process is not performing up to expectations. These measures are internally focused and are associated with internal process steps and inputs into a system. The universal and generally used tool for a manufacturing company's productivity and performance measurement was developed upon these methods which solves the eternal productivity dilemma. The specific features of the designed model will help a company to take the action plans, to see the future trend based on the past performance and simultaneously to realise the calculations of future customer orders, thus helping management with the decision-making process.

---

\* Ing., PhD. Queen's University, Kingston, Canada

\*\* Prof. Ing., PhD. University of Žilina, Industrial Engineering Department, Slovak Republic

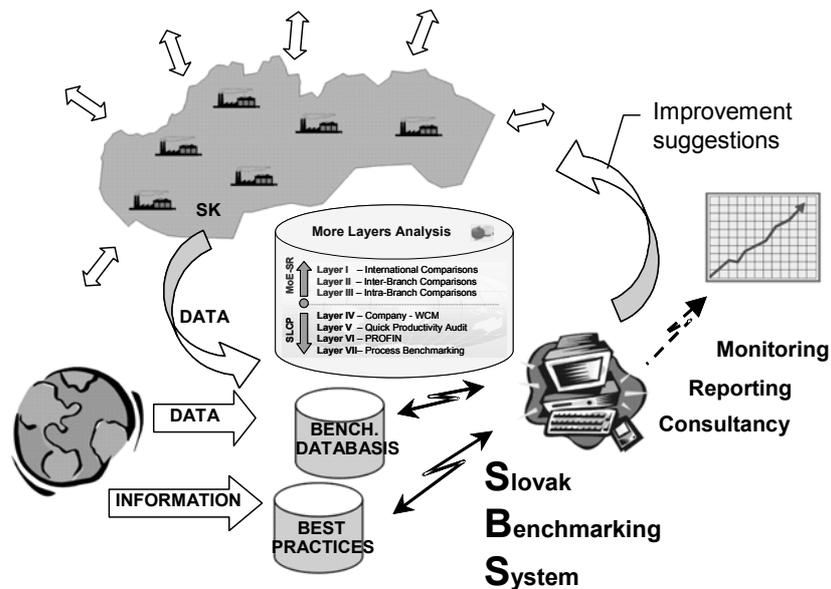


Fig. 1. Onion Model of Productivity Measurement and Evaluation [6]

The model that has caught our attention, is the Total Productivity Model (TPM) of Summanth [17] as well as models published by Lawlor [14], Hannula [7], and Sink [16]. Summanth's model is based on the findings that the partial productivity measures have some limitations when considering performance of a company as a complex. These partial measures shouldn't be used alone when considering a company's productivity performance. Simply said, partial productivity measures are erroneous practices and provide us with non-relevant results of a company's operations as a system.

The proposed tool for performance and benchmarking measures and cost analysis on a micro-assessment level of small or medium size companies' operations are based on the algorithms and formulas presented below and are at the epicentre of this work. This proposal develops the bottom layer of the Onion model – the layer VIII: Process benchmarking, which deals with the comparisons of the chosen areas within a company.

The proposed performance tool consists of two measurement blocks: a productivity/performance module and a benchmarking module [13], [18].

## 2.1 Performance Background

When measuring a company's performance, it is necessary to look at the company as a complex system. From Figure 2 it is visible that the marketplace shapes the company's corporate strategy and reflects the use of resources by the company to achieve a goal.

The operations strategy specifies the employment of the company's production capabilities to support corporate strategy. The decisions made within the operation function are [1]:

- *long-term (strategic) decisions* – for example, the amount of capacity needed, when more capacity should be added, etc.;
- *intermediate-term (tactical) decisions* – for example, the efficient scheduling of material and labour within the constraints of strategic decisions, and
- *short-term (operational) decisions* – for example, what is the production plan for this week, assignment of people to specific tasks, and so on.

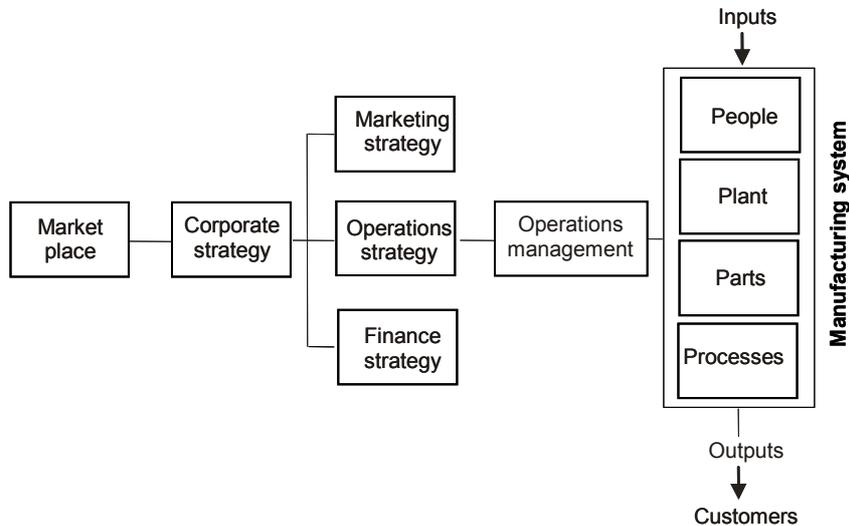


Fig. 2. Company as a Complex System

The proposed tool supports the strategic decision making process required when a company wants to produce particular products and needs to specify the capacity for production. Once the final production volume is determined, the scheduling of material is also supported by the model.

The primary opportunity for improving performance lies in reducing defects generating internally [2]. As a result of this it is necessary to measure performance on a micro level as well. In manufacturing these include individual operations, machines or operators. It is in this way that the performance module of the proposed tool calculates each process-step performance, based on cost performance modelling.

From a results perspective of any company the most important performance measures occupy the top level. They indicate the size of a general problem or reflect positive or negative progress, however the existing models don't provide the information as to the cause of a problem.

This work deals with the heart of a manufacturing company – the transformation process (Fig. 3). The performance module of the proposed tool represents the manufacturing company with every step contained therein. Basic information about inputs and processes are needed in order to get desired results. The use of the performance module can reveal how a company operates, where the bottleneck is, and where the biggest expenses are. It overviews the process by modelling the production process with the associated cost. Based on this information the operations can be easily adjusted to be more efficient and competitive.

Conventional productivity measures use costs. To adequately measure a company's performance, two sets of measurement must be used – one is from a financial point of view and the other from the operations point of view [4]. In the developed proposal both are included. Financial measures are associated with the cost analysis of particular process steps. Some of the financial indicators are taken from the PROFIN [9] analytical and evaluation tool, which represents one layer of the Onion model developed by the Slovak Productivity Centre [6]. An introduction to the proposed performance module capabilities is depicted in the algorithm of Fig. 3. It explains, step-by-step, the calculations this module performs and the results of these calculations.

