International Journal of Engineering Management
2018; 2(1): 15-28
http://www.sciencepublishinggroup.com/j/ijem
doi: 10.11648/j.ijem.20180202.11

Science Publishing Group

A New Manufacturing Improvement Model Based on Overall Equipment Effectiveness and Lean Maintenance

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To cite this article:
Anwar Meddaoui, Ahmed En-nhaili. A New Manufacturing Improvement Model Based on Overall Equipment Effectiveness and Lean Maintenance. *International Journal of Engineering Management*. Vol. 2, No. 2, 2018, pp. 15-28. doi: 10.11648/j.ijem.20180202.11

Received: April 16, 2018; **Accepted**: May 3, 2018; **Published**: May 29, 2018

Abstract: This paper proposes a new model for manufacturing effectiveness measurement and improvement basing on the TPM principles and lean maintenance improvement actions. Its methodology is founded on four main pillars. The first one deals with the maintenance process mapping. This part recaps previous published research on maintenance process optimization. The second pillar, the main Total Productive Maintenance (TPM) indicator Overall Equipment Effectiveness (OEE) is developed to include other parameters. The third part presents the core of this methodology. In this phase, principal wastes are considered and related to both lean tools and improvement actions. The last pillar concerns an industrial application of the proposed model. The paper presents two major contributions: designing a practical tool to understand the impact of improvement actions on industrial system's effectiveness and proposing a set of unavoidable actions and methods which adhere to their relative impact on the OEE rate. The proposed approach suggests to small organizations a new way to implement Lean methodology faster than usual by using directly appropriate tools to identify and kill waste sources. Further research could improve the proposed tool and thus reach a proposed study with other industrial application.

Keywords: Lean Maintenance, Overall Equipment Effectiveness, Process Approach, Maintenance Cost

1. Introduction

The world had recently experienced an economic crisis affected several levels in companies such as benefits deterioration and lack of competitiveness. Unfortunately, the survival of businesses depends on competitiveness and it shouldn't in any case stop from increasing. To keep up with this situation, manufacturers have to adopt some waste cutting strategies, the most well known in the industrial field is the Lean Manufacturing.

Lean theory originated in Toyota Production System created in the 1950's. Its basic ideology is to eliminate waste and reduce cost. Lean system implementation faces most of the time different limitations: the fastest complete Lean systems implementation takes two to three years, top management understanding is superficial [9], and lack of implementation know-how [21, 20], which is not advantageous for companies that want to face and survive unexpected situations in which immediate change and cost savings are requested.

One of the least exploited areas in the company is maintenance activities. Maintenance was usually seen as a strategy requiring high investments but delivering poorer rates of return ([1, 19]). The role of maintenance in modern manufacturing is becoming even more important, with companies adopting maintenance as a profit-generating business factor.

Most of the studies performed to assess the lean maintenance implementation are focused on performance release based on time studies [16, 6], but all of them are usually relative values and are not so significant regarding the quantification of cost savings. In his studies [4] employed the system dynamics approach to model and analyze a maintenance system with aiming at reliability evaluation and control.

OEE is a measure of equipment performance efficiency and is linked directly to 5S and TPM. It's a measure which focuses mostly on production losses in which maintenance policy is one effect among many. By applying the principles of OEE, reduced values of downtime caused by breakdowns may help indicate the effectiveness of maintenance upon machine performance rates [6]. Studies of Singh and Singh (2014) highlights the contributions of continuous improvement function to ensure enhanced equipment improvement related issues, thereby affecting improvements in the manufacturing system performance. Results (case study indicated the average improvement in overall equipment effectiveness (OEE) of about 4.15%, reduction of 88.22% in rejections, decrease in down time of 7.125 hours/week and the net cost savings of $2,420.

This article will be focused on lean approach by applying smart actions to optimize maintenance activities, and effectiveness assessment by proposing improved Overall Equipment Effectiveness (OEE) using technical and economic factors.

Research methodology.

Methodology followed in this article is structured into four main phases as shown in figure 1.

