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Using manufacturing measurement visualization to improve performance

I. Senkuvienė*, K. Jankauskas, H. Kvietkauskas*****
**Kaunas University of Technology, Kęstučio 27, 44025 Kaunas, Lithuania, E-mail: irma@itmecha.lt*
***Kaunas University of Technology, Studentų 50, 51368 Kaunas, Lithuania, E-mail: kestutis.jankauskas@ktu.lt*
****Itmecha Ltd., Metalų 14, Mokolai, 68461 Kaunas, Lithuania, E-mail: henrikas@itmecha.lt*

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1. Introduction

Modern age of information technology offers new possibilities for all branches of industry, including manufacturing. But those possibilities come at a price. As companies are implementing new technologies in their processes to obtain better performances, the competition bar is steadily rising. Each competitor must face new challenges and evolve every day in order to keep up with others. Manufacturer must be versatile by all aspects, including cost, quality, production process design, and so on. So, implementation of new strategies and technologies is embedded into daily routines of a company.

If we are to say that manufacturing company's overall performance is the summation of its resource productivity, in this paper we analyze how taking productivity measurements and representing them visually can improve the performance itself. Suggested methods allow monitoring manufacturing process and helps noticing critical occurrences. Proposed visual representation employs fundamental human cognition-related functions in order to draw viewer's attention to certain pieces of information and helps to understand and compare it.

2. Existing measurement and visualization methods

As this paper discuses manufacturing process measurement visualization methods, there are several aspects related to the subject. This section discusses existing researches, methods and solutions.

2.1. Manufacturing performance

In a broad sense, manufacturing process is the act of transformation. During this process company's resources are transformed into a product. Resources are not just materials, but functions performed by manufacturing machines and employees as well. In general, one could say that the manufacturing performance is directly related to the quality and effectiveness of mentioned fundamental resources. The question is how performance can be estimated using available data and means?

The definitions of performance that can be found in literature are slightly different. Authors who focus on the overall company performance suggest that performance can be described by production cost, quality, flexibility, and time [1-3]. Cost defines how expensive or cheap manufactured production is in comparison to other similar products in a market. Quality indicates if production satisfies end-user expectations towards its functionality, design and etc. Flexibility indicates organization capabilities to adjust technological manufacturing process, product design and volume on demand. And finally, time denotes ability to manufacture and deliver production in timely fashion.

Literature solely focusing on production capabilities, underline that performance is related to supply cost, machine uptime, labor hours and product quantities [4]. However, Ahmad and Dhafr [1] states that performance indicators can be separated into financial, technical, and human contribution performance. This paper focuses on the last item, leaving aside business models and the improvement of equipment. So, in the following sections we investigate means of increasing manufacturing performance through the improvement of human contribution effectiveness.

2.2. Measurement set

In the age of information technology people responsible for process control is overflowed by data. Raw and unprocessed data has little use to person that makes a decision. So useful information must be extracted from given data in order make a decision and take appropriate action later on. Neely and Jarrar [5] gives a performance planning value chain: hypothesis, data gathering, analysis, interpretation, informing responsible staff, decision making, and planning as well as acting. So, one must hypothesize before looking at the data in order to define what exactly he is looking for. Thus, hypothesis defines required information and necessary data for the evaluation of a process. Knowing what kind of information we need allows us to define the set of measurements, which will provide us with data.

Robson [6] underlines the importance of correct measurement set selection. Choosing too many measurements can deteriorate the performance of a process. Unnecessary measurements attach additional cost and time to the process, which decreases its performance. Some measurements may need additional equipment. More data means longer processing time and more complexity for the person that analyses the information. Ben-Zvi [7] confirms that increasing complexity follows inverted U-shaped curve, where increasing system complexity increases the effectiveness of decision making staff up to the certain point. Increasing complexity further degrades the effectiveness (additional information and functions overwhelm cognitive capabilities of a user). Also, choosing certain measurements just because they are easiest to take does not provide required data. Robson [6] notes that local performance can be in conflict with overall performance, therefore, measurement set must be designed carefully and minimized.

As Neely and Jarrar [5] suggest starting from hypothesis, Robson [6] encourages focusing on failure. By defining what failures can degrade overall performance, we can select critical-to-failure measurements. Thus, a person inspecting the process can be alerted if certain components of the process may compromise its success.

Robson [6] also discusses human behavior involved in manufacturing process and its evaluation. Author gives an example when processes of manufacturing and inspection were separated, which caused constant conflicts between operators and inspectors. Whenever operators were qualified enough to inspect the quality of production themselves, the problem was eliminated. Author underlines that apart from intrinsic motivation to remove the deficiency, extrinsic motivation can be stimulated using reward and penalty system.

Modern technologies allow enhancing measurement systems with real-time data processing and output by the means of various visual representations. So operators can use those tools to evaluate their efficiency and contribution to overall performance.

