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MODEL OF INTEGRATED SYSTEM FOR MONITORING AND INCREASING AVAILABILITY AND EFFICIENCY OF PRODUCTION EQUIPMENT

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Abstract: The purpose of this paper was to introduce a model for monitoring of production time and downtimes with increasing the availability and efficiency of production equipment. Methods and tools for improving efficiency and usability of production equipment are proposed. Tools for tracking the nature of downtimes are proposed, resulting in shorter time for collecting the data for the OEE analysis (Overall Equipment Efficiency) which is one of the key indicators of equipment efficiency. Proposed methods and tools are especially useful in productions where one worker is in charge of multiple production stations. With implementation of proposed tools higher availability, efficiency and usability of production equipment can be achieved. Also, collection of data for calculating effectiveness indicators has proven to be done much faster using the proposed tools than using established collection data forms.
Keywords: overall equipment efficiency, Andon, internet of things, calculation of OEE, production losses

INTRODUCTION

Today's advanced production requires innovation, flexibility and intuitiveness from manufacturers in order to keep up with the competition. With production development, in confluence with automatization, computerization and the quality, manufacturers are forced to constantly search for new ways to improve and track quality, reducing waste, and elevate profit. One of the approaches to reduce defects and improve quality is a lean production philosophy. Lean production philosophy is well known across the globe as a method which efficiently reduces waste in production, increases autonomy of employees, increases product quality, improves production control, elevates profit, decreases delivery time, increases satisfaction of customers and so on. One of the most important aspects of lean production is total productive maintenance (TPM) [1].

TPM concentrates on key aspects of production equipment: availability, reliability and efficiency. The main indicator of TPM is overall equipment efficiency (OEE) [2]. When calculated it can show us how reliable and effective our production equipment is. The higher the OEE is the more efficient our production is. Companies have to make sure that data needed to calculate OEE, key performance indicator of TPM, is collected as easily and as accurately as possible. This keeps worker motivation high which results in increased quality and true state of current level of production efficiency.

TPM has only recently gained greater attention because manufacturers had turned their attention to taking maintenance of the production equipment to a higher level. Authors of [2] recognized the importance of increasing the five performance objectives used by companies to stay competitive and maintain their market: speed, pricing, dependability, flexibility and quality. They agree that to achieve quality in all facets of manufacturing operations implementation of TPM is required. Authors examined the impact of TPM implementation on an organization in terms of productivity and quality levels. They also investigated human resource aspect to assess motivation of operators (through training) to reduce set up times, change over stoppages, defect rates and resource wastage on the shop floor. Needless to say, morale and a healthy and optimistic work environment greatly increase chances of successful implementation of TPM [3]. It is one of the most popular maintenance strategies to ensure high machine reliability since it is regarded as an integral part of lean manufacturing. One of the main objectives of TPM is to increase the overall equipment effectiveness of plant equipment with a modest investment in maintenance [4]. Production has many benefits from implementation of TPM such as improved effectiveness of performance of industrial organizations and enhanced financial position and competitively [5]. The crucial benefit of TPM is reducing non- value time. TPM can create value from both a business and an employee perspective. In the employee perspective, TPM reduces the risk of missing/forgetting areas of responsibility and creates more involvement [6].

Also, very important is the human role in the success of TPM. It does not require a huge amount of investment to achieve its purpose, however, companies have to make sure that workers who are conducting the actions behind TPM are well motivated, prepared, trained, and that information is available to them [7].

The role that effective maintenance management plays in contributing to overall organizational productivity has received increased attention. In today's process where almost every company has at least some aspect of lean production, the requirements for equipment availability are increasing. It's obligatory to have equipment which will satisfy the production needs. The ever growing and rigorous savings (material, tact time, set up time) are putting tremendous pressure on the production equipment. In such production, oriented to savings, it is very important to make the most of every available production capacity in order to stay competitive. The key factor is to achieve high level of three important production equipment characteristics: Availability, reliability and efficiency. If only one of characteristics is poor the production goals will suffer. Machines can be unavailable due to the scheduled maintenance activities or unexpected failures. For a successful company, machines are always required to work continuously to make more profit in a certain period.

