USING OEE APPROACH FOR IMPROVING MANUFACTURING PERFORMANCE

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Abstract: Competition and the drive for profit are forcing manufacturing companies to introduce different approaches for improving performance. Because of its holistic view, the Overall Equipment Effectiveness (OEE) approach is the best for managing operations in the context of cost and efficiency-focused manufacturing, while it gives managers the information where the equipment is loosing time. In this paper, the concepts of OEE approach together with the implementation framework are presented. OEE accepted as a key performance indicator and benchmark measure in several machine and asset-intensive industries, like semiconductor, electronics, pharmaceutical or food industry.

We can conclude from our experiences working with industry, that OEE is a very good measure for monitoring manufacturing performance if all key parameters are calculated automatically in real time directly from process data. This requirement can be fulfilled by using information technologies (IT), which provide process equipment connectivity. Using proper IT support, OEE approach provides systematic analysis of equipment utilisation, efficiency and quality. By continuous real-time OEE monitoring and prompt actions, management can drive the factory towards excellence in operational performance and lower production costs.

In the article, a conceptual framework for OEE is introduced using a systematic approach with information technology as an enabler. Based on literature and practical examples, the implementation life-cycle is discussed and critical success factors are outlined. OEE results are interpreted through an example of a packaging line over a one-week working period. Finally some important aspects of an OEE implementation are outlined and as a conclusion, the benefits of using OEE in manufacturing companies are described.

Izboljševanje proizvodne učinkovitosti s spremljanjem skupne učinkovitosti OEE

Kjučne besede: Merjenje učinkovitosti, Izboljševanje proizvodne učinkovitosti, Ključni indikatorji proizvodne učinkovitosti, Skupna učinkovitost

Izvleček: Večina proizvodnih sistemov v praksi izvaja proizvodne procese pod pričakovanimi. Pogosto obratujejo z manjšim obsegom proizvodnje, nižjo produktivnostjo in višjimi stroški. Ker so proizvodna podjetja nenehno pod pritiskom po stalnem zviševanjù proizvodne učinkovitosti, so se prav v proizvodnem okolju izoblikovale številne managerske metode oziroma pristopi za povečevanje kakovosti in produktivnosti. Ena izmed tovrstnih pristopov je tudi izračunavanje in spremljanje celovita učinkovitost opreme OEE, ki obravnava (učinkovitost) proizvodne opreme na osnovi izračunavanja razpoložljivosti, zmogljivosti in kakovosti. Ta pristop je zelo razširjen v visoko-intenzivnih avtomatiziranih industrijskih panogah, med katere sodijo elektronska industrija, živilska industrija, farmacija in druge.

Iz lastnih izkušenj lahko povzamemo, da je OEE zelo dobro merilo za spremljanje učinkovitosti proizvodnega procesa ob pogoju, da se ključni podatki izračunavajo v realnem času. To zahtevo je mogoče izpolniti z uporabo informacijskih tehnologij, ki zagotavljajo povezavo s proizvodnimi napravami. Ob ustrezni informacijski podpori, OEE metodologija zagotavlja transparentno obravnavo vzrokov za neučinkovitosti in na tak način predstavlja dobro orodje proizvodnemu managementu za sprejemanje ukrepov v smeri večje učinkovitosti tako proizvodne opreme kot celotne tovarne.

V prispevku je predstavljen konceptualen okvir, ki odgovarja na vprašanje, kako se na standardiziran (sistematičen) način lotiti obvladovanja (ne)učinkovitosti in kako pri tem čim bolj učinkovito uporabiti informacijske tehnologije. Na osnovi strokovne literature in primerov iz prakse so opisane ključne točke implementacije, ki podjetjem zagotavljajo rezultate. V zaključku bodo predstavljeni tudi učinki, ki jih proizvodna podjetja lahko dosežejo z uporabo opisanega pristopa.