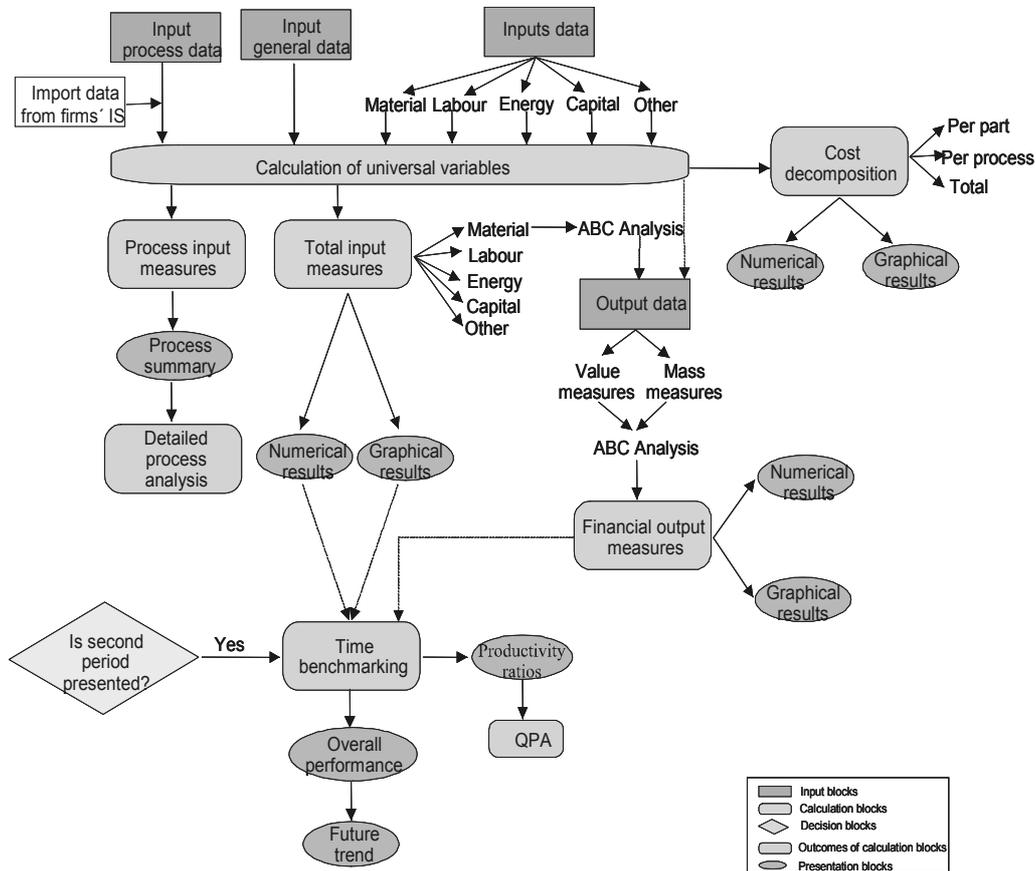


Fig. 3. Performance Module Algorithm of the Proposed Tool [12]

The connections and logic of the algorithm are the basic principles of module process behaviour and one should follow this algorithm to secure that the module is working properly and is understood. This algorithm creates a springboard for the further evolving of other algorithms for obtaining different performance and productivity measures and results.

There are different levels in this module, which serve a company to identify its performance in a specified time period. Usually it is a present period, but different time periods in the past can be chosen as well. Following the automatic built-in calculations, a company can retrieve the

data of how well or poorly the company performs in terms of one specified period. This feature is very helpful in discovering the bottlenecks and problematic issues within the processes of a company's operations. When both specified periods are filled in, the company can obtain the above-mentioned information also for the second period.

Next comes a more detailed step of the module, which uses internal time-benchmarking templates for comparing two periods of a company's performance. This feature, though it doesn't need to be used (if a company needs to know only the present state or the state in one time period), is very helpful in comparing two different company's operation periods and thus to visualize the differences that emerge from production over time. The results of the module will inform the management as to which of the inputs are being utilised efficiently or inefficiently with regard to time periods. Ultimately, it is a tool that allows management to immediately see what kind of corrective action should be taken in a given problematic situation.

One side of the levelling in the module considers time (as mentioned above); another side considers levels of performance measurement in the module. First, there is a primary audit (Fig. 4) that reveals the basic and most general factors in the performance of a company [3].

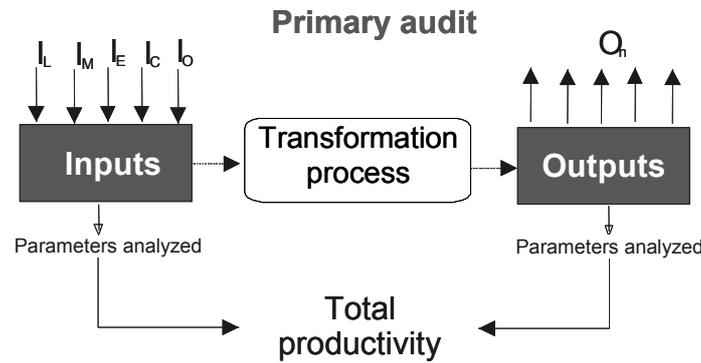


Fig. 4. Algorithm of Primary Productivity Audit

Secondly, a detailed process-oriented audit of performance (Fig. 5) takes place and this is where the operation of individual steps is analyzed and summarised [3].

### 3. MATHEMATICAL ITERATIONS

In the building of the model, different formulas were used, necessary for making the model capable of sophisticated calculation iterations to be more comprehensive. Since the goal was to set up and to build a performance measurement tool, the general formula of total productivity is used (1) and modified for the purposes of model development:

$$TP = \frac{\sum_{j=1}^m O_j}{\sum_{i=1}^n I_i} \quad (1)$$

where:

- $TP$  – total productivity,
- $O$  – total output (incl. finished products and partially finished goods sold),
- $I$  – total input,
- $i$  – type of input,
- $j$  – type of output,
- $n$  – total number of input groups,
- $m$  – total number of output products.

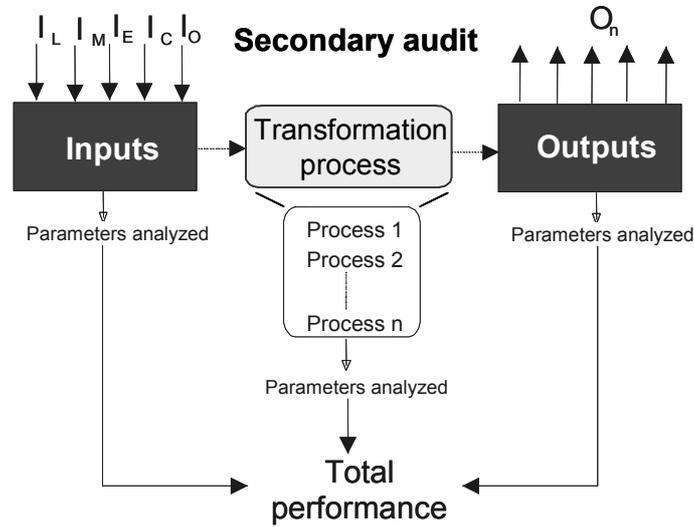


Fig. 5. Algorithm of Secondary Performance Audit

When measuring total productivity, all the inputs must be considered. Grouping them into labour, material, energy, capital and other inputs differentiates among individual input groups that are necessary for establishing the total picture of a company. Thus, in the following, the mathematical explanations of the inputs used in the model are presented.