With automatization, growth savings are visible on the human resources, as well. Workplaces are often optimized in a way where one worker serves multiple work stations. By work station it is implied the space handled by one worker. It is more often the case that one worker serves several machines. In such production, interruptions of production are frequent due to the need of the worker to set the machine in its proper working state, with all the needed materials and tools. Although calculations about work organization show that a certain number of workers are sufficient to a certain number of work stations. In practice, it is hard to accomplish the ideal work distribution. One of the reasons for that is poor awareness of workers about stoppages on work stations. Every moment, the worker has to have the complete and exact state of work stations in order to schedule his time in the most efficient way. Machines can be unavailable due to the scheduled maintenance activities or unexpected failures. For a successful company to maintain its highest working standards, machines are always required to work at optimum levels [8]. This can be achieved by implementing modern solutions based on wireless technology.

Wireless technology is already in use in production especially with the Andon tool (aspect of lean production) for detecting downtimes. Andon is a part of the lean production philosophy which goal is to alert or notify when there is a malfunction or failure in production. Its goal is to notify management, maintenance or other workers that a process has a quality problem, or that the process has stopped. Andon can be implemented as a light panel indicating state of production, screen with information about production lines, or in some other way. Modern Andon systems can include text, graphics, or audio elements. Audio alerts may be done with coded tones, music with different tunes corresponding to the various alerts, or pre-recorded verbal messages. In 2006 Li, J. S. and Blumenfeld, D.E. developed analytical models to study the performance of a transfer production line using Andon. They also investigated conditions under which Andon should be introduced and implemented. Authors showed that when average repair times are short, introducing Andon to stop the line and repair all defects on the line is an effective way to gain a high level throughput time of non- defective jobs [9]. Andon can be customized for any production, such as special construction lines with functions including monitoring. This system can effectively solve the flexibility problems of traditional Andon system in the changeable and special lines [10].

Taking into consideration the constant growth of manufacturing companies around the world, enterprises need to adopt new management methods, improve the market competitiveness, and reduce the production cost. They proposed intelligent manufacturing information management system which can make production process digital. With their implementation, the process accuracy has improved, labour costs have been reduced, and management efficiency has improved [11].

The term that has recently started to be used in such systems for connecting devices to the network is the Internet of Things (IoT). The IoT is a concept by which objects that are seemingly unidentifiable, can indirectly or directly collect, process and exchange data using the Internet. Recently, this concept has become a hot topic in science and industry can definitely benefit from it [12]. According to IoT uniquely identifiable things can indirectly or directly collect process or exchange data via Wide Area Network - the Internet. Research of the concept resulted in multiple new technology developments [12]. In 2011 Yang did an analysis and design mechanical production management system on an actual business process based on IoT. Their paper analyses the system's functional requirements combining the characteristics of production line [13]. IoT is currently an emerging hot technology at home and abroad, bringing significant changes to the production. The IoT also brings about unprecedented challenges for software, even the whole field of information technology [14]. With the rapid development of cloud computer concept and technologies, more and more cloud-based business modes and practical applications are emerging in industrial environments, including cloud manufacturing and cloud logistics. Under the IoT environment, it is possible to create and apply a cloud based production logistics [15]. IoT can find its use in many areas of production. For example, it can be used for Just In Time (JIT) Milk Run

(MR) which makes iterative route planning based on the real-time execution dynamics to realize adaptive control of MR dynamics [16].

2. OVERALL EQUIPMENT EFFICIENCY DATA

The key tool or the key performance indicator for equipment efficiency and productivity in terms of TPM is OEE (overall equipment efficiency). By calculating OEE one can determine how efficient and how available his production equipment is, based on total available production time. OEE can be used to measure the equipment efficiency in order to evaluate state of production availability [17].