Description of the methodology phases showed in Figure 1 is developed as follows:

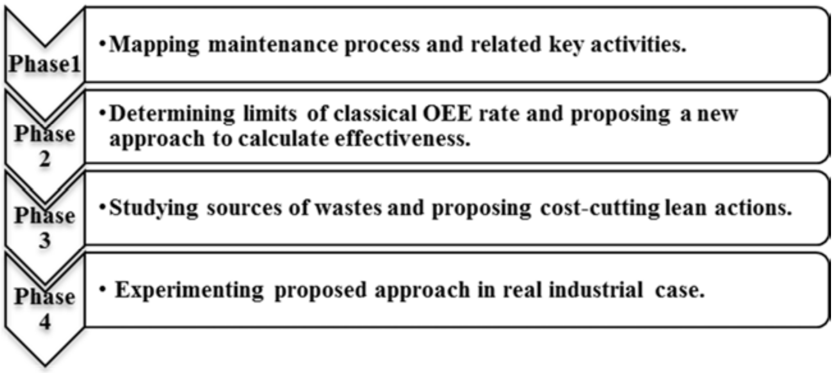

Figure 1. *Methodology phases.*

Phase 1: Mapping maintenance process and related key activities.

This step concerns maintenance process mapping into key activities based on a business process approach and works on maintenance process cost modelling through Business Process Reengineering (BPR) and Time Driven Activity Based Costing (TDABC) developed by [13]. In this phase key activities of maintenance are represented.

Phase 2: Determining limits of classical OEE rate and proposing a new approach to calculate effectiveness.

This phase starts with studying limits of classical Overall Equipment Effectiveness (OEE) and proposes a new approach to obtain effectiveness rate considering a global technical-economic context. The OEE calculation is developed taking in consideration economic factors.

Phase 3: Studying sources of wastes and proposing cost-cutting lean actions

The main objective in this phase is firstly to study leading and potential industrial wastes and link them to lean tools and secondly propose lean improvement actions which will be associated to the proposed effectiveness approach based on the new OEE rate. The impact of implemented actions on the OEE are quantified in the case study.

Phase 4: Experimenting proposed approach in real industrial case

The phase 4 is consecrated to the development of a real case study to test in an industrial process, the applicability and output results and to quantify experimented improvement actions impact on effectiveness rate.

2. Literature Review

While carrying out the current work, the literature was reviewed in three domains, namely Concept of process, lean manufacturing, concept of Overall Equipment Effectiveness, and concept of Time Driven Activity Based Costing. The information gathered by carrying out this literature review is described in the following three sections.

Concept of process:

Referring to the ISO 9000, the concept of process is any activity or set of activities that use resources to convert input elements into outputs, figure 2.

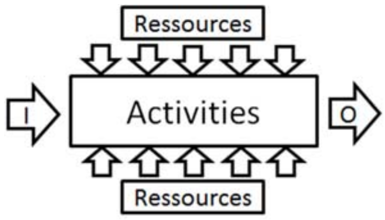

Figure 2. *Concept of Process (ISO 9000).*

Referring to the ISO 9001, a process can be divided into three pillars, operational process, supporting process and management process:

1. Operational process: It manages the production of a product or service, from search from customer needs to their satisfaction. It includes the activities dedicated to the life cycle of a product or service.
2. Supporting process: This process allows the operation of the other process by providing the necessary resources.
3. Management process: It contributes to the development of the company policy.

Elaoufir and Bouami. (2005) [8] had split the previous three main processes of maintenance into 5 intermediate processes then into 14 sub processes, and finally to 49 activities.

Concept of Lean:

According to Womack et al. (1990) [23], the basic Lean concept is to do more with less (e.g., less human effort, less equipment, less time and less space), while coming closer to customer requirements. Essentially, the term 'Lean' implies a series of activities or solutions to eliminate waste, reducing non-value added (NVA) operations, and improve the value added (VA) process [23]. The seven wastes frequently addressed in the lean manufacturing field are over-production, over-processing, waiting, unnecessary transportation, inventory, motion and defects [11, 12].

This philosophy was initially introduced in Toyota Motor Company by Imai in 1986, to improve quality, productivity, and competitiveness of its product due to increasing competition in the world. With the implementation of Kaizen, the manufacturing sector of Japan has earned a lot and become a world class. Since then Kaizen has become a part and parcel of Japanese's manufacturing system [18], [22].