Input of labour  $L$  includes all employees. Two major types of labour input are specified in the model: *blue-collar workers* (people that are directly part of the transformation process: workers on the shop-floor) and *white-collar workers* (people that don't have a direct effect on the production: people working in administration, management and R&D). The remainder of the labour force that cannot be included in neither of the two categories creates a separate group of labour called *other personnel*.

The basic formula for labour computation (2) used in the model is as follows:

$$I_L = \sum_{i=1}^n I_{L_i} = I_{L_{BC}} + I_{L_{WC}} + I_{L_{OP}} \quad (2)$$

where:

- $I_L$  – total input of labour into the system,
- $i$  – labour input sub-group,

- $n$  – total number of input sub-groups,
- $BC$  – blue-collar workers,
- $WC$  – white-collar workers,
- $OP$  – other personnel.

Calculations of particular labour inputs into the system are basic value formulas and they are further detailed in the equations (3), (4), and (5).

$$I_{L_{BC}} = \sum_{i=1}^n BC_i = BC_1 + BC_2 + \dots + BC_{n-1} + BC_n \quad (3)$$

$$I_{L_{WC}} = \sum_{i=1}^n WC_i = WC_1 + WC_2 + \dots + WC_{n-1} + WC_n \quad (4)$$

$$I_{L_{OP}} = \sum_{i=1}^n OP_i = OP_1 + OP_2 + \dots + OP_{n-1} + OP_n \quad (5)$$

To the total labour input for the company, all the blue- and white-collar workers and other personnel have to be summed together. Since there are many different sub-groups of labour, the labour hours are weighted by an average labour cost per hour (6).

$$\begin{aligned} L_C &= \sum_{i=1}^n \sum_{j=1}^p V_{L_{ij}} = \sum_{i=1}^n \sum_{j=1}^p q_{L_{ij}} c_{L_{ij}} = \\ &= \sum_{j=1}^p (h_{L_{BC}} c_{L_{BC}}) + \sum_{j=1}^p (h_{L_{WC}} c_{L_{WC}}) + \sum_{j=1}^p (h_{L_{OP}} c_{L_{OP}}) \\ L_{C_{avg}} &= \frac{L_C}{H_T} \end{aligned} \quad (6)$$

where:

- $L_C$  – labour cost in the system,
- $L_{C_{avg}}$  – average cost per work hour.
- $H_T$  – total work hours (for blue-collar workers),
- $h$  – hours worked by particular white-collar labour group,
- $c$  – cost per hour of labour input.
- $q$  – number of workers.
- $V$  – value of input,
- $j$  – individual process,
- $p$  – number of processes.

$$H_T = d_t \cdot s \cdot sh \quad (7)$$

where:

- $t$  – time period,
- $d$  – number of working days,
- $s$  – number of shift per day,
- $sh$  – number of hours per shift.

$$d_t = (d_w \cdot t) - m_t - v_t \quad (8)$$

where:

- $d_w$  – number of working days per week,
- $m_t$  – maintenance shutdowns,
- $v_t$  – vacations, holidays.

For labour productivity  $P_L$ , the formula is (Equation 9):

$$P_L = \frac{\sum_{j=1}^m O_j}{\sum_{i=1}^n I_{L_i}} \quad (9)$$

Material productivity is usually computed as a simplified method of input of one unit. Even if it is a multi-product company, all the inputs are summarized into one unit of input using value conversions of individual raw material and purchased products entering the system.

The proposed approach to material input ( $M$ ) deals with both continuous and batched processes, creating the base for material input calculations according to mass or value preferences. There is the priority created in including all materials entering the system into the calculations and thus filling in the gap in material input measurements. Obviously, there are cases where it is impossible to use mass parameters (e.g., the process requires hundreds of inputs of different units), and in such cases the module has to use the value approach that works in all cases.

The basic formula for material input calculation is presented below (10), followed by the detailed material computation (11).

$$I_M = \sum_{i=1}^n I_{M_i} \quad (10)$$

where:

- $I_M$  – material input,
- $n$  – total types of material input,
- $i$  – material subgroup.

$$\sum_{i=1}^n I_{M_i} = I_{M_1} + I_{M_2} + \dots + I_{M_{n-1}} + I_{M_n} \quad (11)$$

Thus, the total value of material entering the system, when considering individual processes, will be (12):

$$\begin{aligned} M_C &= \sum_{i=1}^n V_{M_i} = \sum_{i=1}^n q_{M_{ij}} c_{M_{ij}} = \\ &= (q_{M_1} c_{M_1}) + (q_{M_2} c_{M_2}) + (q_{M_3} c_{M_3}) + \dots + (q_{M_{n-1}} c_{M_{n-1}}) + (q_{M_n} c_{M_n}) \end{aligned} \quad (12)$$

where:

- $M_C$  – total cost of material,
- $q$  – quantity of material,
- $c$  – cost of individual material.

The basic formula for material productivity  $P_M$  that is used in the model is as follows (13):

$$P_M = \frac{\sum_{j=1}^m O_j}{\sum_{i=1}^n I_{M_i}} \quad (13)$$

As mentioned above, there doesn't exist a measure of a multi-material approach. In scientists' studies, material input always figures as a unit of one. No matter how many material input items a company deals with, all of these items represent a value unit for a single input of material.

The difference in the proposed approach is based in a multi-material database (Fig. 6). In this database, the material is sorted according to measurement units and based on two ways of entering the system: either as a value material input (if the measurement units are not the same) or as mass material input (if the entering material consists of the same mass).