1. Introduction

Recent trends indicate that many manufacturing processes are not performing as intended, so far as cost effectiveness in terms of their operation and support is concerned. They often operate at less than full capacity, with low productivity, and the costs of producing products are high. To manage the manufacturing (operational) performance, different approaches can be used. Among them, Overall equipment effectiveness (OEE) derived from Total Productive Maintenance (TPM) /14,2/ is considered as most widely used set of performance metrics to analyse the efficiency of a single machine or an integrated manufacturing system (Hansen, 2001). It provides the answer how well the manufacturing equipment is running compared to the ideal plant.

OEE is a function of availability (operating rate), performance rate, and quality rate. The three dimensions are measures of the equipment losses. Nakajima (1988) defined six major loss categories: i.e. breakdown losses, set-up and adjustment losses, minor or idling stoppage losses, reduced speed losses, defect or rework losses and start-up losses, that have direct impact on manufacturing performance and consequently also to operational costs. By reducing or eliminating losses, the management is able to maximise productivity and optimise operational costs.

OEE is especially suitable for equipment-intensive manufacturing where capacity utilisation is a high priority and downtimes are expensive in terms of lost capacity /9/ . Because of its holistic view, OEE is the best for managing operations in the context of cost and efficiency-focused manufacturing, while it gives managers the information where the equipment is loosing time. It is a way to benchmark and provide a quantitative feedback on equipment efficiency. The biggest enabler for getting OEE accepted as a management tool in practice is the development of highly automated production equipment and IT technologies, which enable automatic data collection, such as downtime events, scrap, etc. and leading to the OEE calculation in real time.

As reported by MESA International, OEE is accepted as one of the standard KPI (i.e. Key Performance Indicator) for benchmarking in several machine and asset-intensive industries, such as electronics equipment, semiconductor, medical device, pharmaceutical, food and automotive. In 2001 SEMATECH, the consortium of semiconductor manufacturers, reported that the relative importance of OEE improvement in semiconductor industry has grown significantly and is expected to require 9-15% increment per year in order to stay on the productivity curve /10/. It was noted, that the complete semiconductor industry must move toward highly efficiently factories. A major effort already underway for OEE improvements has been done in collaboration with SEMI (Semiconductor Equipment and Materials International) and resulted in creation of several guidelines and standards (e.g. E10, E79). Based on OEE research conducted by Leachman /7/, SEMI issued a revised standard for measurement of overall equipment efficiency for semiconductor industry /11/.

While machine and assets-intensive industries have used this metric for quite some time, now managers in discrete industries are adopting it (modify it) by making it less equipment specific and introducing labour and assembly operations, OEE becomes more plant-wide representing Overall Factory Effectiveness /6/.

The paper is organized as follows. First a definition of the OEE metrics is given, then it is explained how OEE can be used for driving manufacturing improvements. The third section will present the framework for OEE implementation. At the end, some open questions about OEE approach implementation will be discussed and conclusions will be given.

2. About OEE approach

OEE is a very simple set of metrics to indicate the current status of a manufacturing process and also a complex tool allowing managers to understand the effect of the various events in the manufacturing process. Although OEE is seen to be defined as standard metrics, it still requires further modification on classification of losses. A number of authors have written about the definition and measurement of OEE /5,8/. Dal et al. /3/ described that OEE appears differently in various OEE literatures because the levels of OEE measurement and the factors affected are different in various business sectors and industries. Thus, a customized OEE in different industries or business sectors is required. The standard OEE metrics background is described in the following section.

2.1 OEE metrics definition

From the OEE point of view, the equipment efficiency is lower than the expected full potential, because of equipment availability and utilization losses: such as breakdowns, setup and adjustments (i.e. downtime losses), speed losses, small stops, idling (i.e. performance losses) and product scrap, low product yields (i.e. quality losses). The role of management is to maximise effective operating time for each single piece of equipment while at the same time reducing or eliminating losses /6/.