Table 1 – Data needed for OEE analysis

No.	Type of data	Description
1.	OEE time period	This is the period in which collection of data is carried out, usually 3 to 8 weeks. The longer the period the more accurate the data is.
2.	Information about workplace	Is the analysis conducted on one or several machines or production lines? If production line has several independent units, the analysis has to be made on each of them.
3.	Information about workpiece	Will the monitoring and collection of data be only on one type of workpieces or will the workpieces vary?
4.	Number of shifts	It affects calculation significantly if the number of shifts is not compensated in the calculation.
5.	Working hours per shift	Some companies prefer six-hour working shifts and some ten hours, so it needs to be entered correctly.
6.	Machine or production line tact	It is the vital information for the analysis considering that the calculation is based on the production tact. It is very important that tact is measured carefully and correctly, because even the slight deviation from the real situation can result in false information. Tact is the core of OEE analysis. This is crucial data.
7.	Downtimes	List of downtimes: where they occurred (which station of production line), when they occurred (day, shift, hours, minutes), the length of downtime, the nature of downtime (what was the problem - electrical, mechanical, hydraulic, etc.), which part was produced when the downtime occurred, type of downtime (planned or unplanned)? Type of downtime is also very important information because it directly affects the OEE score.
8.	Quantities	How many parts have been produced each shift (taking care if more than one type of product was produced in same shift) and how much of it was waste, if any?

In order to get results from OEE analysis, the collection of data needs to be made. Many companies which are in a process of implementing or have already implemented Lean tools, including TPM, collect data manually. To get a successful OEE analysis it is obligatory to gather the information shown in table 1.

When the collection and interpretation of OEE data is done, the most important results are as follows:

- TEEP number – Total effective equipment productivity (ranges from 0% to 100%)
- EU number – Equipment utilisation (ranges from 0% to 100%)
- OEE number – Overall equipment efficiency (ranges from 0% to 100%)

where is:

$$\mathrm{TEEP} = \mathrm{EU} * \mathrm{OEE} \quad (1)$$

Total effective equipment productivity number (TEEP) shows how much time of total available hours in the day the certain equipment was producing good parts. It considers maximum time to be all available time – that is 24 hours, 365 days a year.

Equipment utilisation - the EU takes into consideration all the planned downtimes, as well as weekends, sick leaves, trainings, lunch breaks, educations, and all the reasons why equipment wasn't working due to the planned reasons.

Overall equipment efficiency (OEE) looks at the potential production time as a maximum, without calculating time that has been unscheduled. It identifies the percentage of manufacturing time that is truly productive. OEE of 100% means you are manufacturing only good parts, as fast as possible, without downtimes. Term "good parts" mean parts that are satisfying quality need and can be sold. If OEE reaches over 100%, that means that predictions about production tact are wrong. It also means that production capabilities have been underestimated and that parts are produced faster than predicted.

For comparison of production machines, devices or lines, it is best to use OEE statistic, because it represents the pure effectiveness of the machine when weekends and planned downtimes are subtracted. It means that OEE is not affected by time of usage of particular production device, whereas TEEP is. Some devices are used only two or three days per week, and some are used the entire week, 24 hours a day. Nevertheless, that does not affect OEE statistic.

By the very look on the table of needed data, it can be assumed that collection of data for the OEE analysis is a tedious and time-consuming process. Not to mention the possibility of errors. Often, there is no trained person who is collecting the data, so the job falls on the workers on the line. With the daily routine of activities, workers who are in charge of collecting data often tend to fulfil the data forms superficially. Moreover, the data collection is also a time-consuming process for the administrative worker who is interpreting the data from sheets, and translating them into complicated tables in order to get meaningful numbers.

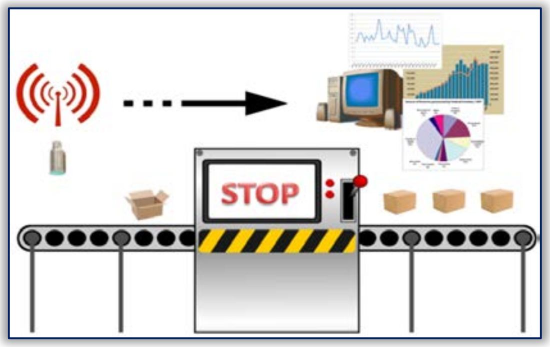

Figure 1 – Example of stoppage monitoring system

The relatively new concept Internet of Things (IoT) is the networking system of connecting physical devices, vehicles, buildings and other items in a way that it enables them to collect and exchange data. These devices are embedded into the electronics, software, sensors and actuators. They are also referred to as "connected" or "smart devices". It's basically connecting things on a network in order to gain data or track input of physical devices or items. It goes beyond machine-to-machine (M2M) communications [17] and covers a variety of protocols, domains, and applications.