2.3. Information visualization methods

There are numerous papers and books regarding the visualization of information and data. Parush and others [7] analyze how different visualization methods affect cognitive abilities of staff responsible for decision making. They used hyperbolic trees and treemaps instead of table grid to represent complex data. Their experiments indicate that alteration of visual representation had more impact on the performance of novice test subjects than on expert subjects. However, effect was positive in both cases.

Keller and coauthors [8] presents experimental proofs that appropriate visualization of information supports knowledge acquisition. Their research reveals that graphical representation is superior to simple text and can help users to notice, understand and memorize the message inscribed in the depicted information. Keller and coauthors found that two-dimensional representations of information are superior to three-dimensional representations. As 3D charts can hide certain information it is required changing orientation of a chart to understand illustrated situation. Moreover 3D pictures demands higher cognitive processing power of a brain, therefore user must spend more time analyzing it. As for 2D representation, it is quite straight forward and can be read without much effort. Keller and coauthors also found that color coding can help retrieve information from the memory, as there is additional relation between memorized color and value or text. This enables the user responsible for decision making to perform slightly better.

Myatt and Johnson [9] talk about fundamental principles to present the data, so it would help user to read information instead of confusing him or her. Visualization should draw user's attention to the substance of data. Representation should be as simple as possible without any additional elements. Illustrated information should not be distorted and must reflect the original relation between data values. E.g. information in 2D chart can be easily distorted by applying wrong aspect ratio. Information should be depicted according to the laws of visual hierarchy, visual flow and grouping. Those laws are derived from basic Gestalt principles, which declare how human brain reacts to certain visual information. By manipulating visual features (e.g. color, size, position, orientation, alignment and shape) certain elements may look important or unimportant, closely related or independent, and etc. Thus, viewer's attention can be guided and concentrated at focal points. Mentioned features are processed in the brain almost instantaneously, so right information illustrated in a right way can be found, compared and grouped without much mental effort.

Myatt and Johnson [9] also provide guidelines for color encoding. It is stressed that background and foreground colors should maintain a certain level of contrast. Authors also discourage using red and green color encoding for values that must be compared. As 10% of men and 1% of women are color blind, they would not be able to see the difference. Authors also suggest that one should not be using colors from the opposite sides of color wheel as background and foreground, because it is hard to read red text in blue background and vice versa. Highly saturated colors also must be avoided, because they tire the eye (photo receptors) when one looks at them for long period of time. More information about Gestalt psychology can be found in sources like [10, 11].

2.4. Existing computer aided control solutions

Modern technology offered a lot of new possibilities to collect and analyze data almost instantly. With the help of computer aided tools a supervising staff can monitor manufacturing activities and initiate appropriate actions that allow staying in control of a process. So-called computer aided tools, in general case, are software packages, containing specific modules designed to process information regarding specific area, like finances, sales, resources, production, personnel, etc. The control is achieved by collecting data and analyzing the information inscribed into data. Aswathappa and Bhat [12] as well as Murthy [12] agrees that mentioned functionality can be implemented into a single system, called ERP (Enterprise Resource Planning), which gathers and processes data generated by different departments of a company.

Sources like [2, 12, 14] provide analysis of other sub-systems that can be integrated into Enterprise Control System. As well as ERP, they are defined by acronyms, like CAD (Computer Aided Design), CAM (Computer Aided Manufacturing), CAQ (Computer Aided Quality Assurance), CRM (Customer Relationship management), SFC (Shop-Floor Control) and some others. Further paper material is solely focused on ERP, because enterprise resource planning involves all the functionality relevant to the control of manufacturing process and its performance

Lödding [15] analyses whole production supply chain from receiving client's request to packing and shipping production. Author stresses the importance of material logistics, manufacturing operation and service control to process planning. In existing ERP software the most of mentioned information is not accessible or scattered over many different software windows [7]. To acquire necessary data user is forced to gather information manually from several windows and perform additional calculations.

Three ERP solutions were analyzed during this research, although their exact names are not revealed: A (developer from Germany), B (developer from Sweden), and C (open source software). Determined missing information related to manufacturing progress and equipment workload is listed in Table 1.

Table 1

ERP performance monitoring functions

Measurement	A	B	C
Real-time manufacturing progress monitoring:			
Material consumption	Partly[1]	Partly[2]	No
Manufacturing progress	No	Partly[2]	No
External manufacturing	No	No	No
Real-time equipment workload monitoring:			
Uptime	Partly[3]	No	Partly[4]
Downtime	No	No	No
Productivity	No	No	No
Current state	Partly[5]	No	Partly[6]

Each table cell indicates if specific measurement is partly provided or omitted by ERP software. The means of outputting partial measurements are given according to superscript number positioned near the label: 1) check-boxes indicate if there is enough material in a warehouse and if material was transferred to manufacturing plant; 2) generic indicator alerts if there is no material present, otherwise it displays information related to a production progress; 3) there is a possibility to monitor equipment state if it is operational or not; 4) can be viewed through the workload of staff; 5) percentage of current operation is displayed; 6) displays if operation is performed or not.