The basis for OEE calculation is scheduled operating time which indicates the overall time scheduled for production without time for breaks, lunch, planned preventive maintenance or periods, where there is nothing to produce. The effective operating time is then calculated from scheduled operating time as represented graphically in Figure 1.

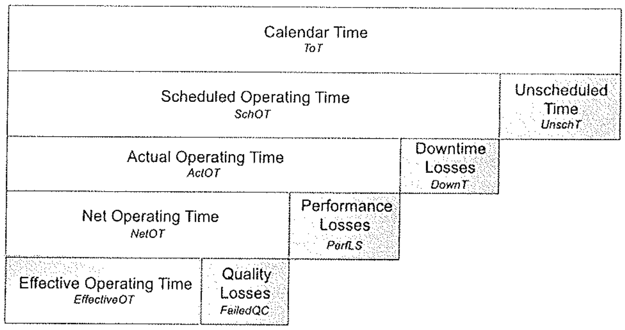

Fig. 1: Schematic representation of Effective Operating Time calculation

The impact of different types of losses to manufacturing performance of a single piece of equipment is measured through calculating its **Operating rate**, **Performance rate** and **Quality rate** /4/.

Operating rate or **Availability** (in %) quantifies equipment downtime and operating time. Downtime loss includes any event that stops planned production for an appreciable length of time. Examples include equipment failures, material shortages, and changeover time. They can be classified as planned (e.g. set-up or changeover time) or unplanned (e.g. equipment failures). Operating rate is calculated as follows:

$$Or(\Delta T)=\frac{SchOT(\Delta T)-DownT(\Delta T)}{SchOT(\Delta T)}=\frac{ActOT(\Delta T)}{SchOT(\Delta T)} \quad (1)$$

where $DownT(\Delta T)$ is referred to the total time that equipment is not available for production and $SchOT(\Delta T)$ to scheduled operating time, both calculated for observed production time period ΔT.

Performance rate (in %) takes into account speed loss, which include any factor that cause the equipment to operate at less than the maximum possible speed, when running. Examples include machine wear, poor materials and operator inefficiency. Performance rate is calculated as follows:

$$\Pr(\Delta T)=\frac{Mp(\Delta T)}{ActOT(\Delta T)\cdot NomCp(\Delta T)} \qquad (2)$$

where $Mp(\Delta T)$ is referred to total production in observed time, $ActOT(\Delta T)$ to actual operating time and $NomCp(\Delta T)$ to nominal equipment capacity, all calculated for observed production time period ΔT.

Quality rate (in %) is a measure of process yield, determining the amount of product that meets quality requirements the first time without adjustments, recycles and so on. It is calculated as follows:

$$Qr(\Delta T)=\frac{Mp(\Delta T)-FailedQC(\Delta T)}{Mp(\Delta T)} \qquad (3)$$

where $Mp(\Delta T)$ is the total production in observed time and $FailedQC(\Delta T)$ the quantity of scrap and rework (product). The measurement of quality losses is restricted to quality losses that are immediately recorded.

The calculation of basic equations defined by (1), (2) and (3) is simple for equipment which is designed to execute only one operation. For cases, when two or more operations can be executed on one type of equipment sequentially or in parallel, the observed parameters for all operations considering relationships factors are aggregated in a separate equation /7/.

Overall equipment effectiveness (in %)

To combine all three measures, the metrics for calculating overall performance (OEE) of a single piece of equipment (i.e. machine or line) is defined as:

$$OEE(\Delta T)=Or(\Delta T)\cdot \Pr(\Delta T)\cdot Qr(\Delta T) \qquad (4)$$

where ΔT is referred to the observed production time period. As such, OEE is measured in percentages (%) and indicates the overall equipment effectiveness. In addition to the basic formula, some authors /2/ argue to use different weights for factors Or, Pr and Qr, while they are not equally important in all industry sectors. Weighted OEE metrics is defined as follows:

$$OEE(\Delta T)=w_1\cdot Or(\Delta T)\cdot w_2\cdot \Pr(\Delta T)\cdot w_3\cdot Qr(\Delta T) \qquad (5)$$

where w_i, $0 < w_i \le 1$ represents the importance weights for each individual OEE parameter.