INPUT OF MATERIAL						
PERIOD 1: January 2004				PERIOD 2: February 2004		
Material	Units	Amount	Cost/Unit	Total Value	Amount	Cost/Unit
1 Material 1	gram	63.50	17.87 Sk	1,135 Sk	63.50	17.87 Sk
2 Material 2	gram	55.00	12.00 Sk	660 Sk	51	12.00 Sk
3 Material 3	gram	56.00	13.00 Sk	728 Sk	23	14.00 Sk
4 Material 4	gram	46.00	24.00 Sk	1,104 Sk	31	24.00 Sk
5 Material 5	gram	345.00	13.00 Sk	4,485 Sk	122	15.00 Sk

Fig. 6. Multi-Material Database

In the case that final conclusions regarding material productivity are too low, the *chart of importance* (Fig. 7) shows the differences in important parts and those that cost a company a great amount of capital while not being productive. As an addition to this chart, the automatic ABC analysis can be used so one can easily determine the sequence, importance, values and percentages of materials entering the production system. Besides the above-mentioned capabilities, the chart of importance in the performance module is used to present the relationships among the numeric values of two comparable periods and to plot these groups of numbers as one series of xy coordinates. Depicted in this chart are visible differences in the values of material between two time intervals (period 1 in blue and period 2 in green). The box that should be paid the most attention is the one labelled as *very important*, since it presents (e.g., in our case of material input) the most expensive and the most supplied items; it represents the A group of the ABC analysis. The box labelled *not so important* represents a small amount of cheap material in comparison with the total variety of material. This is the C

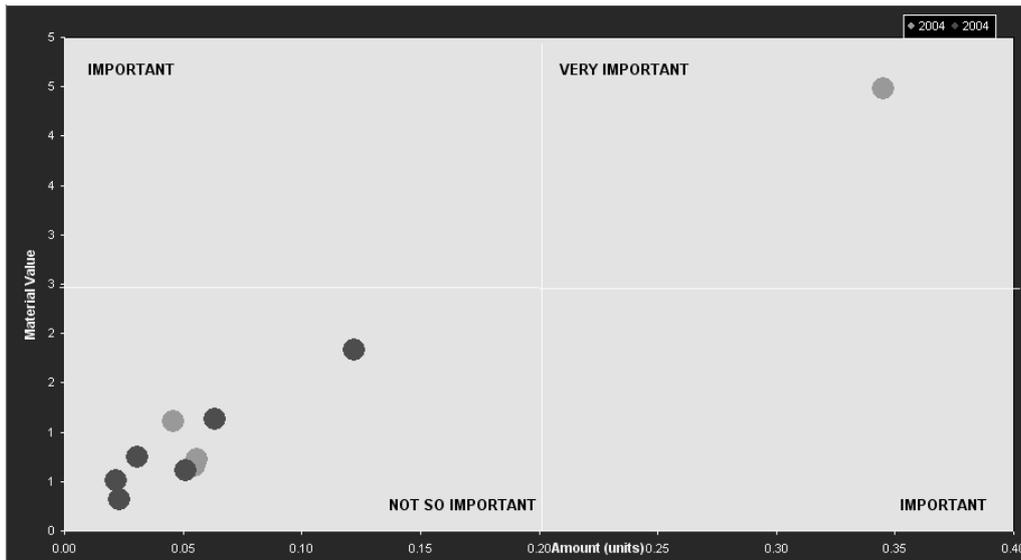


Fig. 7. Chart of Importance for Input of Material

group of the analysis that does not pose a large threat to an organisation, but should be looked into as well, since it might hold some of the capital that can be used elsewhere if these items are not necessary for production. The rest of the boxes (group B of the ABC analysis) are somewhat important, since one of them represents a small amount of expensive material and the second one a large amount of cheap material.

The data obtained from the multi-material database (Fig. 6) is processed with the use of a 3-column approach [12]. This approach uses base and actual prices and relies on the quantity of the information. However, for the purpose of modelling this approach has had to be adapted from a single accounting method into a productivity of internal benchmarking approach. Thus, the adapted 3-column approach is visible in Fig. 8 and it can be used with different parameters of the system (material, labour, etc.).

The total variance of the variables using a 3-column approach is mathematically depicted in the following. Let's assume we have two periods: 1 and 2. There are different prices and quantities used within these periods. Period 1 is assigned with price  $p_1$  and quantity  $q_1$ ; period 2 is represented by price  $p_2$  and quantity  $q_2$ . The following iterations (14) through (19) take place in the above-mentioned approach of three columns:

$$p_1 q_1 \quad (14)$$

$$p_2 q_1 \quad (15)$$

$$p_2 q_2 \quad (16)$$

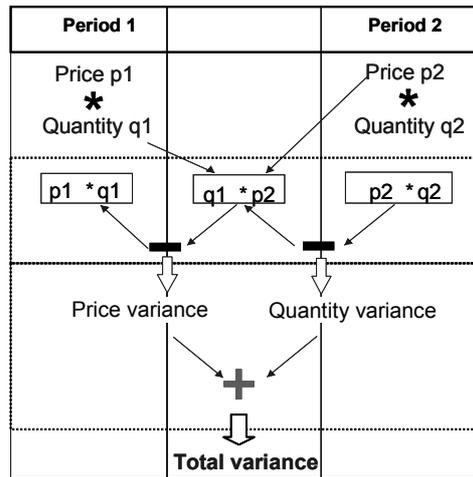


Fig. 8. A 3-Column Productivity of Internal Benchmarking Approach

Price variance from these equations is:

$$q_1 p_2 - p_1 q_1 \Rightarrow q_1 (p_2 - p_1) \quad (17)$$

and quantity variance is:

$$p_2 q_2 - q_1 p_2 \Rightarrow p_2 (q_2 - q_1) \quad (18)$$

$$\begin{aligned} \text{Total variance} &= q_1 (p_2 - p_1) + p_2 (q_2 - q_1) = \\ &= q_1 p_2 - q_1 p_1 + p_2 q_2 - p_2 q_1 = \\ &= p_2 q_2 - q_1 p_1 \end{aligned} \quad (19)$$

Adding together price variance and quantity variance, the total variance of a particular item in the system (19) can be determined and visualized. The result can be positive or negative, but it doesn't explain the cause of variance. It is for this reason that the approach was broken down into two parts (17) and (18) that better explains if the negative or positive variance was of a price or quantity nature.

The next system input – energy (19) – is also one of the most important inputs. There are numerous ways to reduce the use of this input, but are often overlooked, since this input is seldom measured in companies.

$$I_E = \sum_{i=1}^n I_{E_i} \quad (19)$$

Analogous to the process seen in (11), the energy input into the system is calculated by the (20).

$$\sum_{i=1}^n I_{E_i} = I_{E_e} + I_{E_w} + I_{E_g} + I_{E_o} + I_{E_c} + I_{E_{oe}} \quad (20)$$

where:

$I_E$	– energy input,	$g$	– gas,
$i$	– energy input sub-group,	$o$	– oil,
$n$	– number of energy sub-groups,	$c$	– coal,
$e$	– electricity,	$oe$	– other energy input.
$w$	– water,		

For the total energy cost of the system with individual processes in mind, the calculation formula is as follows (21):

$$\begin{aligned} E_C &= \sum_{i=1}^n \sum_{j=1}^p V_{E_{ij}} = \sum_{i=1}^n \sum_{j=1}^p q_{E_{ij}} c_{E_{ij}} = \\ &= \sum_{j=1}^p (q_{E_e} c_{E_e}) + \sum_{j=1}^p (q_{E_w} c_{E_w}) + \sum_{j=1}^p (q_{E_g} c_{E_g}) + \\ &+ \sum_{j=1}^p (q_{E_o} c_{E_o}) + \sum_{j=1}^p (q_{E_c} c_{E_c}) + \sum_{j=1}^p (q_{E_{oe}} c_{E_{oe}}) \end{aligned} \quad (21)$$

where:  $E_C$  – total cost of energy.