Practical analysis of mentioned software shows that visual representation of displayed information can be enriched in order to simplify the search of information that is critical to the manufacturing process control. Correct visualization can simplify and accelerate the decision making as well. Parush, Hod, and Shtub [7] confirms the same insight by stating that visualization methods in ERP software can be enhanced to improve staff effectiveness and through it the overall performance of manufacturing process.

3. Manufacturing measurement visualization methods

This section identifies measurements and derives values that are necessary to monitor and control manufacturing process. Section also involves guidelines how measurements should be taken and how acquired data should be represented visually to obtain better reaction effectiveness of operators and supervising personnel. As the improvement of overall performance is achieved through the human contribution, staff motivation issues should be regarded as well. Proposed methods are separated into real-time manufacturing progress monitoring and real-time equipment workload monitoring.

3.1. Real-time manufacturing progress monitoring

Real-time manufacturing progress monitoring or in short MPM method should be designed in a way that helps supervising personnel to identify problems that may be critical to a success of manufacturing process. The full range of this process includes formulating a production order, the development of product and process design, estimating required resources, acquiring resources, allocating resources, manufacturing, packing and shipping product to a customer. Generally, manufacturing resources are materials, equipment and personnel. Before actual manufacturing starts, necessary types and amounts of materials must be estimated and allocated, appropriate available equipment (machines, tools) must be selected and required specialists must be assigned.

Simplified scheme of mentioned process is given in a form of Gannt chart in Fig. 1. Scheme indicates that entire process starting at resource estimation and finishing at the manufacturing of final product must be carefully monitored and controlled. The process is accompanied by the stream of information between administration (supervising personnel) and other participants, like an external provider, a warehouse, and a manufacturing plant (Fig. 2). Thus, actions can be initiated and coordinated. Fig. 2 also illustrates the flow of materials between an external supplier and a warehouse as well as between a warehouse and a manufacturing plant. Materials can be transported from a warehouse to a plant and vice versa, if need to change material arises.

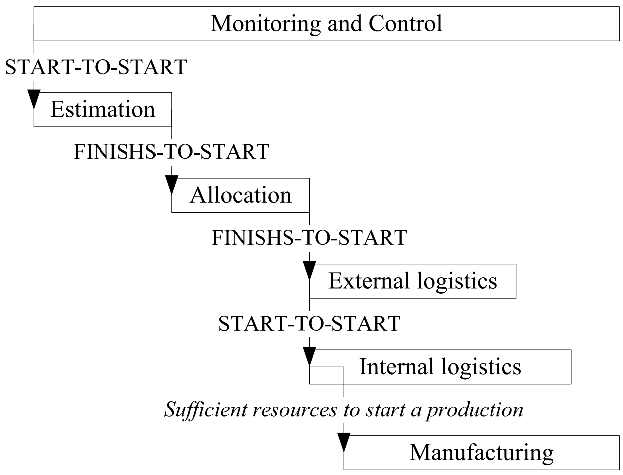

Fig. 1 Gannt chart of manufacturing process

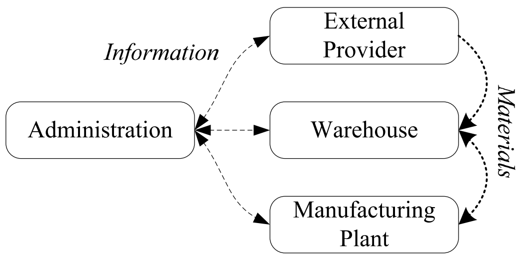

Fig. 2 Manufacturing information and material flow

If one is to say that estimated material amount required for a production is M and amount m_W is present in a warehouse, then missing amount m_S must be requested from a supplier (material quantity units may vary, common units are kilograms and meters):

$$m_S = M - m_W \, . \tag{1}$$

Let m_P denote the amount of material delivered to a manufacturing plant (production facility) and m_P always equals zero before logistics processes are initiated. So initial goal is to acquire estimated material amount ($m_W = M$) and transport this amount to a plant ($m_P = M$). In addition, the following restriction is set:

$$M = m_S + m_W + m_P \, . \tag{2}$$

To keep the restriction valid, it is necessary to update m_S, m_W, and m_P values after each logistics operation. Therefore, after each operation a certain amount m is transported from m_S, to m_W and from m_W to m_P. In Fig. 1 transportation from a supplier to a warehouse is represented as external logistics and transportation from a warehouse to a plant is represented as internal logistics. Those processes may be performed simultaneously. After supplier delivers amount m, his obligation is reduced by that amount, so m_S is updated to m_S - m and m_W is updated to m_W + m. Internal logistics operation triggers updates from m_W to m_W - m and from m_P to m_P + m.