For the purposes of collecting data for OEE analysis, a similar concept can be used. An example of the concept is shown on figure 1. If a sensor is put on the machine signaling when the machine is operating, and when it isn't, it can be used as an input signal to software which keeps track of downtimes. All sorts of software capable of doing such tasks are available. Of course, customized software can also be made to satisfy one's production tracking needs. Interface can be made, which will have all the invariable data of OEE analysis related to the specific machine or production line: information about workplace, information about workpiece, number of shifts, number of working hours and production line tact. Downtimes would be tracked in a way that when the failure occurs the software starts the counter and writes in its memory the exact time and date when the failure occurred. After the malfunction has been removed, the worker would simply choose one of the predefined possibilities of failures such as: need of row material, packing, inspection, replacing of the product containers, maintenance, lunch break, electronics, hydraulics, mechanics, station 1, station 2 and so forth. Each of the failures would be related with one of the loss categories and would automatically be assigned to that category whereas overall equipment efficiency analysis requires losses to be categorised. When the OEE analysis needs to be made it can be done in minutes. It would no longer require several weeks to complete the statistics. All that would be needed to be done is choosing the time period that you would like to take into consideration for the analysis and entering the quantities. Data from the program would be similar like on figure 2.

Machine	Product	Tact [s]	Shifts	h/ shift	Date	Begin	End	Cause	Duration	Explanation
M1	A	4,1	3	8	3.9.2016	13:30:55	13:38:02	Filler	0:07:07	Raw material replace
M1	A	4,1	3	8	3.9.2016	18:52:43	19:07:45	Maintenance	0:15:02	Lubrication
M1	A	4,1	3	8	4.9.2016	10:20:23	12:03:33	Hyraulics	1:43:10	Hydraulic valve replacement
M1	A	4,1	3	8	4.9.2016	14:05:22	14:08:03	Product	0:02:41	replacing product collector
M4	B	8,5	2	8	5.9.2016	9:06:56	9:45:22	Pneumatics	0:38:26	Replacing of air filter
M1	A	4,1	3	8	5.9.2016	11:02:07	12:01:45	Training	0:59:38	Worker education
M3	C	12,8	1	8	6.9.2016	10:00:59	10:31:02	Lunch break	0:30:03	Lunch
M1	A	4,1	3	8	6.9.2016	12:05:52	13:55:06	Inspection	1:49:14	Planned maintenance
…	…	…	…	…	…	…	…	…	…	…

Figure 2 – Data about production equipment downtimes

Downtime tracking can be achieved by hand, but data is often not accurate and usually is too old to be taken into consideration and cannot be used effectively. OEE data tracking software can automatically collect downtime data and compile it in a way that is easy to use. In the end the procedure can save a great amount of time and can eliminate possible errors in interpretation of the data.

3. IMPROVING OEE TROUGH WIRELESS PAGER SYSTEM

In order to get better understanding of improvements OEE, analysis needs to be explained more in detail. The analysis is not only giving us the equipment efficiency but also it enables us to divide losses into several categories. When losses are divided into categories we can focus on one of the categories and work in a specific area of improvements. It's easier to correct the losses overall by focusing on losses one by one. Categories of losses are shown in table 2.

When OEE data collection is done we should be able to calculate and categorise every loss. In the end, quality production time is nothing less than the total available time reduced by the stoppage time. In figure 3, categories of losses are displayed within a 24-hour period. The OEE analysis was conducted in the company Elektro-kontakt d.d. within a period of 24 hours split between 2 shifts. The measurement of downtimes occurred on the stamping machine for producing metal pieces from raw metal band. It is an example of real OEE analysis. In one day, there are 1440 minutes of total available time for production. Total productive time is when aggregated losses are subtracted from the total time. The first loss is a planned interruption (two shifts production, maintenance, and training) and it doesn't enter into OEE result.