Concept of OEE:

Overall Equipment Effectiveness (OEE) is a quantitative metric used primarily to identify and measure the productivity of individual equipment. It improves equipment performance by identifying and measuring the loss of potential sources namely availability, performance rate, and quality rate. OEE can be used to measure and compare the overall performance of an organization, compare the production line performance, and spot the machines that require immediate maintenance [10, 2].

Figure 3 highlights how OEE rate is related to equipment effectiveness, the six losses, and how it is calculated. For a typical lean production environment, an ideal OEE for a profitable TPM should be at least 85% [16].

Overall Equipment Effectiveness (OEE) methodology is a proven approach to increase overall performance of equipment. Badiger, A. S. and Gandhinathan, R. (2008) [13] proposed a method to evaluate OEE by including a factor known as usability, in the OEE calculation method. Further, an approach is developed to evaluate the earning capacity of addressing the six big losses, with incremental improvement in OEE, as an extension to the maturity of OEE.

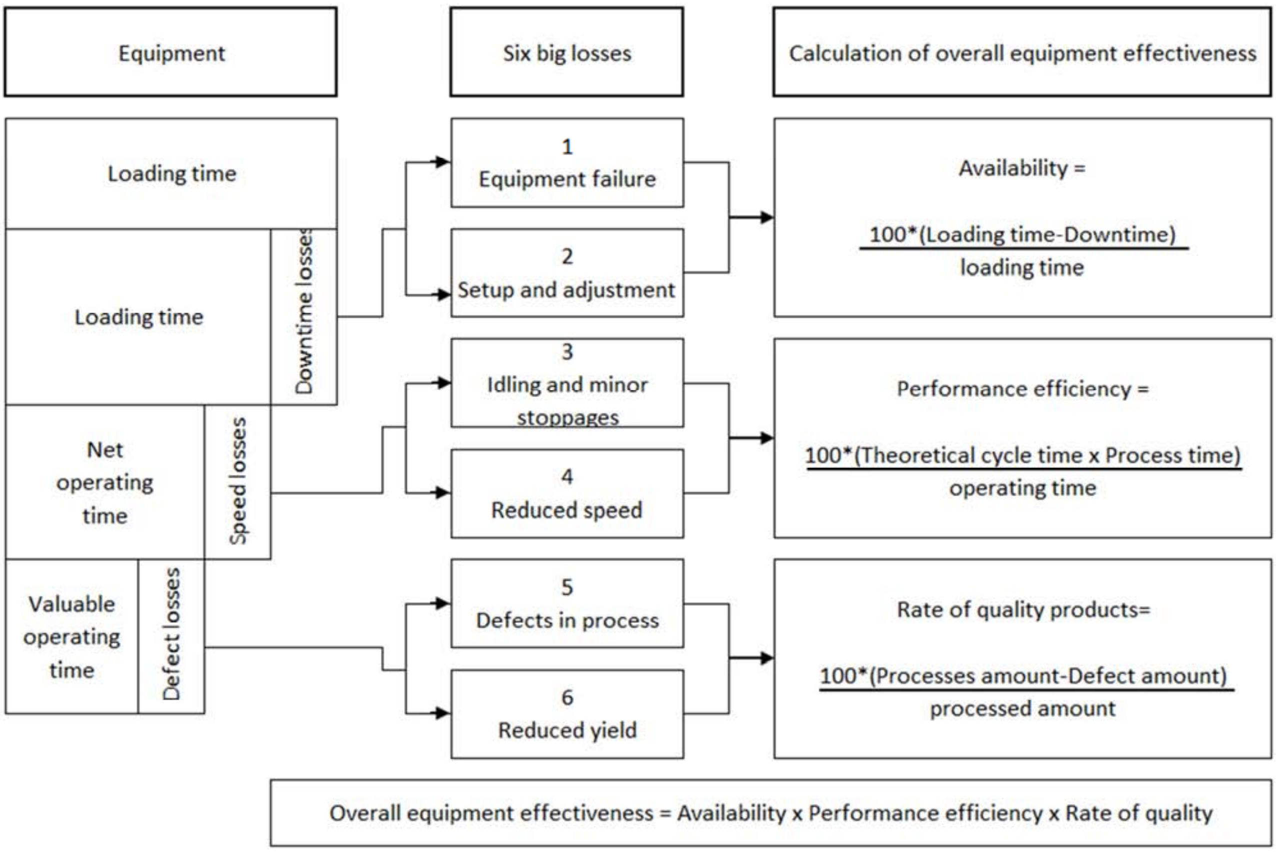

Figure 3. *Overall equipment effectiveness (Nakajima, 1988).*

Concept of TDABC:

Kaplan and Anderson. (2006) [10] presented developed activity-based costing to create the time driven activity-based costing. This method was presented as a revolutionary method in the field of determined costs. Considering the assignment of sources to activities, the method uses time equations. The principle of this method is based on the transformation of cost drivers to a time equation that expresses the time needed for the performing of the activity as the function of some drivers.