Described model allows tracking external and internal logistics progress and taking appropriate actions if actual values deviate from estimated values (be the means of amount and schedule). The part of estimated materials to be provided by supplier μ_S, the part of materials present in a warehouse μ_W, and the part of or materials transported to a plant μ_P can be calculated from the following expressions:

$$\mu_S = m_S / M ; \tag{3}$$

$$\mu_W = m_W / M ; \tag{4}$$

$$\mu_P = m_P / M . \tag{5}$$

Each of values can be multiplied by 100% to represent a percentage from the total material amount. Eq. (2) ensures that $m_S/M + m_W/M + m_P/M = 1$. So entire process that needs to be monitored can be defined by the following step sequence: 1) production request (resources are not estimated); 2) resources estimation (m_W is known); 3) m_S request, resource allocation; 4) logistics initiation; 5) if there is enough workable m_P and production is not complete then do manufacturing. Also change of material amount m can be initiated (if $m < m_W$ then go to step 3, else go to step 4. If production was spoiled then additional materials from a warehouse must be requested (if $m < m_W$ then go to step 3, else go to step 4.

As estimated amount consists of three components, it would be handy to monitor all three percentage values at a time. But this would burden the visual representation with redundant information (e.g. when two percentage values are known, third can be calculated). In order to reduce the amount of displayed information, worst case scenario should be employed, because supervisor must see system states that are the most likely to cause failure. According to practical manufacturing experience it is considered that internal logistics are easier to control than external logistics, therefore external logistics progress is treated as more critical. Generally, all material transportation progress is divided into states which are listed from the most critical to the least critical:

- undefined (resources is not estimated);
- missing (material deficiency detected in a warehouse);
- reject (materials were spoiled);
- supplier (supplier hasn't delivered all materials);
- change (material change is requested);
- warehouse (not all materials were delivered to a plant);
- plant (all materials were delivered to a plant).

Material transportation states can be changed due to certain occurrences. Occurrences are listed along with material transportation states and related percentage values are displayed as a colored progress bars in Fig. 3 as overall material status. Red color represents the most critical state and percentage of material (undefined, missing, reject), orange represents indirectly controllable material (supplier), yellow represents directly controllable material (warehouse) and green color denotes material that has reach its destination (plant). Cyan color represents change request. In given visualization supervisor can see the most relevant information (states and percentage value) and the part of material amount that needs direct or indirect control.

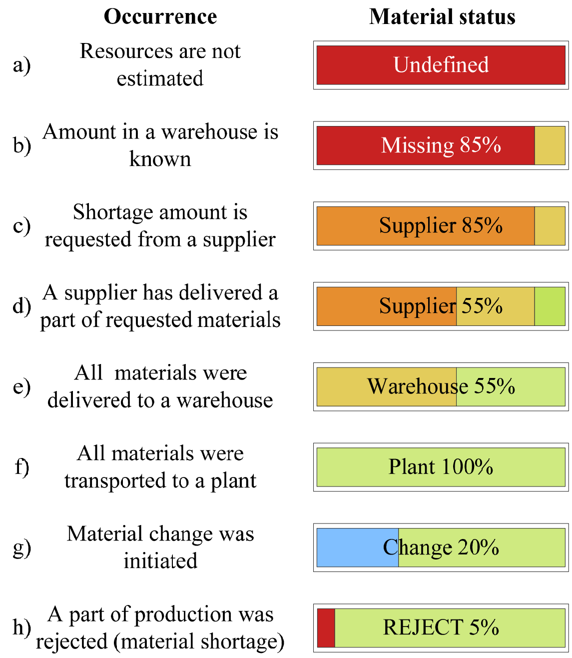

Fig. 3 Material status visualization

As mentioned in Section 0, 10% of men and 1% of women are color blind, so they cannot take advantage of comparing progress bar colors. In order to compensate this drawback of representation, colored bars must keep constant positions relatively to each other and a tag with additional information should pop up when hovering cursor over the bar (all material state labels and percentages). Proposed color ordering follows state sequence from the worst to the best: red, orange, cyan, yellow, and green.

All data related to MPM method must be inputted right at the end of each logistics operation. Data input can be done using computerized work place, special mobile devices or data collection terminals. Thus, information is uploaded into a system and updated at the basis of real-time. Given model discussed amounts of a single type of material, but it can be modified to monitor state of multiple material types. All type amounts must be assembled into a single value using unified amount measurement system (mass, volume, unit count, etc.).

Manufacturing process can be split into internal and external manufacturing. Those processes are monitored simultaneously. Internal manufacturing progress can be described by the means of material consumption, spent working time, and produced amount of a product. Presume that estimated material amount required for internal production is M_I, a quantity of products to be produced is Q_I and estimated production time is T_I. If one can measure actual material consumption m_I, work time consumption t_I, and evaluate produced quantity q_I at any point of time during the manufacturing process, then manufacturing process can be monitored before the process ends. It is important to note that time T_I and t_I is estimated on the basis of staff and equipment work hours (or minutes).