Energy productivity ( $P_E$ ) is calculated according to the following (22):

$$P_E = \frac{\sum_{j=1}^m O_j}{\sum_{i=1}^n I_{E_i}} \quad (22)$$

In the following, capital will be the subject of discussion. This is the most problematic area of the existing models and some productivity models don't include capital in their calculations at all. Capital is divided into two major groups:

- fixed capital* – land, plant (building and structures, machinery, tools and equipment, others (amortized R&D, etc.), and so on);
- working capital* – money to support inventory, cash, accounts receivable, notes receivable.

Input of capital ( $C$ ) and capital productivity calculations (23), (24) compute the value of this input analogically to the inputs mentioned before.

$$I_C = \sum_{i=1}^n I_{C_i} \quad (23)$$

$$P_C = \frac{\sum_{j=1}^m O_j}{\sum_{i=1}^n I_{C_i}} \quad (24)$$

where:

$I_C$  – input of capital,  
 $P_C$  – productivity of capital.

The computing of fixed capital comprises land, buildings, machinery, tools and equipment and is measured by the depreciation method, which is an approximation of the fixed capital consumed. The value of fixed capital is computed according to (25).

$$C_{CF} = \sum_{i=1}^n V_{C_i} = \sum_{i=1}^n \left[ \frac{(c_{C_{ij}} + c_{I_{ij}} + c_{Ae_{ij}})}{D} * q_{C_{ij}} \right] \quad (25)$$

where:

$C_{CF}$  – total cost of fixed capital,  
 $D$  – depreciation period,  
 $q$  – quantity of capital assets of the same origin,  
 $c_{C_{ij}}$  – cost of asset,  
 $c_{I_{ij}}$  – cost of installation,  
 $c_{Ae_{ij}}$  – cost of additional equipment.

Other expenses (26), (27) include everything other than the already mentioned inputs. If we want to measure total productivity, it is necessary to count all the important inputs; with this input we are sure everything is accounted for. Other expenses of the system can include travel, taxes, professional fees, marketing, information processing, office supplies, R&D, general administration expense, etc.

$$I_O = \sum_{i=1}^n I_{O_i} \quad (26)$$

$$P_O = \frac{\sum_{j=1}^m O_j}{\sum_{i=1}^n I_{O_i}} \quad (27)$$

where:

$I_O$  – other input,  
 $P_O$  – productivity of other input.

Total input requires the consideration of all the partial inputs into the system. In the proposed module, total input must contain inputs of labour, material, energy, capital and other input.

Thus, the following equation will represent the total input (Eq. 28) placed into this system of measurement.

$$I_T = \sum_{i=1}^n I_{M_i} + \sum_{i=1}^n I_{L_i} + \sum_{i=1}^n I_{E_i} + \sum_{i=1}^n I_{C_i} + \sum_{i=1}^n I_{O_i} \quad (28)$$

where:  $I_T$  – total input.

Calculations also include the total factor productivity formula (29) and the total productivity formula (30) with the consideration of all the individual processes and their individual inputs.

$$TFP = \frac{\sum_{j=1}^m O_j}{\sum_{i=1}^n I_{L_i} + \sum_{i=1}^n I_{C_i}} \quad (29)$$

where:  $TFP$  – total factor productivity.

$$TP = \frac{\sum_{j=1}^m O_j}{\sum_{i=1}^n I_i} = \frac{\sum_{j=1}^m O_j}{\sum_{i=1}^n I_{M_i} + \sum_{i=1}^n I_{L_i} + \sum_{i=1}^n I_{E_i} + \sum_{i=1}^n I_{C_i} + \sum_{i=1}^n I_{O_i}} \quad (30)$$

where:  $TP$  – total productivity.

The difference in this approach to total input measurement is that the emphasis is on the individual process steps of the total manufacturing operation in detail, not on the generalized approach. This detailed approach states, which particular process and particular input causes the increase or decrease of overall input into the system and its influence on the total input of the whole manufacturing operation.

### 3.1 Output

Acquiring a longer-term perspective on problems is essential for setting priorities. The module of system measurement enables managers to quickly review the performance of the plant at each process step for any time period. The results provided by the module can be generated in any time interval, for instance, those past 1 day, 7 days, 30 days, 90 days, 180 days or a one-year period, to provide a recapitulation of performance.

When dealing with inputs moving into the system, the ABC analysis is used to decide, which inputs are the most consumable. It is similar when considering outputs from the system. With ABC analysis a company can very easily find out which 20% of all manufactured products leaving the system create 80% of the value of all manufactured products that includes very important input costs coming into the system necessary for producing this output. The criterions of this analysis are the values of particular items and the amount of manufactured products. Since there can be a couple of thousands of items in a manufacturing system, this analysis of micro-performance assessment depicts the most crucial parts. The sequence used, when auto-calculating appurtenances, follows: after fabricated goods are placed in descending

order from the highest value of manufacturing costs, a percentage of the particular product price of the total value of the finished products is calculated.

The first step in this analysis is to define the value of examined items in the system (31), followed by the data sorting in descending order according to the calculated value. The percentage of each part from the total value (32) foregoes a cumulative sum of percentages (33).

$$V_T = \sum_{j=1}^m (q_j * p_j) \quad (31)$$

$$\%_{(V_T)_m} = \frac{p_j}{V_T} = \frac{p_j}{\sum_{j=1}^m (q_j * p_j)} \quad (32)$$

$$Cum\% = \sum_{j=1}^m \left( \frac{p_j}{V_T} \right) = \sum_{j=1}^m \left( \frac{p_j}{\sum_{j=1}^m (q_j * p_j)} \right) \quad (33)$$

where:

- $V_T$  – total value of items,
- $q$  – quantity,
- $p$  – price of items,
- $m$  – total products,
- $j$  – particular product.

### 3.2 Productivity Indexes

Productivity indexes are used in different places and in different variations throughout the module and represent the important aspects of decision making in a company and goal achievement determination. A productivity index ( $PI$ ) is based on a ratio of the current period (in this case period 2) productivity value ( $PV$ ) to an earlier period (period 1) productivity value (34).

$$PI = \frac{PV_2}{PV_1} \quad (34)$$

If the value of a productivity index is greater than 1, an increase in productivity is achieved; the opposite occurs when the value of a productivity index is less than 1, whereby productivity has decreased. The percentage change in productivity is calculated using the following formula (35):

$$\Delta P = \left[ \frac{PV_2}{PV_1} - 1 \right] * 100 = (PI - 1) * 100 \quad (35)$$

The basic total productivity ratio (1), also used to track changes in productivity (36) for period 1 and (37) for period 2), represents a figure. For example, if a productivity rate of the

first period was 18 and the second period 20, then we know that productivity increased from 18 to 20. However, we don't know the monetary value of this increase. In this case, it is suitable to express inputs in the productivity rate (38).

$$TP_1 = \frac{\sum_1^m O_1}{\sum_1^n I_1} \quad (36)$$

$$TP_2 = \frac{\sum_1^m O_2}{\sum_1^n I_2} \quad (37)$$

$$\sum_{i=1}^n I_i = \frac{\sum_{j=1}^m O_j}{TP_t} \quad (38)$$

where:  $t$  – time period.