Table 2 – Different categories of losses in production

Category of losses	Explanation
Planned interruption	Number of shifts, if is less than 3 shifts, events, maintenance, trainings
Planned availability losses	Set ups, breaks, calibrations, tests, sample production
Unplanned availability losses	Interruptions >10 min, errors, missing material
Performance losses	Cycle time, produced pieces, worker response to stoppage, interruptions <10 min
Quality losses	Rejects, rework

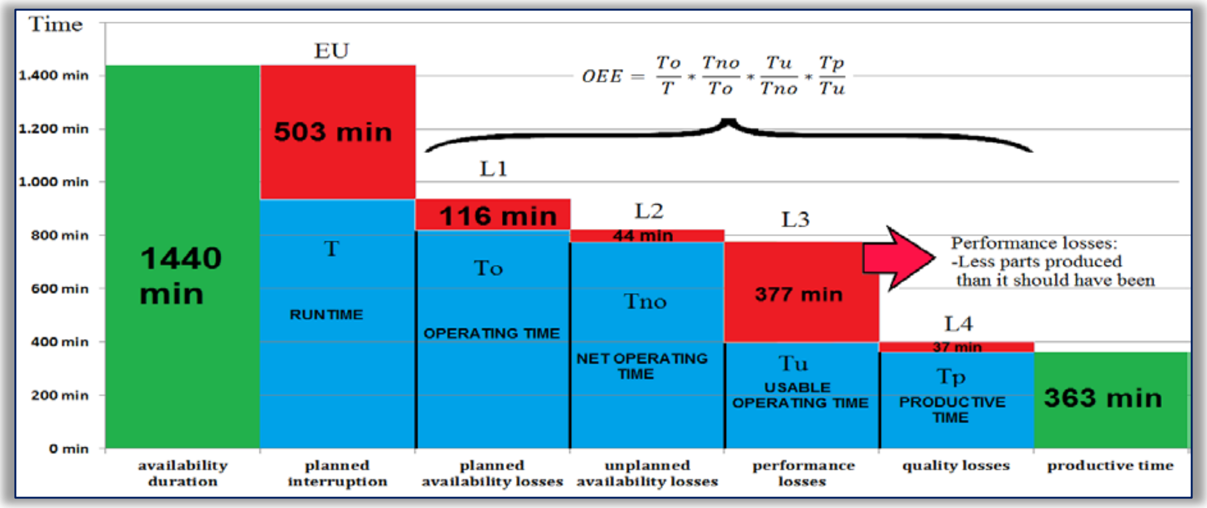

Figure 3 – Categories of production losses according to OEE analysis

As mentioned earlier, OEE analysis doesn't take planned interruption time into consideration in order to have objective data used for comparison between production lines and machines.

$$\mathrm{OEE} = \frac{\mathrm{To}}{\mathrm{T}} * \frac{\mathrm{Tno}}{\mathrm{To}} * \frac{\mathrm{Tu}}{\mathrm{Tno}} * \frac{\mathrm{Tp}}{\mathrm{Tu}} \quad (2)$$

$$\mathrm{OEE} = \frac{\cancel{\text{Oper.time}}}{\text{Runtime}} * \frac{\cancel{\text{Net oper.time}}}{\cancel{\text{Oper.time}}} * \frac{\cancel{\text{Usable oper.time}}}{\cancel{\text{Net oper.time}}} * \frac{\text{Productive time}}{\cancel{\text{Usable oper.time}}} \quad (3)$$

If, L1 is planned availability losses time, L2 is unplanned availability losses time, L3 is performance losses time, T4 is quality losses time and T runtime then the equation is:

$$\mathrm{OEE} = \frac{\text{Productive time}}{\text{Runtime}} = \frac{\mathrm{T_p}}{\mathrm{T}} = \frac{\mathrm{T - L_1 - L_2 - L_3 - L_4}}{\mathrm{T}} = \frac{\mathrm{T} - \sum \mathrm{L_n}}{\mathrm{T}} = 1 - \frac{\sum \mathrm{L_n}}{\mathrm{T}} \quad (4)$$

Every category of losses is defined, explainable and measurable. But in the performance losses category it can be only stated how much time was lost due to the poor performance. For example in unplanned availability losses list of breaks can be conducted which explains why the time is lost. In quality loses, the exact number of faulty pieces can be counted which turned into time results in lost production time. However, in the performance losses category it is difficult to explain the resulting loss time. Those are all the little downtimes that are not documented in any way. It is the worker's late response to stoppage of machine because of required repetitive actions such as: the filling of raw material, packing, inspection or replacing of the product containers, as well as the other short disturbances. It's calculated knowing the machine tact and available net operating time. All the products that are not made but should have been made in given period of time - (using the machine tact) are a direct consequence of performance losses.