As client who ordered specific production is interested only in the quantity of requested production, actual manufacturing progress ω is tracked by the means of produced and requested quantity:

$$\omega = q_I / Q_I \,. \tag{6}$$

Actual work time and consumed material values tend to deviate from estimated ones. Therefore, t_I/T_I and m_I/M_I may not represent actual progress if work time or material consumption effectiveness drops. Resource consumption effectiveness can be represented by inverted progress functions:

$$\varepsilon_T = T_{min} / t_I \,,\; T_{min} = min\left(T_I, t_I\right); \tag{7}$$

$$\varepsilon_M = M_{min} / m_I \,,\; M_{min} = min\left(M_I, m_I\right), \tag{8}$$

where ε_T is the effectiveness of work time consumption and ε_M is the effectiveness of material consumption. Minimization functions indicate that T_{min} and M_{min} values must be minimized. Whatever methods are employed to obtain estimated values, the values must be corrected if actual consumption is more effective. As material consumption can be monitored in material status visualization, time consumption can be attached to manufacturing progress monitoring visualization (see Fig. 4). Actual progress is calculated using Eq. (6) and represented by green progress bar. Red progress bar appears at the left side if time consumption effectiveness drops below hundred percent. Red bar represents time overhead τ and is calculated using the following expression:

$$\tau = \frac{t - t_I}{T_I}; \tag{9}$$

where τ denotes time overhead (value depicted in text), t equals the amount of work time passed from production start to the moment when measurement was taken, and t_I represents work hours spent effectively (producing quality production). As t_I relation to quantity of manufactured production q_I is $t_I = q_I \times T_I/Q_I$, Eq. (9) can be rewritten:

$$\tau = \frac{t}{T_I} - \frac{q_I}{Q_I}; \tag{10}$$

$$\tau_{disp} = min\left(\tau, 1\right); \tag{11}$$

where τ_{disp} denotes a value depicted by the red progress bar. In this case progress bars are depicted differently in comparison to material status visualization. Green bar represents full progress from 0% to 100%. Red bar is placed over the green bar and appears if time consumption exceeds schedule. For example, during the measurement 50% production time was passed, but only 40% of production quantity was declared, so time overhead equals 10%. As illustrated in Fig. 4, red bar is always at the left and green is at the right side. Text value indicates if production is progressing in tamely fashion (label "On time") or is late (label "Late"). In case of latency work time overhead percentage is displayed after plus sign.

External manufacturing progress is defined using two measurements. The first one indicates what amount of materials was shipped to an external manufacturer and the second one denotes the quantity of production delivered from an external manufacturer back to a warehouse. Presume that estimated values for external manufacturing are M_E and Q_E. Actual values are m_E and q_E. The progress of shipped materials μ_E and the progress of returned quality production ρ_E can be calculated using expressions:

$$\mu_E = m_E / M_E \,; \tag{12}$$

$$\rho_E = q_E / Q_E \,. \tag{13}$$

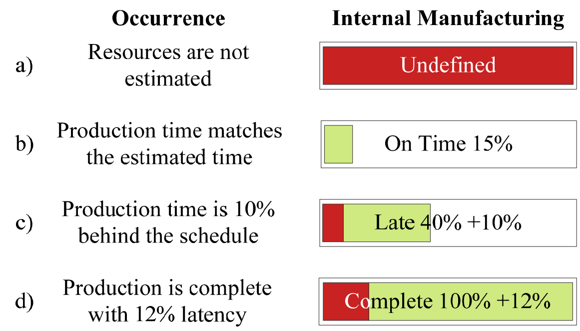

Fig. 4 Internal manufacturing progress visualization

Considering restriction $\mu_E \geq \rho_E$ (production cannot be made without materials, so material shipment progress always exceeds or is equal to the progress of production), it is handy to put both progress bars on top of each other. In Fig. 5 orange bar (depicted in c) as the only bar as well as in d) and e) as the right bar) represents shipped materials and is always greater (or equal) than green bar, which represents production progress. Green bar is on the top of orange bar and is stretched less to the right than an orange one, unless both progresses are equal.