According to the specific study of Meddaoui and Bouami. on TDABC and decision making in the maintenance process, this approach is very important to maintenance cost understanding. It can be very useful to model both maintenance process costs and resources. Those authors experimented on the TDABC in a maintenance case study to demonstrate its capability in costs modelling and process capacity understanding.

3. To a New Approach to Evaluate Effectiveness and Improvement

As described before, the objective of the research methodology beyond defining maintenance key activities (phase 1) is studying classical OEE limits and proposing a new effective rate reflecting also the process cost evolution (phase 2) but especially integrating all potential improvement actions associated with leading lean maintenance tools in the global scheme of cost cutting and improved effectiveness (phase 3). The last step in the current study is the experimentation of the proposed approach to facilitate lessons learned as feedback for conclusion and further studies.

Phase 1:

In this phase a global process mapping methodology is presented. In order to map business processes of the company, each department must be considered separately to simplify the Lean implementation, the steps followed to list main activities is described in figure 4.

After definition of studied department key activities, time and cost of each activity are defined using the Time Driven Activity Based Costing method. For this need, findings of Meddaoui and Bouami are used as support.

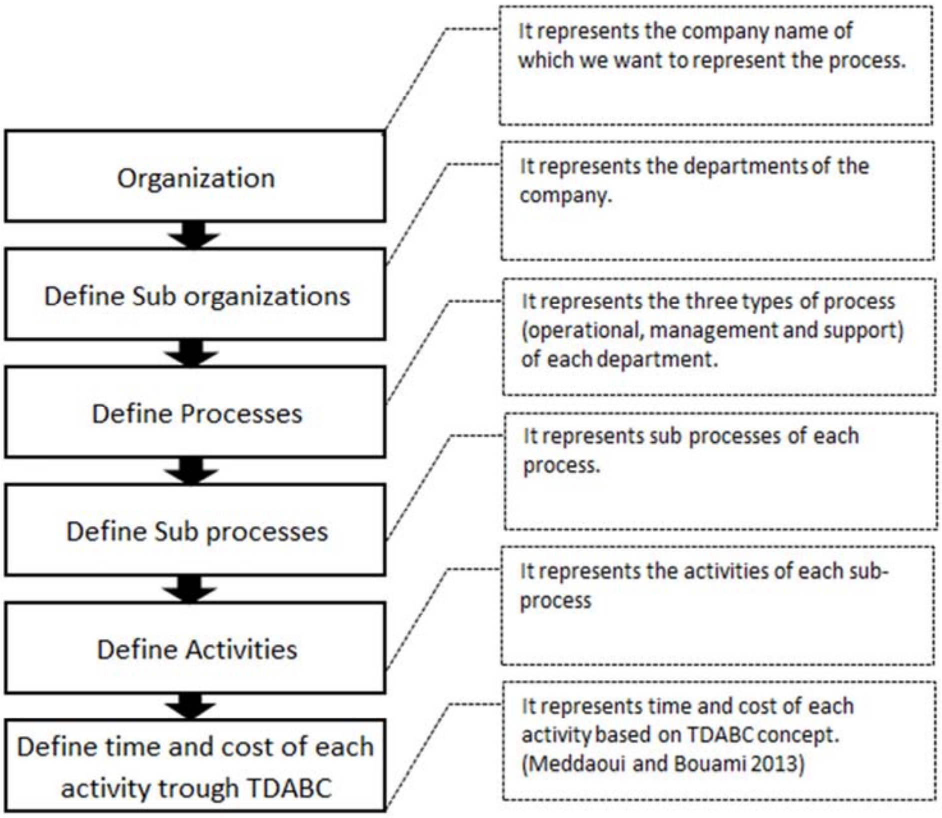

Figure 4. *Process mapping steps.*

Phase 2:

The overall equipment effectiveness (OEE) is a hierarchy of metrics to evaluate how effectively a manufacturing operation is utilized. OEE is calculated as the product of its three contributing factors: Availability, Performance, and Quality:

OEE = Availability x Performance x Quality

Availability = Operating Time/ Planned Production Time

Performance = Ideal Cycle Time/ (Operating Time/ Total Pieces)

Quality = Good Pieces/ Total Pieces

OEE has been the most broadly adopted measurement. However, the output of OEE is usually a relative value and it cannot allow users to quickly estimate a production line's potential savings costs as a result of OEE improvements and can't help guide the improvement efforts actions for companies engaging in a continuous improvement initiatives.

A new paradigm has been emerged that tries to link OEE to costs (Atkinson, 2007), other contributions try to evaluate how effectively a manufacturing operation is utilized by mainly using both maintenance and finance efficiency (Ennhaili et al. 2014) [7].

According to [2]., TDABC and OEE provide an interesting pair of tools that managers can use to classify and cost-idle time and the downtime, speed, and quality losses associated with the fixed factors of production. Such information should be useful in identifying and prioritizing opportunities for operations improvement".

According to [7] maintenance VSM is used to describe main operational processes of maintenance: preventive and corrective. The discussed application gives an idea on maintenance global efficiency indicator using Non-Value added time, Value added time, Maintenance Efficiency and Maintenance Financial Efficiency.

A new reasoning purpose can be developed to have a better understanding where opportunities for improvement exist when a continuous improvement initiative has OEE as its key performance indicator and can answer also to the questions how do you demonstrate to management the value of a one-point improvement in OEE? How can use OEE number to calculate savings through the three contributing factors: Availability, Performance, and Quality?

The purpose will overcome classical OEE limits and will be a development of Atkinson's contribution research. (2007). Classical OEE can firstly be consolidated by a control rate: Average Cost Performance (ACP) related to each cost elements (direct and indirect) to study the cost efficiency based on budgeted and actual cost driver rate (CDR). The main objective pertaining to the use of ACP is to integrate fourth contribution factors in order to assimilate financial performance into the OEE calculation and provide a technical-economic OEE: (OEE-TE). Secondly, calculation results can be used to demonstrate to management the value of a one-point improvement in OEE by calculating savings by each OEE Category.

ACP is defined as the ability of an operational function to respect budgeted cost elements. The method is based on budgeted and actual CDR calculated by using the basics of TDABC.

CDR is defined as cost (Direct and Indirect cost) per hour consumed by the cost element. The primary objective of the CDR is to calculate savings in value related to improvement hours of each OEE factor.

ACP development can be summarized by the following steps mentioned below:

1 Identify Cost elements: Universal Cost category: Labor, Overheads, and Depreciation

2 Link Cost elements to each OEE Function: Affectation of each cost elements to the OEE contribution Factor.

3 Identify Budgeted costs: Budgeted costs defined in year N-1 as objective for year N

4 Identify cost driver rate: The cost per each hour consumed by the cost element by using the basics of the TDABC

5 Calculate cost performance: Cost performance for each cost element: CDR Budget/ CDR Actual

6 Calculate Average Cost Performance: Average (CDR 1; 2 …...n)

OEE-TE = Availability x Performance x Quality*ACP

ACP $(F_i) = \sum CDR_i$ Budget/$\sum CDR_i$ Actual

ACP: Average Cost Performance (for each OEE function F_i)

F_i: OEE factors (Availability i=1, Performance i=2, Quality i=3)

CDR_j: Cost Driver Rate (for each cost elements j)

Finally, absolute saving value on OEE is calculated by an evaluation of each saving OEE factor hours with the total cost driver rate (Saving hours $_{(Fi)}$*CDR $_{(Fi)}$) in order to have an overview of cost reduction and evaluate the efficiency of the corrective actions made to improve OEE between two periods. The sum of cost reduction on each function will give the global absolute value on OEE improvement.