Overall factory effectiveness (in %)

OEE metrics defined by equations (4) and (5) are about achieving excellence in individual equipment. However, successful analysis of individual machine OEE's only is not sufficient, as no machine is isolated in a factory, but operates in a linked and complex environment. Overall factory effectiveness (OFE) is about combining activities, the relationships between different machines and processes, integrating information, and the decisions and actions across many independent systems and sub-systems. Several different approaches to OFE can be found in the literature /6/. The most common and simple ones are **straight average** and **weighted average methods**.

Using straight average method, OFE metrics for the entire plant is calculated as a product of average values for Or, Pr and Qr as follows:

$$OFE(\Delta T)=\frac{\sum_{i=1}^{N} Or_i(\Delta T)}{N}\cdot\frac{\sum_{i=1}^{N} \Pr_i(\Delta T)}{N}\cdot\frac{\sum_{i=1}^{N} Qr_i(\Delta T)}{N} \qquad (6)$$

where N is the total number of equipment with OEE measuring.

Weighted average method is using weights for separate piece of equipment and it is calculated as follows:

$$OFE(\Delta T)=\frac{\sum_{i=1}^{N} w_i\cdot Or_i(\Delta T)}{\sum_{i=1}^{N} w_i}\cdot\frac{\sum_{i=1}^{N} w_i\cdot \Pr_i(\Delta T)}{\sum_{i=1}^{N} w_i}\cdot\frac{\sum_{i=1}^{N} w_i\cdot Qr_i(\Delta T)}{\sum_{i=1}^{N} w_i} \qquad (7)$$

The weights can be set-up using plant production time, equipment importance for production, etc. Both approaches for OFE calculation do not include information on different types of equipment connections and dependencies. More sophisticated approaches incorporate also a so called equipment coordination factor /6/. Because of their complexity, these approaches are not widely used in practice.

The fundamental concept of OEE is not new. By evolution of new production management strategies, such as lean manufacturing /13/ along with high-technology production equipment and developments in information technology (IT), the OEE principles are finding wider application in the industry.

3. OEE implementation

OEE implementation is connected with two important issues: how to use OEE as a management tool and how to get accurate data for OEE metrics calculation. The second issue is covered by using appropriate IT, while the first one has a business context.

3.1 OEE as a management tool

OEE approach concentrates around activities needed for systematic improvement of production equipment and consequently business results. There are several ways, how managers can use it as a business tool. The most common way is to use OEE as a systematic approach to run actions for improving manufacturing performance. Quite often, the OEE indicator is also used for benchmark purposes and to drive business decisions /9/.

a. OEE as a systematic approach to run (continuous) actions for improving manufacturing performance

The main objective to measure OEE is to make constraint or bottleneck equipment run more efficiently. OEE and its individual factors can provide managers real-time information to see where the equipment is loosing performance, i.e. if it has much downtime or speed losses or if the quality is poor. If the OEE score is below an acceptable benchmark, the analysis of its three components can direct the attention of managers toward downtime and other indicators of poor performance, determine their causes and rectify them. Downtimes are associated to categories, therefore reasons and sub-reasons have to be associated. In this way, the manager is able to properly analyze downtime categories. The managers' focus should not be on a snapshot for a single day, but rather to monitor the trends in real time and see if improvement efforts actually make the equipment run more effectively.

b. OEE for benchmarking

Managers can use OEE indicator to benchmark or analyze it across similar plants to identify best practices /3/. By comparing the historical and current index against these benchmarks, managers can gain valuable insights into the effectiveness of their capital assets (production equipment), identify bottlenecks and make investment decisions.