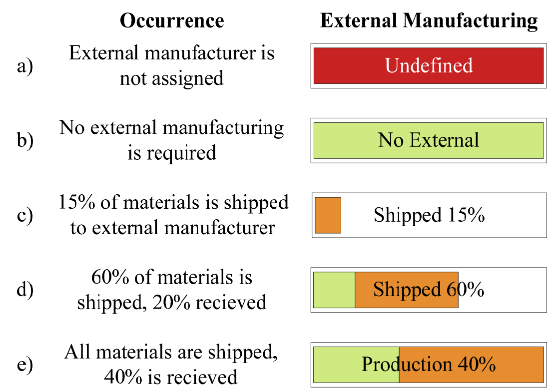

Fig. 5 External manufacturing progress visualization

As in the case of material state visualization, in internal and external manufacturing progress visualization full progress information can be provided by hovering mouse cursor over the progress bar. Those three progress bars allow monitoring the most important manufacturing measurements that enables supervisor to decide if production is performed according to the plan or not.

3.2. Real-time equipment workload monitoring

Real-time Equipment Workload Monitoring or in short EWM allows to observe performance critical measurements. One of the ways to keep high manufacturing performance is maintaining high usage of existing resources. Therefore, reducing equipment and staff idle time should be a priority goal. Improving equipment and increasing staff qualification would also result in the output of higher effectiveness, but these topics are not analyzed in this paper.

Fischer and coauthors [17] use term “utilization time” to describe time span when equipment was functional. Utilization time consists of setup and production times. Setup time is a sum of basic setup and unproductive setup time and production time consists of time per unit work multiplied by produced quantity. Each time span spent on one unit is separated into floor-to-floor time and unproductive time; the first one is distributed to main productive time, auxiliary productive time and idle time.

It is possible to simplify work time measurement. As mentioned before, utilization time (uptime) consists of setup time and production time. Estimated setup and unit production times (production time per unit) are marked as T_S and T_P, and actual values are denoted by t_S and t_P accordingly. If the estimated quantity of (internal) production equals Q_I and actual quantity equals q_I, then estimated utilization time (uptime) T_U and actual uptime t_U can be calculated from expressions:

$$T_U = T_S + T_P \times Q_I \; ; \tag{14}$$

$$t_U = t_S + t_P \times Q_I \; . \tag{15}$$

Eq. (15) denotes uptime when production process was completed. Both setup and production times are calculated by capturing start and finish dates. Replacing t_P with T_P would give an effective uptime $\tilde{t}_U$ (if T_P is minimized). Moreover, effective uptime can calculated before the end of production process:

$$\tilde{t}_U = t_S + T_P \times q_I \; . \tag{16}$$

Naturally, because of restriction $T_P \times Q_I \leq t_P \times Q_I$, $\tilde{t}_U$ is not greater than t_U when process is finished.

If it is necessary to take measurement before the end of production at the point of time t (measured in work hours from the beginning of setup) and q_I is known, setup effectiveness δ_S and production effectiveness δ_P values can be calculated:

$$\delta_S = T_S \,/\, t_S \; ; \; t \geq t_S \; ; \tag{17}$$

$$\delta_P = \frac{T_P \times q_I}{t - t_S} \; ; \; t \geq t_S \; ; \tag{18}$$

$$\delta_P = T_P \,/\, t_P \, , \; t \geq t_P \; . \tag{19}$$

Obviously, setup time must be complete in order to calculate the effectiveness of setup time δ_S, though it is possible to tell how effectively production goes before it is finished (Eq. (18)). If production is finished we can use Eq. (19) instead. As we observe the workload of a single piece of equipment (e.g. specific machine or tool), it may perform many production operations during certain time frame (e.g. month). If the number of production operations is n, then total equipment downtime T_D (during selected time frame) is:

$$T_D = T_{max} - \sum_{i=1}^{i \leq n} t_{Ui} \; , \tag{20}$$

where t_{Ui} represents actual uptime of i-th production operation and T_{max} denotes maximum workload for the selected time frame. T_{max} is calculated by multiplying work hours of a shift by the number of shifts and the number of days in a certain time frame. In addition to total downtime, actual downtime t_D can be registered along with a downtime reason. This allows defining the nature of actual downtimes. Theoretically, a sum of actual downtimes t_{Di} equals total downtime defined in Eq. (20), but in reality theoretical value is greater or equal (it depends of registration methods and precision):

$$T_D \geq \sum_{i=1}^{i \leq n} t_{Di} \; . \tag{21}$$

As T_{max} consists of uptime (all setup times plus all production times) and downtime, a percentage of productive and unproductive time can be calculated as well:

$$\pi_U = \sum_{i=1}^{i \leq n} \tilde{t}_{Ui} \Big/ T_{max} \; ; \tag{22}$$

$$\pi_D = 1 - \pi_D \; . \tag{23}$$

Productive time π_U (effective uptime) and unproductive time π_D (ineffective uptime and downtime) percentage can be expressed using a single progress bar. In Fig. 6 two situations are illustrated. The bar on the left is always green and indicates productive time percentage. The bar on the right represents unproductive time and changes color respectively if unproductive percentage is above or below set threshold. Bar is orange when it is above the unproductive threshold (Fig. 6, a) and red otherwise (Fig. 6, b). Material and work time consumption effectiveness values are given as text when hovering cursor over the bar.