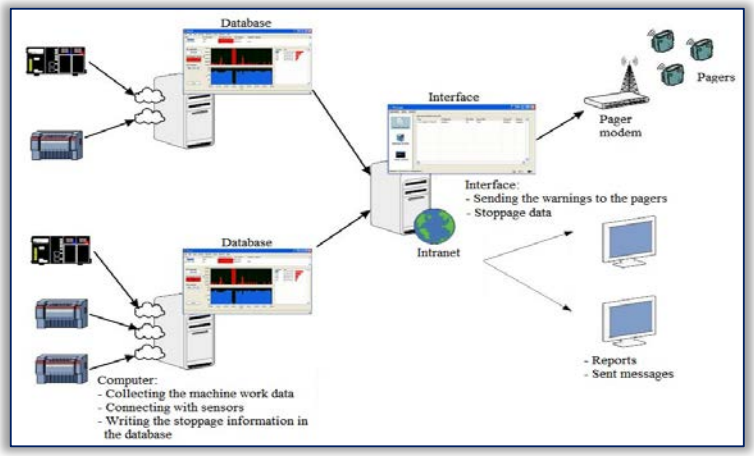

Figure 4 – Model of the paging system

Often it isn't the worker's fault if he doesn't immediately see the stoppage in production because, as mentioned earlier, he is under constant pressure because the workers often perform on several machines or production lines simultaneously, supplying them with fresh material and other assistance. In order to reduce performance losses the integrated wireless paging model is proposed. The integrated paging system shown on figure 4 would alert the worker of any discrepancy as it happens so that he can tend to the problem immediately and efficiently.

The basic pager system consist of sensors connected to the machines, with an industrial computer utilizing a database for collecting the work data, Intranet interface, pager modem and pagers are all part of this system. Sensors are sending the information to the machine computers which are inputting the data into the database for real-time or later analysis. Intranet interface would receive data from machine computers and send the data to the pager modem. The pager modem, then, sends the data to wireless personalized pagers specifically assigned to the machine responsible for the stoppage.

If the worker is responsible for the group of machines, he would have a personalized pager which alerts him when one of the machines from his group has stopped. When the machine or production line stops for any reason, the worker responsible for that machine group can quickly decide if he needs to concentrate on that machine immediately, resolve the problem, and then go back to his previous assignment. For example, let's say that he has a half an hour work on machine 1 (repairs, maintenance or adjustments). Then, machine 2 stops because of lack of raw materials. Filling the raw materials, for example, takes 5 minutes. He can decide to fill machine 2 and then go back to machine 1. In the first case, without the paging system, both machines would be at full-stop for 30 minutes each. An event like this means that both machines would experience an hour of stoppage time. In the second case, if the worker concentrates on machine 2 first, and then goes back to machine 1 to attend to the problem, it would result in stoppage of 35 minutes on machine 1 and only a 5-minute stoppage of machine 2. So the total stoppage would be 40 minutes for both machines instead of 60 minutes. The 20-minute difference would be recorded in the performance losses category shown on picture 2. That is the advantage of an integrated paging system, the redistribution of work among multiple machine failures and actionable knowledge about the stoppage of the affected machines.

This way we are concentrating on the actual performance losses where before we could not be sure of why the time was lost. In the example on figure 3, performance losses are a great part of total lost production time. Often there is no explanation for the performance losses. Simply there are not enough products at any given time that should have been produced. It is very difficult, as mentioned, to determine the exact moment and reason when the time was lost. Such small and frequent stoppages are usually caused by workers' late responses, due to the lack of information and timeliness in the discovery of the stoppage, or downtimes that have not been recorded. Implementation of an integrated paging system would have a great and measurable effect on the performance losses and reduce the downtime caused by workers' late response. This will enhance the overall equipment effectiveness and availability as well as increase production at any given time period.