Phase 3:

According to (Ohno, 1985; Bicheno, 2000; and Davies, 2003) the wastes frequently addressed in lean manufacturing are:

1. W1- Overproduction: example of too much preventive maintenance
2. W2- Waste of waiting: example of waiting for resources
3. W3- Waste of transporting: example of transport of equipment
4. W4- Waste of processing: example of non-standard preventive maintenance
5. W5- Waste of inventory: example of excessive stock
6. W6- Waste of motion: example of double handling
7. W7- Waste of defect: example of poor maintenance
8. W8- Waste of human potential: example of lack of training
9. W9- Waste of inappropriate systems: example of poor information
10. W10- Waste of energy and water: example of energy management
11. W11- Waste of material: example of too much preventive maintenance
12. W12- Waste of service and office: example of poor and service operation
13. W13- Waste of customer time: example of poor procedure
14. W14- Waste of defecting customers: example of poor maintenance

Several lean tools were created; most used tools are listed below (Womack and Jones, 1996; Womack et al. 1990; Davies. 2003) gave us a summary and a definition of each tool.

1. Value stream mapping: is a tool to map material and information flow of a productive process.
2. 5 Why: Its method to trace a cause by asking 'why' five times when confronted with a problem
3. 5S house keeping: It's a system for cleaning, organizing and maintaining a work area.
4. Pareto: It's a tool to represent data on graphs in order of frequency of occurrence.
5. A3 Report: It's a presentation of a problem on a single sheet of paper, including all the background information on the problem, root causes, potential solutions and action plans.
6. Bottleneck Analysis: It's a process to identify the step in the process where the capacity available is less than the capacity required.
7. 5M: It displays graphically the factors and underlying

causes of a defect or problem.

8. Check Sheet: It's a written document listing critical elements to be checked on a regular basis.
9. Kaizen Events: It's a philosophy and set of tools dedicated to small increments of continuous improvement at all levels of a company.
10. Kanban: Kanban is the tool for managing and achieving just in time philosophy.
11. One Piece Flow: One Piece Flow is a scheduling technique where the batch size is set to one.
12. Poke-a-Yoke/Error-proofing: It's a tool which prevents the occurrence of defects
13. Single Minute Exchange of Dies: is an approach to machine setup and design that strives to minimize setup times.
14. Spaghetti Diagram: It's a tool to monitor the actual flow of material or workers in a process.
15. Standardized Work: It's a technique where process procedures are documented so that an ideal standard work process is developed.
16. Visual Management: It's a technique which provides visual cues that alert anyone in an area on how a process should be completed, or how a workstation should be setup.
17. Skill matrix: It's a chart used to identify current capability and future training needs to developp the skills of employees

To identify the area for lean tools application, first the adequate lean tool was highlighted for each kind of waste Table 1 ('i' for improvement and 'd' for detection), in Table 2 the wastes were linked to activities.

Table 1. *Link between wastes and lean tools.*

		Lean Tools								
		Value stream mapping	**5 Why's process analysis**	**5S house keeping**	**Pareto**	**A3 Report**	**Bottleneck Analysis**	**Cause and Effect Diagram**	**Check Sheet**	**Kaizen Events**
Wastes	W1:Waste of over production	d			d			i		i
	W2:Waste of Waiting	d	i	i	i		i	i	i	i
	W3:waste of Transporting	d		i						i
	W4:Waste of processing		i				i	i	i	i
	W5:Waste of inventory	d		i						i
	W6:Waste of motion	d	i	i			i			i
	W7:Waste of defects		d	i	d	i		i	i	i
	W8:Waste of human potential									i
	W9:Inappropriate systems		i							i
	W10:Energy and water				d			i	i	i
	W11:Wasted material		i	i		i				i
	W12:Service and office wastes									i
	W13:Customer time	d				i	i		i	i
	W14:Defecting customers				i	i	i		i	i
	detection	d								
	improvement	I								
	detection and improvement	d/I								

