SELECTING THE RIGHT KPIs FOR SMEs PRODUCTION WITH THE SUPPORT OF PMS AND PLM

Sergei Kaganski, Aleksei Snatkin, Marko Paavel, Kristo Karjust

Department of Machinery, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia
Email: sergei.kaganski@outlook.com, aleksei.snatkin@ttu.ee, marko.paavel@ttu.ee, kristo.karjust@ttu.ee

ABSTRACT:

The finding right metrics and monitoring them can provide companies with additional benefits. Continuous study of indicators promotes enterprises with regular development and innovation aspects. The main objective of this study is to analyze the influence of key performance indicators (KPI) for product life management (PLM) and production monitoring systems (PMS) on production efficiency and on profit of small and medium sized enterprises (SME). The amount of different KPIs nowadays is very large and it causes difficulties for enterprises to make the right choice, what to measure and how to collect the data. PLM and PMS can provide managers and engineers with necessary information and KPIs, which are constrained by PLM and Monitoring, can reduce the amount of unwanted data to zero. During the study, the package of benefit KPIs would be created.

Keywords: Key Performance Indicators (KPI), Productivity, Effectiveness, Product Lifecycle Management (PLM), Production Monitoring System (PMS)

1. INTRODUCTION

The objective of this paper is to give an overview of existing KPIs, their structure and dividing by groups. Additionally to show, how KPIs are connected to PLM and PMS and how those two processes can help to choose right package of KPIs for companies.

Measurements are important; they are showing to managers the problematic points and are helping to solve different issues for getting benefits. It is substantial for companies to figure out the pertinent indicators, clarify how they are connected to the formulated goals and how they rely on the performed activities [1].

The main purpose of measuring is to compare the previous data to new and to make the right conclusions for improving and revising the processes in enterprises. However, to know exactly, what measurements should be done, managers should know not only what common problems, questions and situations are appearing in SME processes in different fields (not only production, there are also logistic, quality etc.) but exactly the main problems in THEIR enterprise. On the one hand, is good to have theoretical base, on the other hand, is better to know that situations in practice are on different level, that the theory was describing them. Watt has distinguished following steps in the risk management process, which should be taken into account by managers [2]:

- Establishing the SMEs risk strategy;
- Determining the SMEs risk appetite;
- Identification and assessment of risk;
- Prioritizing and managing risk.

However, Small and medium enterprises (SME) have thoughts, that they should not monitor systems/processes and also won’t spent time for searching of performance indicators, that should be studied and improved. If we try to find the answer, why it is so, then one of the general reasons is the lack of skilled educated workers, managers, since large companies, factories are aiming for specialists with university degree [3]. According the report, which was done by Institute of Chartered
Accountants in England and Wales (ICAEW Institute of Chartered Accountants in England and Wales) in 2004, the gap between skills and regulatory barriers were choose the strongest barriers (“staff skills “17% of pollee and “general management skills” 16% of pollee [4].

2. KEY PERFORMANCE INDICATORS

According to different authors, KPIs can be defined in different ways. First of all, we will make clear, what is performance measurement-if we know the processes then is easier to define indicators.

Performance measurement is, first of all, the ongoing monitoring and secondly, reporting of project accomplishments, notably progress toward predetermined goals. Typically it is performed by a program or management. [5]

The concrete representation of a volume, process flow, or outcome deemed relevant to the evaluation of performance. Additionally it is quantifiable and can be recorded. [6]

Performance measurement is regular process, which means the collection and reporting of data for showing what results were achieved. [7]

Nowadays, the definition has become complicated but the main point is the same-to measure and monitor the parameters that have direct impact on efficiency in company in general or separate processes inside it (production, sales, logistics etc.)