The advantage of this equation is the identification of the increase or decrease in value of inputs using theoretical and actual required input data. The following equation can help us to compare, for example, the inputs that would be required in period 2 if we had performed at the productivity rate of period 1 (39).

$$\sum_1^n I_2 = \frac{\sum_1^m O_2}{TP_1} \quad (39)$$

Table 1 shows the simple example of this case.

Tab. 1. Example of Changes in Productivity

	<b>Period 1</b>	<b>Period 2</b>
<b>Output (O)</b>	100,000 Sk	120,000 Sk
<b>Input (I)</b>	5500 Sk	6000 Sk
<b>Productivity (P=O/I)</b>	18.18	20
Increase of productivity from 18.18 (period 1) to 20 (period 2).		
<b>Input theoretical (I<sub>t</sub>)</b>		O <sub>2</sub> /P <sub>1</sub> = 6600 Sk
<b>Savings (+)/Expense (-)</b>		I <sub>t</sub> - I <sub>2</sub> = + 600 Sk
Because productivity increased in period 2, the output O <sub>2</sub> was produced with 6000 Sk rather than 6600 Sk.		

The monetary result of Equation 39 explains the savings or spending from a productivity increase or decrease in period 2 with the use of the period 1 productivity rate. Thus, we produced an output in period 2 only with 6000 Sk instead of 6600 Sk that would be required with the productivity of period 1. The result is that a company saved 600 Sk on inputs.

The part of this module, dealing with internal benchmarking productivity assessment, is capable of performing the following tasks. It calculates:

- a) the change in productivity between two fiscal periods (e.g., year 2005 compared to year 2004),
- b) the change in productivity between periods within a fiscal year – quarters, months, weeks or days (e.g., May 2006 compared to April 2006 or 31<sup>st</sup> day of 2006 compared to 20<sup>th</sup> day of 2006),
- c) the change in productivity between seasonal periods (e.g., summer 2006 and summer 2005).

### 3.3 Break Even Point of the Total Productivity (BEP)

To obtain the minimum value of total productivity for the business to be profitable, the break-even point analysis is used, which is based on the amount of working capital in the system. The more working capital a company uses, the smaller the value of the break-even point is. The maximum financial loss of a company can incur when total productivity of the company is zero.

The break-even point is the value of the total productivity given by the formula (40) that Summanth [17] derived.

$$TP_{BEP} = 1 - \frac{I_{C_w}}{\sum_{i=1}^n I_i} \quad (40)$$

where:

- $TP_{BEP}$  – break-even point of total productivity,
- $I_{C_w}$  – input of working capital.

When using break-even analysis, the computation of minimum total productivity value a company should reach in order to make a profit, can be performed. So, for example, from Fig. 9 we can read for period 1 that the break-even point for a company should reach the minimum of 0.78 and 0.37 in period 2 if it wants to generate profit. From the chart it is clearly seen that in period 2 more working capital is used compared to period 1, since the break-even point is smaller than that of period 1.

### 3.4 Cost

This is a highly important part of the performance module, since costs uncover the most problematic areas of a system money-wise. Two worksheets dealing with costs reveal the data that help management to specify the most cost consumable areas in the system from the total, variable and fixed cost point of view. Moreover, the micro-level cost assessment of the system permits the cost decomposition per produced part, per period or per individual process. Thus, even the smallest portion of the whole system is paid attention to and cannot be overlooked. The cost summary of the manufacturing system might be seen from Fig. 10 and cost specification of individual processes from Fig. 11.

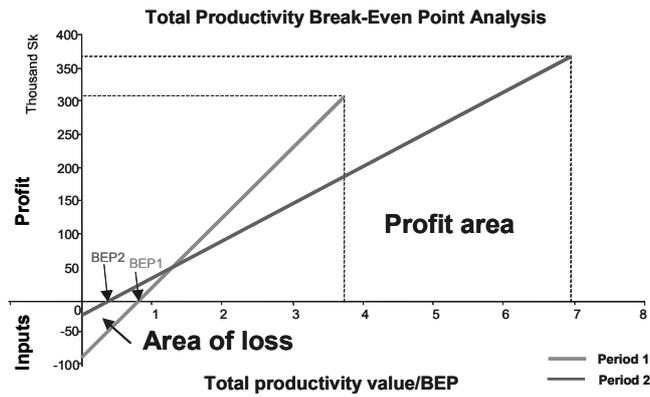


Fig. 9. Break-Even Point Example Chart

PERIOD 1: 2001		PERIOD 2: 2002						
Variable costs	Per part		Per period		% cost variable		% cost total	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Material cost	1.69 Sk	#DIV/0!	1,690,750 Sk	0 Sk	70.61%	0.00%	64.29%	0.00%
Blue-collar labour cost	0.00 Sk	#DIV/0!	0 Sk	0 Sk	0.00%	0.00%	0.00%	0.00%
White-collar labour cost	0.06 Sk	#DIV/0!	61,200 Sk	0 Sk	2.56%	0.00%	2.33%	0.00%
Other labour cost	0.00 Sk	#DIV/0!	0 Sk	0 Sk	0.00%	0.00%	0.00%	0.00%
Energy cost	0.45 Sk	#DIV/0!	447,372 Sk	0 Sk	18.68%	0.00%	17.01%	0.00%
Water cost	0.00 Sk	#DIV/0!	0 Sk	0 Sk	0.00%	0.00%	0.00%	0.00%
Oil cost	0.00 Sk	#DIV/0!	0 Sk	0 Sk	0.00%	0.00%	0.00%	0.00%
Coal cost	0.00 Sk	#DIV/0!	0 Sk	0 Sk	0.00%	0.00%	0.00%	0.00%
Gas cost	0.00 Sk	#DIV/0!	0 Sk	0 Sk	0.00%	0.00%	0.00%	0.00%
Variable tooling cost	0.20 Sk	#DIV/0!	195,000 Sk	20,000 Sk	8.14%	100.00%	7.41%	1.24%
<b>Total variable cost</b>	<b>2.39 Sk</b>	<b>#DIV/0!</b>	<b>2,394,322 Sk</b>	<b>20,000 Sk</b>	<b>100.00%</b>	<b>100.00%</b>	<b>91.04%</b>	<b>1.24%</b>
Fixed costs	Per part		Per period		% cost fixed		% cost total	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Principal equipment cost	0.12 Sk	#DIV/0!	115,616 Sk	1,230,000 Sk	49.08%	77.21%	4.40%	76.26%
Auxiliary equipment cost	0.02 Sk	#DIV/0!	19,006 Sk	200,000 Sk	8.07%	12.55%	0.72%	12.40%
Fixed tooling cost	0.01 Sk	#DIV/0!	7,500 Sk	50,000 Sk	3.18%	3.14%	0.29%	3.10%
Maintenance cost	0.06 Sk	#DIV/0!	56,421 Sk	100,000 Sk	23.95%	6.28%	2.15%	6.20%
Installation cost	0.02 Sk	#DIV/0!	23,123 Sk	13,000 Sk	9.82%	0.82%	0.88%	0.81%
Building cost	0.01 Sk	#DIV/0!	13,901 Sk	0 Sk	5.90%	0.00%	0.53%	0.00%
<b>Total fixed cost</b>	<b>0.24 Sk</b>	<b>#DIV/0!</b>	<b>235,567 Sk</b>	<b>1,593,000 Sk</b>	<b>100.00%</b>	<b>100.00%</b>	<b>8.96%</b>	<b>98.76%</b>
<b>Total fabrication cost</b>			<b>2.63 Sk</b>	<b>#DIV/0!</b>	<b>2,629,889 Sk</b>	<b>1,613,000 Sk</b>	<b>Total investment:</b>	