According to the literature /9/ the average OEE (ΔT) score for production plants is approximately 60% and the best OEE (ΔT) is generally considered to be 85% for batch and discrete production plants ($Or \geq 95\%$, $Qr \geq 95\%$ and $Pr \geq 95\%$) and even 95% for continuous ones /1/.

c.OEE for supporting business decisions

OEE can be used with financial metrics such as return on capital employed (ROCE), to make decisions on whether to keep a plant open, close it, invest in it, or consolidate it with another operation /3/.

In all three cases, input data quality for calculating OEE metrics is the most critical factor to accept OEE approach as a management tool that brings results. Traditional approach to OEE is based on manual data entry of downtime events by operators into a specialised software application. This approach does not guarantee complete and accurate input data. The evolution of high-technology production equipment and IT development bring the so called "bottom-up" approach centred on raw process data acquired from process control equipment or SCADA systems /12/. By using specialized OEE software products, which leverages modern technology for real-time data collection, raw process data are automatically evaluated based on predefined fault models and OEE metrics are calculated and displayed to the managers. The specialized OEE solution providers are mainly global companies developing software for process automation and control, such as GE Fanuc and Siemens. The main strength of this approach is that all required data are acquired automatically from the process in real time and can provide also automatic reasoning about downtime causes.

3.2 Implementing OEE using information technologies

Implementing OEE using IT technologies is considered as a classical software-project approach with its own life cycle. The major stages are the following:

- **Requirements and system analysis.** Each OEE project starts with the requirements definition and extensive analysis from the equipment and efficiency point of view.
- **Downtime modelling.** Based on requirements and analysis, downtime model for each production component (under OEE study) is defined. The downtime model represents the relations between observed raw process data, downtime events and the root cause (or causes) of downtime. The relations can be expressed in terms of expert rules or decision AND-OR trees, or by using other known modelling techniques (for example qualitative modelling approach). The model complexity increases in case of more interconnected devices, while their interdependence represents another dimension of the model. It is important to realise, that the accuracy and completeness of the downtime model plays a key role in correct downtime detection and classification.
- **OEE system specification and design.** The purpose of the specification and design phase is to propose a complete solution to the OEE by taking into account the aspects investigated in the previous stages, which is feasible for implementation.
- **Implementation.** Implementation is often done by using specialized configurable and modular OEE software products, which covers the following functional segments:
    a. **Process data collection.** Standard interface for automated production equipment, i.e. a single machine or production line, provides automated collection of raw process data to process historian in real-time. Examples of raw process data are equipment operating condition (i.e. produc-

tion line is working, production line is stopped, etc.), initial and end time of downtime, downtime location, produced product quantity, scrap, etc.

b. **Downtime detection.** Using raw process data, pre-defined downtime models are evaluated in a real-time. Downtime events are stored to the relational data base automatically together with the time stamps for start and end.

c. **Classification.** First, OEE system tries to identify the root cause (or causes) for downtime automatically from the model. If not possible, the operator is able to define it manually based on pre-defined list of possible causes. This task can be done through a specialized application clients installed in the production floor. One example of such OEE production client can be seen at Figure 2.

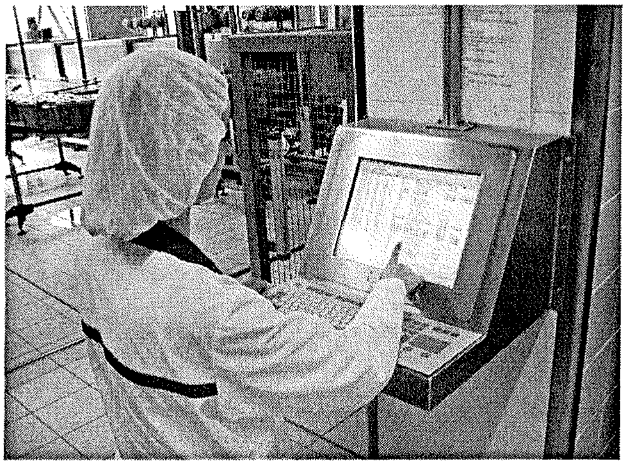

Fig. 2: OEE production client

d. **OEE metrics calculation.** Based on evaluated downtime events, data about produced products and scrap, OEE parameters are calculated along with the OEE metrics automatically. The calculation is triggered by an event, which is often production order start and production order end. These events are triggered manually by the operators or automatically by appropriate electrical signal, captured automatically from production line.