KPI are measurements that show the health of an organization and of its business development system. They combine firm’s goals and strategies to its incomes, outcomes and provide management with information of common condition: past, current, future. [8]

It is not enough just to measure; you should understand WHAT you are measuring. So the successful procedure should include next steps:

- Collecting the RIGHT (selected) information;
- Monitoring and collecting at the right time;
- Understanding the meaning of collected data and making improvements. Data should be useful and the meaning should be defined

Additionally, the ideal way to show that KPI are successful is to link them to the reasons, goals and visions of your company. Everyone can see the benefits that maintenance brings to the business when there is a clear connection between firm’s goals and activities, which are needed to achieve. [9]

3. THE STRATEGIES OF MEASURING AND FINDING RIGHT KPIs

The main problem faced by a typical manager is the right KPIs to be selected for the process. The amount of KPIs which are working in one enterprise shouldn’t work in other firms.

Many companies think, that they have found right KPIs and are measuring them, but like David Parmenter said: “There are many companies which measure different KPIs periodically, however, I can show them, that those measurements do not create changes, growth and regulation and have never been KPIs”. [10] It is a typical situation, when managers are trying to measure and calculate all, that can be measured/calculated although they do not understand exactly what they are measuring and why. Making the effect, that something is done and is doing also at this moment in this field, is pointless.

According to Eckerson [11], manager should pay attention to next characteristics that are standing for winning KPIs:

- Sparse: the less KPIs, the better;
- Drillable: Users can can go deeply into detail;
- Simple: the meaning of each KPI is clear;
- Actionable: Users know how to affect results;
• Owned: there is owner for every KPI;
• Referenced: Users can view background and context;
• Correlated: KPIs drive desired outcomes;
• Balanced: KPIs consist of financial and non-financial metrics;
• Aligned: KPIs don’t disrupt each other;
• Validated: Workers can’t come our the KPIs.

If the 10 characteristics are too many, then there is another way, which was proposed first by Doran (1981) [12]:

• Specific;
• Measurable;
• Attainable;
• Realistic;
• Time bound.

“S-M-A-R-T” is a fine way to spell KPIs, as this is a solid framework for making decisions about KPI selection. However, organizations still find themselves unsatisfied with the results of these techniques due to a misinterpretation of the term “relevant” (realistic) [13].

Talking about measuring and about characteristics, criteria that KPIs should possess, there is possibility to describe the measuring mechanism and process/data flow of KPI. Figure 1 is showing what exactly should be done by SMEs to determine indicators [14]. The process is similar to peoples’ health control procedure. According that, we can assert that the SMEs are living organism and the diagnostic is one of the important things.

The first step is to understand, that something is going wrong and something should be done to change the situation. However, is not necessary to wait till the situation will become worse even if at this moment all seems to be going well. No one knows, what would be tomorrow, so it is better to prevent than to repair/correct or treat. Considering the machines in production, the first step can be equal to monitoring processes.

For effective production, maintenance is normally delayed to prolong continual operational life of a system or component. This may be achieved only if remaining time to failure is known. And number of false alarms should be maximally decreased. The decision how early to detect the fault (forecast the failure) depends on the application specific prognostic perspective.

The second step is measuring process itself. Answer on questions: “What should be measured? In what state should the measurements be (dimensions)?”-should be funded.

The first two steps can be done with Production Monitoring and PLM systems. Monitoring systems would provide with information based on present and historical knowledge of production situation. The main tasks of a PMS are to collect, analyse and distribute data on/ from the shop floor. Diverse factors are considered when choosing a measurement method. Signals detected by the sensors are correlated with the process conditions. Collected signals can be evaluated by decision making tools in order to suggest appropriate action. Fault detection is conducted by use of neural networks, fuzzy logic or synergetic schemes. Data collected by the sensors is a vital part of predictive maintenance that seeks to reduce unplanned down-time. At the same time collected data should be abstracted using as an example performance indicators to make it more understandable and descriptive comparing to just presenting it as a raw data.

PLM can help to collect data about products and about pre-productions processes. PLM is a huge bundle of complex IT tools and applications which support digital design and manufacturing practices in several ways [15]. The main idea is to manage product and its lifecycle including items, documents and BOMs. It also supports analysis results, test specifications, environmental component information, quality standards, engineering requirements, changing orders, manufacturing procedures, product performance information, and component suppliers. Modern PLM system are capable for workflow management, program management, project control, features that standardize, automate and speed up product management operations [16].