4. DISCUSSIONS

In order to better understand of the availability of production equipment, OEE analysis is one of the tools that can be used. It represents the valuable data about downtimes upon which corrective measures can be conducted. In order to collect the data for the analysis correctly, and as quick and accurate as possible, modern computing technologies can be used. It can find its practical application in almost every production if there is a need to keep track of the state and productivity of equipment. The proposed integrated pager system is in direct relationship with production equipment downtimes and efficiency measured by the OEE analysis. By implementing such a solution, better understanding and overview of production equipment is achieved. Workers responsible for the group of equipment have better understanding of the production equipment state in real time. Analysis can be done retroactively as well since all the stoppages are measured in the database and stored for further examination and data extraction. In this paper, guidelines have been given on collecting the data and calculating the level of equipment efficiency. Also a model, tools and concepts for implementing smart computer based wireless solution for tracking the downtimes are proposed. All of these systems proposed represent a move towards better business production model, and overall efficient way for keeping material input, product output and worker awareness at optimum levels.

5. CONCLUSIONS

In the final analysis concerning production and maintenance in the textile, machinery or production-line manufacturing industry, we must never overlook the underlying reason why some businesses are massively popular or financially successful, while others maintain a status quo perspective and eventually drop into mediocrity or fade from public view. The underlying reason is a company's strength or weakness in the concept of failure reaction or failure maintenance. This concept, in my opinion, stems from the ability to realize problems and concerns early and rectify them 'on-the-fly' rather than using ad hoc methods or time-consuming analyses after a minor or major stoppage of work. Companies that can make in-course corrections are more effective, and needless to say – more profitable, than companies who wait for catastrophic failures to occur before making changes to their management or manufacturing model.

Managers, production supervisors and shop employees alike understand and accept the fact that if a device, a piece of gear, or a major machine is designed, made or assembled by a human being, then by the law of averages and common sense, that device, piece of gear or machine will at some point begin to weaken, lag, skip, break or utterly fail. My question is: Why wait for this inevitability? Why not construct a working model whereby production can flow 24-7 with a seamless 'fast responder' maintenance strategy that can ultimately save the company money after its initial financial installation?

Maintenance, whether scheduled or done randomly, has always been the traditional way to prevent such inevitable failures and reduce the number of down times and work stoppages. However, such preventative measures are not full proof or guaranteed, and can be very costly, especially if there are stoppages when deadlines are coming up, or during an acceleration of production to meet a new quota for a customer. If the machine stops, even after a scheduled maintenance check, there are the ramifications of loss time, the stoppage of production, an increase in man-hours, paperwork, phone calls, locating the right replacement parts, installing those parts, testing the installation, initiating dry-runs, etc. – and all the while, the clock is ticking. The threat of not meeting the required deadlines or fulfilling the required quota can be damaging. And this is exacerbated during times when manpower is at a minimum during vacation periods, holidays, illness, medical leave or what not. Just one or all of these conditions could have negative ramifications on the company's name or reputation, to say nothing of the morale of the workers involved. I believe that all of this can be prevented.

In this paper, the description of total productive maintenance, overall equipment efficiency, and total effective equipment productivity is given, as well as guidelines on collecting the required data to achieve these initiatives. Calculations of OEE, as one of the key performance indicators of equipment effectiveness was also given and explained. Solutions and explanations for faster and more accurate collection of data were proposed. Categories of production losses were listed and explained describing how they affect the actions needed to be done in order to reduce production stoppages. Also, a model was proposed for reducing the performance category of losses in order to increase overall equipment efficiency.

This study has attempted to introduce methods and platforms by which in addition to maintenance, a dynamic and active practice can be put in place to repair machines as the problems happen, 'on-the-fly', with the bare minimal of down time and labour costs. Not only would such practices help with workers to ensure continuous production, but it will elevate their skills, expand their working knowledge in computer-based maintenance systems, increase the morale in the workspace, and look impressive on a manager's spread sheet, audit evaluation or end-of-year report.

Note

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