e. **OEE visualisation and analysis.** OEE indicators together with three separate parameters *Operating rate*, *Performance Rate* and *Quality rate* are displayed in a way to be understood by production managers in real time. The downtime analysis enables them to explore the causes that have generated production efficiency losses. In such a way, managers are able to understand where the factory bottlenecks are and which are the real downtime reasons, and allow them to react accordingly. Often, OEE monitoring is performed using web application client or modern communication devices such as GSM, PDA etc.

One example of such OEE visualisation client can be seen at Figure 3.

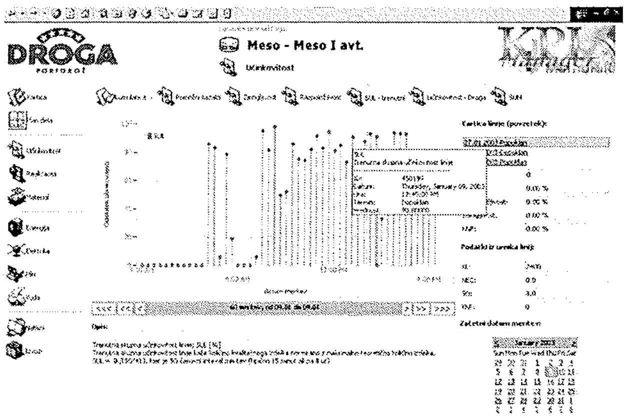

Fig. 3: OEE visualisation client

Such specialised OEE software product also fulfils IT requirements for reliability, scalability, ease-of-administration, security and low cost of ownership.

- **Maintenance.** Maintenance of OEE system is an unavoidable step in the cycle since any technological change to the production process equipment might involve the redesign of some parts of the OEE solution.

3.3 OEE interpretation through an example

To illustrate OEE concept, consider a packaging line for soft drinks scheduled to operate in two or three shifts starting at 6:00 a.m. Process data are collected and evaluated automatically with time period of 15 minutes. Downtime events are stored in a relational database together with identified the root cause (or causes) for downtime. As an example for downtime set records, the sample for a single day is shown in Table 1.

From industry practice, monitoring OEE per shift to improve operational shift performance shows good results. Therefore, operating rate, performance rate and quality rate are calculated along with the OEE metrics automatically per working shift. The OEE results for a week-time period are shown in Figure 4. The results show that the overall efficiency for packaging line goes from maximum 75% to lower values, while the average value is 35%. Figure 5 shows in detail all three parameters governing the OEE. The average value of performance rate *Pr* (40%) lead us to conclusion that only 40% of time was spent on actual production.

The analysis of *Or*, *Qr* and *Pr* results (Figure 5) can give us the a detailed interpretation for poor performance of this packaging line.