PMS helps to close loops in Product Lifecycle Management. By providing needed information from manufacturing. In beginning of
life phase this information moves through system to development [17].

The third step is the analysis. Answer on questions: “How can we use the data to perform actions? What the data is meaning? If there no use for it, should we still measure it?” should be funded. If the measured data cannot be used for further, then there is no need to spent time on measuring. The right data should be collected and right things should be measured. The final step is to use analyzed data to improve the situation.

The Figure is cycle, so the process should be continuing even if the improvements were done and the situation was changed to better way.

4. CATEGORIZATION OF KPIs ON MANUFACTURING LEVEL ON BASE OF PLM AND PMS

For project managers, to achieve a maximum efficiency from using KPIs, is very important to categorize indicators according to where they should be monitored and by whom. The categorization process of KPI makes the picture clearer and helps to understand how the components of each group/division interact with each other. In the table 1, which is based on Roberts and Latorre categorization table, are presented deviation of KPI, on which level the monitoring should be done and how it should be done [18, 19]. Roberts and Latorre have categorized KPIs based on large enterprises, where global enterprise is divided into headquarters and factories/business units, which functionality and structure is based on structure of independent company but still they are subordinates of HQ. Considering Roberts and Latorre classification table 1 the table 2 for SME has been created.

![Figure 1: KPIs process flow in SME (adapted from [14])](image)

<table>
<thead>
<tr>
<th>Level</th>
<th>KPI</th>
<th>Designation</th>
<th>Frequency and Method Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>Cost</td>
<td>KPI 1</td>
<td>Using activity schedule and monthly cost reviews</td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>KPI 2</td>
<td>Using project programs. Monthly</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>KPI 3</td>
<td>Using agreed monthly audits</td>
</tr>
<tr>
<td></td>
<td>Profitability</td>
<td>KPI 4</td>
<td>Using activity schedule and monthly cost review meetings</td>
</tr>
<tr>
<td></td>
<td>Productivity</td>
<td>KPI 5</td>
<td>Using agreed monthly audits (Tonnage or units per month)</td>
</tr>
<tr>
<td></td>
<td>Defects</td>
<td>KPI 6</td>
<td>Using weekly and monthly quality audits</td>
</tr>
<tr>
<td></td>
<td>Cost predictability</td>
<td>KPI 7</td>
<td>Audit at monthly cost review meetings (HQ)</td>
</tr>
<tr>
<td></td>
<td>Time predictability</td>
<td>KPI 8</td>
<td>Audit at monthly project review meetings</td>
</tr>
</tbody>
</table>
Company

<table>
<thead>
<tr>
<th>KPI</th>
<th>Use agreed questionnaires and meetings at regular intervals to establish why the Client is dissatisfied. Monthly monitoring at HQ.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client satisfaction-product</td>
<td>KPI 9</td>
</tr>
<tr>
<td>Client satisfaction-service</td>
<td>KPI 10</td>
</tr>
<tr>
<td>Environment</td>
<td>KPI 11 Monthly</td>
</tr>
<tr>
<td>Investment in staff</td>
<td>KPI 12 Monthly</td>
</tr>
</tbody>
</table>

The table can be a base for every manufacturing enterprise; however, additional KPIs can be added.

In comparing to Roberts and Latorre classification, the main difference is the separation of manufacturing level. If we will look on manufacturing process, then generally, it can be divided into two levels or two main groups:

- Machinery (production lines, machine tools, cutters and etc.);
- Human Resource (HR) (here we will involve only shop floor workers);