Table 1. *Continued.*

		Lean Tools							
		Kanban	**One Piece Flow**	**Poke-a-Yoke/Error-proofing**	**Single Minute Exchange of Dies (SMED)**	**Spaghetti Diagram**	**Standardized Work**	**Visual Management**	**Skill matrix**
Wastes	W1:Waste of over production	i							
	W2:Waste of Waiting	i			i	d/i	i	i	
	W3:waste of Transporting	i			i	d/i			
	W4:Waste of		i				i		

	Lean Tools							
	Kanban	**One Piece Flow**	**Poke-a-Yoke/Error-proofing**	**Single Minute Exchange of Dies (SMED)**	**Spaghetti Diagram**	**Standardized Work**	**Visual Management**	**Skill matrix**
processing								
W5:Waste of inventory	i							
W6:Waste of motion				i	d/i		i	
W7:Waste of defects			i			i		i
W8:Waste of human potential						i		
W9:Inappropriate systems								
W10:Energy and water								
W11:Wasted material								
W12:Service and office wastes								
W13:Customer time	i		i	i	d/i	i	i	i
W14:Defecting customers detection improvement detection and improvement			i	i	d/i	i	i	i

__Table 2.__ Link between maintenance activities and wastes

		Wastes						
		W1:Waste of over production	**W2:Waste of Waiting**	**W3:waste of Transporting**	**W4:Waste of processing**	**W5:Waste of inventory**	**W6:Waste of motion**	**W7:Waste of defects**
	A01:Work order (WO) treatment	*	*			*		
	A02:Allocation of resources		*	*			*	
	A03:WO data saving	*	*			*		
	A04:Emergency maintenance	*	*	*			*	*
	A05:Testing and restarting	*	*				*	
	A06:Technical support and diagnosis	*	*					*
Activities	A07:Maintenance and replacement of spare Parts		*	*		*	*	
	A08:Testing and restarting	*	*				*	*
	A09:Preparation planning of periodic maintenance							
	A10:Preparation planning of shutdowns							
	A11:Monitoring of data registering					*		
	A12:Preparation of regular inspections							
	A13:Regular inspection of equipments	*	*	*			*	
	A14:Inspection	*						

		Wastes						
		W1:Waste of over production	**W2:Waste of Waiting**	**W3:waste of Transporting**	**W4:Waste of processing**	**W5:Waste of inventory**	**W6:Waste of motion**	**W7:Waste of defects**
	reports							
	A15:Preparation of regular preventive maintenance							
	A16:Preventive maintenance and replacement	*	*			*		*
	A17:Testing and restarting	*	*				*	*
	A18:Technical preparation of shutdown							
	A19:Technical diagnosis	*	*	*				*
	A20:Preventive maintenance in shutdown	*	*			*		*
	A21:Testing and restarting	*	*				*	*

Table 2. *Continued.*

		Wastes						
		W8:Waste of human potential	**W9:Inappropriate systems**	**W10:Energy and water**	**W11:Wasted material**	**W12:Service and office wastes**	**W13:Customer time**	**W14:Defecting customers**
Activities	A01:Work order (WO) treatment	*	*			*	*	
	A02:Allocation of resources	*	*				*	
	A03:WO data saving	*	*			*		
	A04:Emergency maintenance	*					*	*
	A05:Testing and restarting	*					*	
	A06:Technical support and diagnosis	*						
	A07:Maintenance and replacement of spare Parts	*			*		*	*
	A08:Testing and restarting	*			*		*	
	A09:Preparation planning of periodic maintenance							
	A10:Preparation planning of shutdowns							
	A11:Monitoring of data registering					*		
	A12:Preparation of regular inspections							
	A13:Regular inspection of equipments	*						
	A14:Inspection reports					*		
	A15:Preparation of regular							