Fig. 10. Example of Cost Tables

Total production cost							
Period 1	Period 2	Process 1		Process 2		Process 3	
Cost per part	#DIV/0!	Lathe		Drill		Cutter	
Cost per period		Period1	Period2	Period1	Period2	Period1	Period2
2,63 Sk	#DIV/0!						
2,629,889 Sk	1,613,000 Sk						
Cost breakdown per part							
Variable costs							
Material cost							
Blue-collar labour cost	0.00 Sk			0.00 Sk		0.00 Sk	
White-collar labour cost	0.00 Sk			0.00 Sk		0.00 Sk	
Other personnel labour cost	0.00 Sk			0.00 Sk		0.00 Sk	
Energy cost	0.17 Sk			0.17 Sk		0.01 Sk	
Water cost	0.00 Sk			0.00 Sk		0.00 Sk	
Oil cost	0.00 Sk			0.00 Sk		0.00 Sk	
Coal cost	0.00 Sk			0.00 Sk		0.00 Sk	
Gas cost	0.00 Sk			0.00 Sk		0.00 Sk	
Other energy cost	0.00 Sk			0.00 Sk		0.00 Sk	
Variable tooling cost	0.00 Sk			0.00 Sk		0.00 Sk	
<b>Total variable cost</b>	<b>0.17 Sk</b>			<b>0.17 Sk</b>		<b>0.01 Sk</b>	
Fixed costs							
Principal equipment cost	0.02 Sk			0.02 Sk		0.00 Sk	
Auxiliary equipment cost	0.00 Sk			0.00 Sk		0.00 Sk	

Fig. 11. Example of Process Cost Tables

Equation 41 is a general representation of partial inputs variable cost calculations per part produced. It serves as a basic formula, into which individual inputs can be substituted.

$$PVC_{i_{part,t}} = \frac{\sum_{j=1}^p \sum_{i=1}^n VC_{ij_t}}{PV_t} \quad (41)$$

where:

$PVC$  – partial variable cost,  
 $i$  – specified input,  
 $j$  – specified process,  
 $part$  – per part produced,  
 $p$  – total number of processes,  
 $t$  – time period,  
 $VC$  – variable cost,  
 $PV$  – production volume.

By partial cost we can understand the cost of labour, material, energy and other inputs. Another partner of variable cost making up the total cost are fixed costs. The next formula (42) represents the share of fixed costs in a finished product. The total manufacturing costs (43) will be the sum of total fixed and variable costs.

$$PFC_{i_{part,t}} = \frac{\sum_{j=1}^p \sum_{i=1}^n FC_{ij_t}}{PV_t} \quad (42)$$

where:

$PFC$  – partial fixed cost,  
 $FC$  – fixed cost.

$$TMC = FC + VC \quad (43)$$

where:  $TMC$  – total manufacturing cost.

Among fixed costs belongs principal equipment cost, additional equipment cost, maintenance, installation and building costs, and fixed tooling cost.

The following calculates the percentage of individual input cost into total variable cost ( $TVC$ ) (44), respective individual input cost in a total fixed cost ( $TFC$ ) ratio (45). Further, the individual inputs of fixed and variable costs as a percentage of total manufacturing costs are represented in (46) and (47).

$$PVC_{i,t}(\%TVC) = \frac{PVC_{i,t}}{TVC_t}; \quad \sum_{i=1}^n \%PVC_i = 100\% \quad (44)$$

$$PFC_{i,t}(\%TFC) = \frac{PFC_{i,t}}{TFC_t}; \quad \sum_{i=1}^n \%PFC_i = 100\% \quad (45)$$

$$PVC_{i,t}(\%TMC) = \frac{PVC_{i,t}}{TMC_t} \quad (46)$$

$$PFC_{i,t}(\%TMC) = \frac{PFC_{i,t}}{TMC_t} \quad (47)$$

$$\sum TFC + \sum TVC = 100\% \quad (48)$$

### 3.5 Financial Performance Measures

In the beginning of the proposed solution it is mentioned that two sets of measures must be used in order to get adequate performance results. The operations measures were discussed and the financial measures will be briefly dealt with in the following. Financial measures are represented by net profit, return on investment (ROI) and cash flow [5]. These measures should be used together to ascertain the complex picture of the company. For example, a net profit of 10 million Sk has meaning only if we know how much investment it took to generate net profit. If the investment was 100 million Sk, there is a 10% return of investment (49). Cash flow is important, because a company might have high profit and high ROI, but not enough cash necessary for everyday operations. Cash can be tied up in inventory or invested in new equipment.

$$ROI = \frac{P}{IN} \quad (49)$$

where:

- $IN$  – investment (assets that are used to run a company regardless of who manages the investment – plant, equipment, inventories, etc.),
- $P$  – profit.

$$P = S - E \quad (50)$$

where:

- $S$  – sales,
- $E$  – expenses.

Every single company or business venture has been established with the main goal in mind – to make money. It is for this reason that profit (50) is one of the most discussed measures aligning the interests and speculation of top management everywhere. Profit belongs to a whole matrix of performance measures and it can be used in various combinations to reveal important data about a company.

Some of the above-mentioned formulas are substituted into (51) with the meaning of performance measures already considered.

$$P = S - I_T = S - (\sum_1^i I_{M_i} + \sum_1^i I_{L_i} + \sum_1^i I_{E_i} + \sum_1^i I_{C_i} + \sum_1^i I_{O_i}) \quad (51)$$

Sales, in this case, include only that part of the output that represents all the finished goods sold to the final customer. This means not all the output produced is sold; some of it creates a part of finished-goods inventory to be sold in the future, the other part might be products that didn't pass the quality control and need to be re-processed since the damage was not so significant. Or, perhaps, they can be products staying in the output inventory awaiting the liquidation since a product was significantly damaged and is not suitable for re-processing.

The assets in the investment base can be valued in different approaches. Within the module is used the most common net book value of investment valuation, which means that gross book value is subtracted by accumulating any cost already depreciated.