Table 2: Classification on manufacturing level

<table>
<thead>
<tr>
<th>Main Level (Global)</th>
<th>Secondary Level (aim on production process)</th>
<th>KPI I</th>
<th>KPI II</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>Machine resource/phase</td>
<td>Process downtime</td>
<td>Produced defective units %</td>
<td>KPI1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Raw material yield</td>
<td>Performance rate of the machine</td>
<td>KPI2.1</td>
</tr>
<tr>
<td></td>
<td>Pre-Production Time</td>
<td>Defective materials %</td>
<td>MTBF, MTTR, Availability</td>
<td>KPI3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OFE, OTE</td>
<td>Pre-Production Time</td>
<td>KPI4.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OPE</td>
<td>KPI5.1</td>
<td>KPI6.1</td>
</tr>
<tr>
<td>Human resource</td>
<td>Revenue per employee</td>
<td>Mistakes per employee</td>
<td>KPI7.1</td>
<td>KPI7.2</td>
</tr>
<tr>
<td></td>
<td>Injury rate % of skilled workers</td>
<td>Absenteeism</td>
<td>KPI8.1</td>
<td>KPI8.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Satisfaction</td>
<td>KPI9.1</td>
<td>KPI9.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grievance</td>
<td>KPI10.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learning time</td>
<td>KPI11.2</td>
<td></td>
</tr>
</tbody>
</table>

For real time monitoring systems, considering the table 2, the important KPIs are in group KPI II. These KPIs would be studied during the research:

Table 3: KPIs for PMS

<table>
<thead>
<tr>
<th>KPI II</th>
<th>Real time monitoring systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Produced defective units %</td>
</tr>
<tr>
<td></td>
<td>Performance rate of the machine</td>
</tr>
<tr>
<td></td>
<td>Machines/tools downtime</td>
</tr>
<tr>
<td></td>
<td>MTBF, MTTR, Availability</td>
</tr>
<tr>
<td></td>
<td>OEE</td>
</tr>
<tr>
<td></td>
<td>Pre-Production Time</td>
</tr>
</tbody>
</table>
Downtime is one of important KPIs that should be measured and the manager’s goal is to reduce it. The reducing of downtime is one of the easiest ways how to increase profitability. Downtime can be divided into three indicators:

- Unscheduled downtime (hours);
- Scheduled downtime (hours);
- Shutdown overrun (hours).

Additionally, it is important to make difference between “machine/tool downtime”, where the machine is unable until the broken part will be replaced but the production itself is not stopped and “process downtime”, when all production is stopped. This is the main reason why downtime should be watched on two difference levels according table 1.

Mean time between failures (MTBF) is very useful, if enterprise has old machines and the appearing of errors is rising exponentially. This KPI can be used to predict the appearance of next failure, additionally, can help to make right time service of the machine. Taking into account the production monitoring systems that are available in our time, the electronic data (speed of the machine, bearing’s temperature, cutter temperature and etc.) received from them can be used for further analyzing.

If device is working under conditions beyond normal, for example: high vibration, load, etc. - MTBF will decrease. Additionally it may help to predict that failure will occur.

\[
MTBF = \frac{\text{Total Breakdown Time}}{\text{Number of occurrences}} \quad \text{(Eq. 1)} \quad \text{[22]}
\]

Mean time to repair (MTTR) is a metrics that can be used for measuring maintainability of repairable items. It is showing the average time required to repair machine or replace/repair component.

\[
MTTR = \frac{\text{Total repair time}}{\text{Number of occurrences}} \quad \text{(Eq. 2)} \quad \text{[23]}
\]

Availability is an aspect of system reliability that takes equipment maintainability into account. In turn, reliability can be defined as probability of successful maintenance or performance of systems and their related equipment, with minimum risk of loss or disaster or of system failure. Knowing MTBF and MTTR, availability can be calculated [24]:

\[
\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \quad \text{(Eq. 3)}
\]