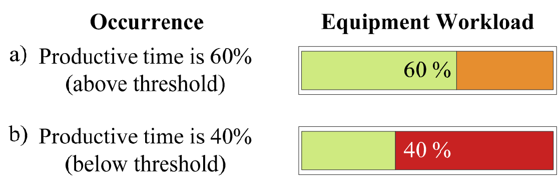

Fig. 6 Equipment workload visualization

It is important to note that material status and external manufacturing monitoring is designed for personnel that supervise manufacturing process. Internal manufacturing and equipment workload monitoring is intended for both – staff using the equipment and supervisors.

4. Implementation and results

Suggested methods were implemented in Lithuanian manufacturing company Stevila Ltd. This company specializes in CNC machining. It was founded in 1997 and has over 130 employees by now. Stevila employs 22 CNC turning lathes, 13 CNC milling machines as well as non-computerized traditional metal-working machines.

4.1. Requirements and conditions

Proposed methods were integrated into company's centralized management system. System architecture is based on client-server model. In this case server is DBMS (database management system) and client is a software module. Modules were developed using Microsoft .NET framework which defines the following requirements for software implementation: Windows XP (or newer) operating system, Microsoft MSSQL Server 2005 (or newer) DBMS, and Microsoft .NET 2.0 (or newer) framework.

Supervisors monitored the process from their office using standard personal computer setup. Personnel using the equipment in the manufacturing plant accessed information from computers with LCD displays, which, in general case, can have specific setup (additional protection from hazardous environment, minimized input devices, e.g. barcode scanner instead of keyboard, touchscreen).

Presented measurement visualization methods do not improve manufacturing performance, but they allow personnel to monitor the process in order maintain certain performance level. Therefore, it is important to discuss human factor. Leaving aside intrinsic motivation, extrinsic motivation is necessary to stimulate the improvement of personnel effectiveness, which results in better overall performance. Stevila Ltd. employed financial bonus system whenever employee's salary was based on his qualification and productive work hours. Thus, employee was interested in improving his qualification (increasing effectiveness) and reducing unproductive time (reducing equipment downtime).

4.2. Outcome analysis

MPM and EWM methods were implemented into existing software (itMecha) in December of year 2010. The performance evaluation period involves first halves of three years from 2010 to 2012. Six months were selected to avoid data discrepancies because of the seasonal nature of market.

Implementation of new visualization methods has affected company's ability to perform manufacturing in timely fashion. If manufacturing meets a deadline or is finished up to eight days earlier it is considered to be performed on schedule. Finishing production before or after that period is considered faulty. Fig. 7 illustrates percentage values of manufacture projects that were finished within tolerated period. Illustration denotes monthly totals. There are tree bars at six month positions from January to June. The first bar indicates the values of year 2010, the second bar denotes the values of year 2011, and the third one reflects the values of year 2012. As visualization methods were integrated into the company's software in the end of 2010, the first bar illustrates situation before the implementation.

It is clear that information visualization allowed supervisors to track process more easily and to react more effectively. According to the given figure, the percentage of timely production has increased by several percent (in the worst case 1%, in the best case 33%). The average improvement reaches 14.3%.

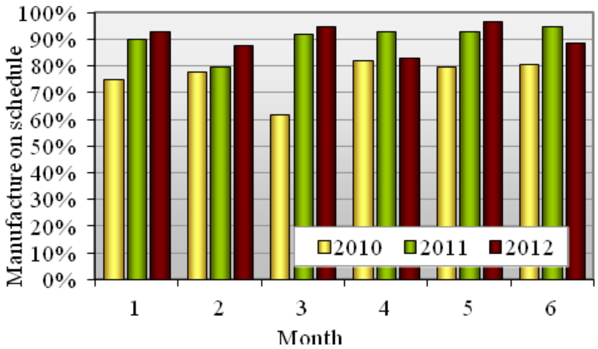

Fig. 7 Overall manufacture on schedule

Equipment workload analysis was carried out on the basis of productive work time percentage. Total work hours of 22 mostly used machines were taken into account and productive time values were derived by using Eq. (22). Acquired average values are given in Fig. 8.

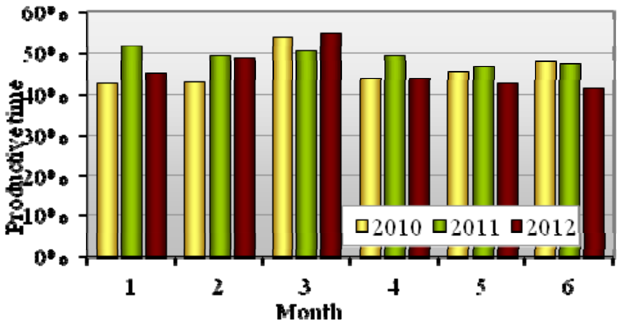

Fig. 8 The productive time of equipment

Fig. 8 illustrates slight variation of productive time value since the implementation of visualization methods (year 2011 and year 2012). Unfortunately, no considerable improvement was detected. Average values for entire 6 month period are given in

Table 2 along with average manufacture on schedule percentage values.