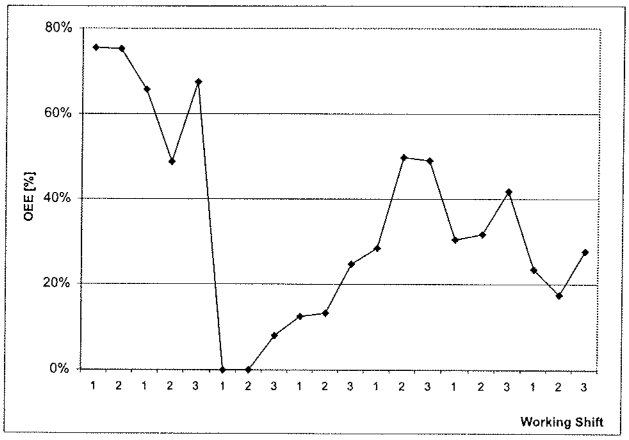

Fig. 4: OEE trends for packaging line calculated per shift in a week

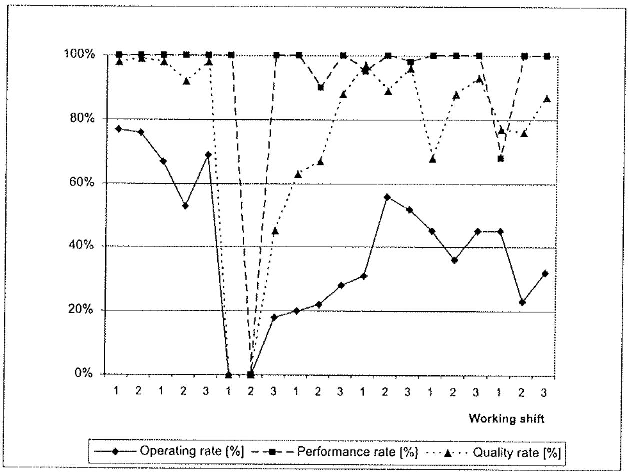

Fig. 5: Or, Qr and Pr results for OEE shown on Figure 4

Looking at the performance rate trend line, the value reaches zero during the third day. To analyse deeper, downtime records show that stoppage of packaging line was planned because of the product change. Changeover took time of two working shifts. Then production continued with the start-up phase and equipment tuning after it has been restarted. In this phase, the scrap quantity increased, while several short line stoppages caused by tuning resulted in low operational rate.

Further more, it can be seen from Figure 5 that the first two working days performance rate was higher than the last ones. Again, downtime analysis shows (see Table 1) that breakdowns of supporting systems and machine failure were the main reason for poor performance.

The overall performance rate trend shows that the total downtime (scheduled and not-scheduled) for packaging line is relatively big. This packaging line was not operational because of several not-scheduled reasons at average 2.4 hours per day, which can be classified in the following categories: problems between production (organizational problems), supporting systems breakdown, material shortage, machine failure, short automatic stops and not defined events. The Figure 6 shows which categories of downtimes had impact on operational performance discussed in this section. Product change (37%) and short automatic stops (30%) dominate among the downtime categories.

Table 1 One day sample of downtime records (the 6th day from Fig. 4 or 5)

Downtime	Total duration (min)	Error	Type
01-Product change	65,45		
08:43:57	26,88	116-Operator manual stop	scheduled
14:19:32	18,17	0001-Line is stopped	scheduled
15:06:53	17,40	0001-Line is stopped	scheduled
02-Loading	24,80		
08:16:52	2,02	0001-Line is stopped	scheduled
13:05:31	3,78	0001-Line is stopped	scheduled
03-Control procedure	10,38		
07:20:57	0,97	0001-Line is stopped	scheduled
10:44:34	3,42	0001-Line is stopped	scheduled
04-Problems between production	32,07		
08:08:13	0,22	0001-Line is stopped	non-scheduled
10:48:11	6,77	0001-Line is stopped	non-scheduled
11:48:00	12,42	112-Short disturbance	non-scheduled
07-Supporting systems breakdown	62,00		
05:45:23	14,60	0001-Line is stopped	non-scheduled
06:00:00	35,43	0001-Line is stopped	non-scheduled
99-Machine failure	65,54		
07:22:30	3,35	052-Filling machine	non-scheduled
07:27:06	1,15	052-Filling machine	non-scheduled
07:30:30	1,33	113-Tetra TOP machine is stopped	non-scheduled
07:32:36	0,67	113-Tetra TOP machine is stopped	non-scheduled
07:42:40	6,70	116-Operator manual stop	non-scheduled