Overall Equipment Effectiveness (OEE) is a measure of total equipment performance. The idea was born from TPM (total productive maintenance) concept launched by Nakajima (1988). OEE can be calculated

\[
\text{OEE} = \text{Availability} \times \text{Performance (P)} \times \text{Quality factor (Q)} \quad \text{(Eq. 4)}
\]

where:

\[
\text{Availability rate (A)} = \frac{\text{Operating time (hours)}}{\text{Loading time (hours)}} \times 100; \quad \text{(Eq. 5)}
\]

\[
\text{Operating time} = \text{Loading time} - \text{Downtime}; \quad \text{(Eq. 6)}
\]

\[
\text{Performance efficiency} = \frac{\text{Theoretical Cycle time (hours) x Actual output (units)}}{\text{Operating time (hours)}}, \quad \text{(Eq. 7)}
\]

\[
\text{Quality rate (Q)} = \frac{\text{Total Production amount} - \text{Defect Amount}}{\text{Total Production (units)}} \times 100; \quad \text{(Eq. 8)}
\]

\[
\text{Total OEE} = \frac{\text{Valuable operating time}}{\text{Theoretical production time}} \quad \text{(Eq. 9)[25, 26]}
\]

Pre-Production time like downtime should be looked on 2 different levels: from production point of view and from machines point of view. Considering the production, this is required time to start the production (time for preparation of needed documents + time for receiving needed components/materials + time that is needed to prepare machines and workers). On the second level, this is required time for prepare the machines (time for checking the condition of the machine + time for preparing workplace + time for preparing needed items).
Considering the PLM systems and our goal to investigate the influence of indexes on machinery level, KPIs should be connected to pre-production time. However, the indicators should show the time, which is required to prepare documentation.

5. CASE STUDY

The influence of productivity/efficiency KPIs on production and on company’s profit with the support of PLM and PMS will be analyzed. First of all, using the monitoring process (real time performance of the machines), necessary data would be received. The different sensors will be installed to different machine-tools to acquire information about voltage consumption, vibrations temperature etc.

Collected and correlated data will give early warnings of machine degradation or impeding accident and will provide input parameters for prognostics module of PMS. From a user’s point of view, warning to failure should be far enough to predict required actions ahead: for operators to prepare tools; for the purchasing department to order spare parts, for the logistic to deliver it etc.

The main challenge of prognostics is uncertainties that lead to inaccurate forecasts and false notifications which can cause incorrect decisions or even system failure. So designers of the system should develop such methods that are capable to handle uncertainties.

The monitored parameter features should exhibit wide separation between the failure and normal modes with low uncertainty. Otherwise monitored parameter may be wrongly interpreted.

Wireless sensors will be preferred. Wireless sensors can help to connect different equipment. Monitoring systems, based on wireless sensor nodes, are relatively inexpensive and it can be installed on old and modern manufacturing equipment [27]. Those sensors can eliminate the cost of cables and simplify the installation. Wireless monitoring is used rarely in the shop floors [28].

At the same time data on the shop floor can be collected by RFID technology, scanners, operators, etc. Understanding the detection process on the one hand, can eliminate the use of unnecessary devices, and on the other hand, can result in efficient use of real-time data.

Data received from the monitoring system information will be used for creation of the virtual model, which would show the efficiency of machines and could give the evaluation of production process on the whole. The main idea is to maximize the efficiency of production on the one hand and minimize costs on the other hand. Solving multi criteria task would be the priority of this study. Using Excel and Solver solution the background for further study would be created. After that the model would be used with real data of enterprise. Taking into account the suggested classification and package of KPIs in this paper, further studies would be done.

6. FURTHER RESEARCH

Taking into account, that there are different SMEs that are operating in different fields and with different finance opportunities, next questions should be answered:

- Which data should be collected first?
- How the data should be collected (holding in mind Real time monitoring systems)?
- How to handle received data? (connection between KPIs and other systems)
- What should be included in the virtual model?
- How to evaluate the influence of KPIs on profit and performance?

7. CONCLUSION

Considering the productivity issue (low productivity in SME), the measuring and improving of factories activities was and still remains the main research and is a real challenge to all enterprises and managers. KPI categorization and different strategies in finding the right efficiency indicators methods were described. Necessary KPIs on manufacturing level were chosen and described for further studies in more detail. The methodology and achieved results would be, first of all, a good base to further study in this field and secondly
the provided method and model can be used for other enterprises to achieve better productivity. Development of the maximization function of profit and efficiency based on table 2 has been foreseen as next task.

8. REFERENCES