Table 2

Performance measurement comparison

Year (first half)	2010	2011	2012
Manufacture on schedule	76.3%	90.5%	90.8%
Productive equipment time	46.4%	49.3%	46.4%

Percentage values given in

Table 2 column 2010 represents situation before suggested methods were implemented. It is obvious that manufacturing performance was improved greatly by supplying supervising staff with new visualization tools. Timely production rates were increased from 76.3% to 90.5% in year 2011 (improved by 14.2%) and to 90.8% in year 2012 (improved by 14.5%).

The productive time of equipment was slightly improved in year 2011 (improved by 2.9%), but went back to its previous state in year 2012 (improved by 0.0%). So, average improvement is 1.5%. Extrinsic motivation system, whenever employee salary is based on productiveness was used throughout all period of an experiment. Clearly, visualization tools acting as intrinsic motivation stimulator provided little contribution to the productivity. There may be other reasons that didn't allow further improvement, like lack of production orders, change of personnel, and etc. Despite this fact, implemented methods introduced more transparency into process monitoring.

5. Conclusion and discussion

In this paper real-time manufacturing progress monitoring and real-time equipment workload monitoring methods were presented. Mentioned methods extract important information from the manufacturing process and display to a user by means of visualization. Visualization helps user notice critical process related occurrences so he or she may react accordingly.

According to the output of the experiment performed in Stevila Ltd. during the period of three years, implemented methods had considerable impact on staff effectiveness improvement in supervision level. Better resource management led to overall manufacturing performance improvement. The amount of timely production was increased by 14.3%.

Implemented tools had little effect on the productivity of staff working with manufacturing equipment. Productive work time was increased only by 1.5%. So, direct improvement to employee performance is slight, but indirectly measurement visualization makes manufacturing process more transparent and allows supervisors to detect issues, prevent problems, improve resource quality, modify strategy, while monitoring the results, and so on.

Naturally, because of a human factor outcome is prone to variation. Methods do not guarantee that supervisors will make correct decision at the correct time and employees will work more productively just because of visual information output. Like in a case of any other tool, its usefulness depends on the user employing it. Future research includes further research in motivation strategies applicable with presented methods.

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I. Senkuvienė, K. Jankauskas, H. Kvietkauskas

GAMYBOS PROCESO VEIKLŲ MATAVIMO IR VIZUALIZAVIMO METODAI, LEIDŽIANTYS PADIDINTI GAMYBOS PROCESŲ EFEKTYVUMĄ

R e z i u m ė

Straipsnyje aptariami nauji gamybos proceso veiklų matavimo ir vizualizavimo metodai, padedantys personalui greičiau reaguoti į gamyboje iškylančias problemas ir teigiamai veikiantys gamybos procesų efektyvumą. Siūlomi kompiuterizuoti veiklų matavimo ir vizualizavimo metodai apima gamybos eigos (vidinės ir išorinės medžiagų logistikos, vidinės ir išorinės gamybos eigos) bei įrenginių apkrovimo (produktyvaus ir neproduktyvaus darbo laiko, darbo našumo rodiklio) atvaizdavimą realiu laiku. Metodai buvo įdiegti 2010 metų pabaigoje įmonėje „Stevila“. Analizuojant 2010, 2011 ir 2012 metų rezultatus nustatyta, kad pasiūlyti metodai leido nemažai pagerinti gamybos terminų įvykdymo rodiklius. Taip pat nustatyta, kad pasiūlyti vizualizavimo metodai daro gamybos procesą skaidresnį, padeda aptikti problemas ir suteikia informacijos, kaip tobulinti gamybos procesus.

I. Senkuvienė, K. Jankauskas, H. Kvietkauskas

USING MANUFACTURING MEASUREMENT VISUALIZATION TO IMPROVE PERFORMANCE

S u m m a r y

Paper discusses how manufacturing process can be measured and represented visually in order to help employees react quickly to new occurrences that may compromise effectiveness or production process itself. Suggested measurement and visualization methods include real-time manufacturing progress monitoring (internal and external logistics of materials, internal and external manufacturing progress) and real-time equipment workload monitoring (productive and unproductive work time, resource consumption effectiveness). Methods were implemented in Stevila Ltd. in the end of year 2010. According to result obtained in 2010, 2011, and 2012, proposed methods proved to be very effective in increasing production on schedule rates. Also, experiment indicates that equipment workload visualization makes manufacturing process more transparent, helps identifying issues and provides information that is vital for process improvement.

Keywords: ERP, real-time performance monitoring, measurement visualization, human behavior, CNC.

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