Equation (49) can be, with the use of pyramid decomposition, modified to reveal other important factors about a company's activity that the simplest ROI formula doesn't show. Thus, we arrived at the formulation of (52) with a profit margin on sales and investment turnover. This is stated briefly here, since it was described in detail in Knežníková's work [8].

$$ROI = \frac{P}{IN} = PMS \cdot INT = \frac{P}{S} \cdot \frac{S}{IN} \quad (52)$$

where:

*PMS* – profit margin on sales,

*INT* – investment turnover.

The above two indicators reflect the company's activity. Investment turnover explains how active a company has been and a profit margin on sales indicates how profitable the activity has been.

Often, exchange rates are an issue when discussing their effect on the financial performance of an organisation. This work does not purport to particularly examine the circumstances and repercussions surrounding exchange rates. However, this topic should warrant attention in future endeavours examining financial performance, since companies reliant on exports are drastically affected by the strength and stability of their currency and the fluctuation of exchange rates.

Production volume, inventory and operating expenses represent the operational level measurement. Production volume needs to be specified in more detail, since the figure itself doesn't explain how much of the produced goods were sold and thus it distorts the final results. Once the goods are sold we get the throughput of the system. Inventory is the value of goods in the product stream. It often represents tied cash in the company. Operating expenses are all the money needed to turn inventory into throughput. Operating expenses include production costs (such as direct labour, indirect labour, inventory carrying costs, equipment depreciation, and materials and supplies used in production) and administrative costs. The key difference here is that there is no need to separate direct and indirect labour.

From an operations standpoint, the goal of the firm is to increase throughput while simultaneously reducing inventory and reducing operating expense.

## 4. SUMMARY

Performance measurement is, amongst other things, a powerful tool for assisting all concerned with the improvement of productivity and efficiency within a factory setting. It accurately depicts where inefficiencies lie and where improvements are possible. Furthermore, it measures the effects of changes in equipment, processing conditions and factory organisation.

The purpose of this paper was to clearly and effectively explain what productivity means and with the help of a model to show how can be conducted performance measurement.

Because of complexity of this topic, the benchmarking and the forecasting module of the entire model were not described in this paper. All details completed with examples and computer programme were introduced in [12], [10], [11].

Productivity improvement is one of the key drivers of progress and it should reflect all aspects of production such as manufacturing more goods with less input resources, higher quality of goods with less input resources, and so on. The experimentation with the proposed model shows just that.

Throughout researching the existing files regarding performance and productivity and trying out the proposed tool for performance measurement, some finalizing conclusions can be drawn. It is apparent that measuring the specific problems in a manufacturing company greatly facilitates improving its performance by explaining what factors and variables are affecting performance and identifying where resources can be best applied. A measurement tool must be used in order to identify the weak points of the system, so the following corrective actions can be taken, based on the proposed scenarios. The above-mentioned measurement tool should not be implemented in a company to deter the employees, but the opposite, to encourage them to provide accurate data so that changes for better operations can be applied.

When using the tool the following must be kept in mind: the measurement tool can be only as good as the accuracy of the data inputted into the model. The less information provided for the model, the less final results and figures the system will calculate.

Every work should be written with a goal in mind – to provide some contributions to the researched field. The contributions of the proposed model to the productivity and benchmarking field lie in the complexity of existing performance measures, and adapting these measures and proposed measures into one general system model that is worked out in Microsoft Excel. The numerous advantages of the tool possess great positive repercussions when applied effectively to companies. The tool provides general and detailed productivity indexes, pointing out which products is profit generating and which are not. It shows which particular input resources are being utilized inefficiently and offers forecasts for the future based on the past performance all in one comprehensive tool.

*This work was supported by the Slovak Agency for Science and Research through the Grant No. APVT-20-026304“.*

## References

- [1] AGHAMIRIAN, M. - KORTIŠOVÁ, M.: Blanking Line Analysis, Alcan International Inc., Research Report, Kingston, 2003

- [2] FRONTINI, G. F., - KENNEDY, S. L. - KORTIŠOVÁ, M.: Enhancing Product Properties Through the Manufacturing Supply Chain Using New Dynamic Decision-Making Tools, Grant Proposal, CAMM, Kingston, 2002
- [3] GREGOR, M.: Produktivita. Unpublished lectures. University of Žilina, 2005
- [4] GREGOR, M.-CAJCHANOVA, O.-GRZNAR, P.: Quality and Productivity Improvement of Products and Processes based on Application of DoE Methods. Produktivita a inovácie, 2006, č.2, s. 2-4 (in Slovak)
- [5] GREGOR, M. - KORTIŠOVÁ, M.: Productivity Measurement and Evaluation. 10. Slovak Statistical Conference, Smolenice, May 2000
- [6] GREGOR, M.-ŠTEFÁNIK, A.-KNEŽNÍKOVÁ, M.: Multilevel Benchmarking Analysis Model Proposal. Research Work, Ministry of Economy of the Slovak Republic, 2002 (in Slovak)
- [7] HANNULA, M.: Expedient Total Productivity Measurement, ESPOO, 1999
- [8] KNEŽNÍKOVÁ, M.: The Analytical Tool for the Evaluation of Internal performance of the Company. University of Žilina, Industrial Engineering Department, 2003 (PhD Thesis, in Slovak)
- [9] KNEŽNÍKOVÁ, M. - GREGOR, M.: PROFIN. The system for productivity analyses and financial analyses. Slovak Productivity Center, Žilina, 2002
- [10] KORTIŠOVÁ, M.: Cost Analysis of Bipolar Plate Fabrication for Fuel Cells, Research Report, CAMM, Kingston, 2002
- [11] KORTIŠOVÁ, M.: Model of Alcan Williamson Plant, Alcan International Inc., Final Research Report, Kingston, 2004
- [12] KORTIŠOVÁ, M.: Model Proposal for Productivity Measurement and Evaluation in a Manufacturing Organisation with External Benchmarking. University of Žilina, Industrial Engineering Department, 2005 (PhD Thesis)
- [13] KORTIŠOVÁ, M. - GREGOR, M: Problems on Benchmarking, TRANSCOM 2001, 4<sup>th</sup> European Conference of Young Research and Science Workers in Transport and Telecommunications, Žilina, June 2001
- [14] LAWLOR, A.: Productivity Improvement Manual, Gower, USA, 1987
- [15] PROKOPENKO, J.: Management Consulting Focused on Productivity, International Labour Organization, Geneva, 1994
- [16] SINK, S. D.: Productivity Management: Planning, Measurement and Evaluation, Control and Improvement, John Wiley & Sons, 1985
- [17] SUMMANTH, J. D.: Productivity Engineering and Management, McGraw-Hill, 1984
- [18] ŠTEFÁNIK, A.-GREGOR, M.-KNEŽNÍKOVÁ, M.-GRZNAR, P.: The Proposal of the Index Benchmarking Model. Research Work, Ministry of Economy of the Slovak Republic, 2002