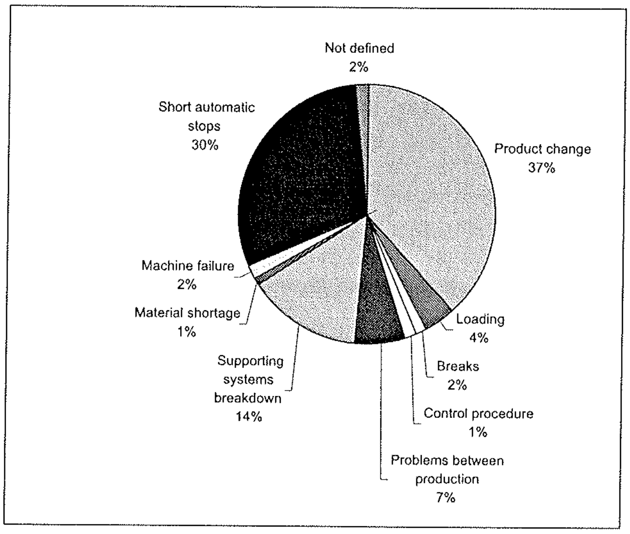

Fig. 6: Downtime categories relating to OEE from Figure 4

There are many ways to raise the OEE on this packaging line. Additional training of operators has already been implemented to minimize the downtime during the product change on the production line. Furthermore, organizational changes or technical improvements could be introduced. However, some of these improvements may raise additional investment costs.

4. Discussion

As described above, the concepts of overall equipment effectiveness for improving manufacturing performance are under constant development. By evolution of new production management strategies, along with the "bottom-up" OEE approach expansion, the OEE principles are becoming more and more accepted in the industry. Not only in semiconductor or electronic equipment industry, but in many other branches like pharmaceutical or food industry. It can be proved by several successful implementations that continuous monitoring of the OEE metrics; in relation with clear target values can have a strong impact on productivity. In spite of this fact, more than 60% OEE implementation failed or did not bring expected results to the production company /9/. As the OEE implementation is a complex engineering task, several reasons for implementation failures can be outlined and discussed.

It is often a case, that management business strategy does not drive OEE implementation. If managers are not involved in OEE project, they are not familiar with the OEE results interpretation and do not accept it as a support for systematic analysis of equipment utilisation, efficiency and quality.

Further on, pre-implementation preparation activities (system analysis and downtime modelling) are often poorly planned. First, understanding OEE concept and customised it suitable for the industry sector is important precondition for success. The second thing to be aware of is that incomplete knowledge about production process and equipment under OEE study leads to unreliable downtime models and therefore, do not correspond to the real process behaviour.

Several early OEE implementations were not successful because of using traditional approach to OEE based on manual data entry of downtime events by operators. The main reason can be found in incomplete and untrustworthy input data. Consequently, the OEE results can be misunderstood or does not give complete information about production. Another problem of this approach is flexibility. In every production environment, the changes of technology and equipment are frequent. If implemented OEE solution is not flexible enough to incorporate these changes on a fast and easy way, the upgrading can be very complicated, time consuming and also quite expensive.

And at the end, it is very important to finish OEE implementation in planed time period and budget. Often, the OEE implementation took much longer than expected and users were not well-prepared to accept and operate with the OEE solution. Such projects are often not successful.

5. Conclusions

The strength of the OEE approach is systematic analysis of equipment utilisation, efficiency and quality. Continuous real-time monitoring of the OEE metrics in relation with clear target values can have a strong impact on productivity and makes it possible to establish a relationship between performance measures and business objectives. In particular, it enables the reduction of downtime and rate losses by increasing equipment utilization. The main benefits are in optimizing equipment utilization, better working transparency, increasing quality by reducing scrap and reworks. These benefits have important impact to overall production costs optimization, especially in the maintenance segment.

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