		Wastes						
		W8:Waste of human potential	**W9:Inappropriate systems**	**W10:Energy and water**	**W11:Wasted material**	**W12:Service and office wastes**	**W13:Customer time**	**W14:Defecting customers**
	preventive maintenance							
	A16:Preventive maintenance and replacement	*			*		*	*
	A17:Testing and restarting	*			*		*	
	A18:Technical preparation of shutdown							
	A19:Technical diagnosis	*						
	A20:Preventive maintenance in shutdown	*			*		*	*
	A21:Testing and restarting	*					*	

Table 3. *Proposed actions with their weights.*

ID	Actions	Weight
IA 01	Definition of work order procedure treatment	0.01
IA 02	Implementation of electronic work order emission system	0.03
IA 03	Optimization of physical and information flow	0.01
IA 04	Detection and reduction of waiting events	0.01
IA 05	Work only on one problem at the same time	0.01
IA 06	Definition of standard work procedures	0.01
IA 07	Definition of clear reaction plan based on the work order	0.01
IA 08	Identification of the constraint processes	0.01
IA 09	Insure safety and maintainability of machines	0.04
IA 10	Insure safe access to ensure maintenance inspection and diagnosis	0.04
IA 11	Control of emergency maintenance procedure	0.03
IA 12	Organization of maintenance tools	0.03
IA 13	Organization of the shop floor for easy access to the equipment	0.03
IA 14	Availability of diagnosis material	0.02
IA 15	Reliability of diagnosis material	0.03
IA 16	Definition of diagnosis procedure	0.02
IA 17	Control of diagnosis procedure	0.02
IA 18	Availability of communication tools	0.02
IA 19	Organization of maintenance tools	0.02
IA 20	Management of spare parts stock	0.04
IA 21	Improvement of the visual management of the equipment	0.02
IA 22	Planning of preventive maintenance during holidays	0.01
IA 23	Definition of inspection frequency by equipment	0.02
IA 24	Definition of regular inspection check list	0.02
IA 25	Availability of adequate tools for disassembly/Replacement/Assembly	0.02
IA 26	Implementation of E- check list/report	0.03
IA 27	Implementation of tele-maintenance (supplier of the equipment)	0.02
IA 28	Automatic data saving, and generation of reports (Pareto charts)	0.02
IA 29	Identification 20% worst cases	0.03
IA 30	Reduction of technician movements	0.03
IA 31	Reduction of change over	0.05
IA 32	Cleanness of the equipment	0.02
IA 33	Definition of Disassembly/Replacement/Assembly procedure	0.02
IA 34	Standardization and simplification of access to machines	0.02

ID	Actions	Weight
IA 35	Control of Disassembly/Replacement/Assembly procedure	0.02
IA 36	Identification of real root cause	0.03
IA 37	Definition of causes related to 5M	0.03
IA 38	Definition of clear check list for validation test	0.03
IA 39	Quality control of purchased spare parts	0.02
IA 40	Implementation of error proofing systems	0.04
IA 41	Identification of relevant points to be checked	0.03
IA 42	Description of problems with actions and background	0.03

Through these two Tables the possible lean tool which can be used to improve each activity could be pinpointed easily.

Basing on table 1 and table 2, the most adequate actions to improve maintenance activities are summarized in the table 3. The weight of each action was calculated based on the AHP methodology (Meddaoui and Bouami. 2014) [14].

Each action could have an impact on the OEE through positive impact either on quality, performance or availability. This impact was defined based on the nature of each action.

The implementation area of each action and its impact on specific part of the OEE is presented in Figure 5.

Figure 5 presents an inter-connection between activities (Corrective and preventive maintenance), improvement actions and OEE-TE contribution factors affected. Output is global improved OEE-TE issued from the integral inter-connections. Some inter-connections can affect more than one OEE-TE contribution factor (Example A04-IA 25: affects Availability & Performance)

Phase 4:

As mentioned before, the proposed approach will be implemented in the maintenance department. Consideration is only placed on the operational process for its consistency referring to Meddaoui and Bouami. (2013) [13]., and other similar studies which demonstrate that the operational process is the most expensive. It has been established that corrective maintenance and preventive maintenance represent approximately 80% of the total maintenance cost. In fact, the current study will be limited to the two sub-processes of the operational process.

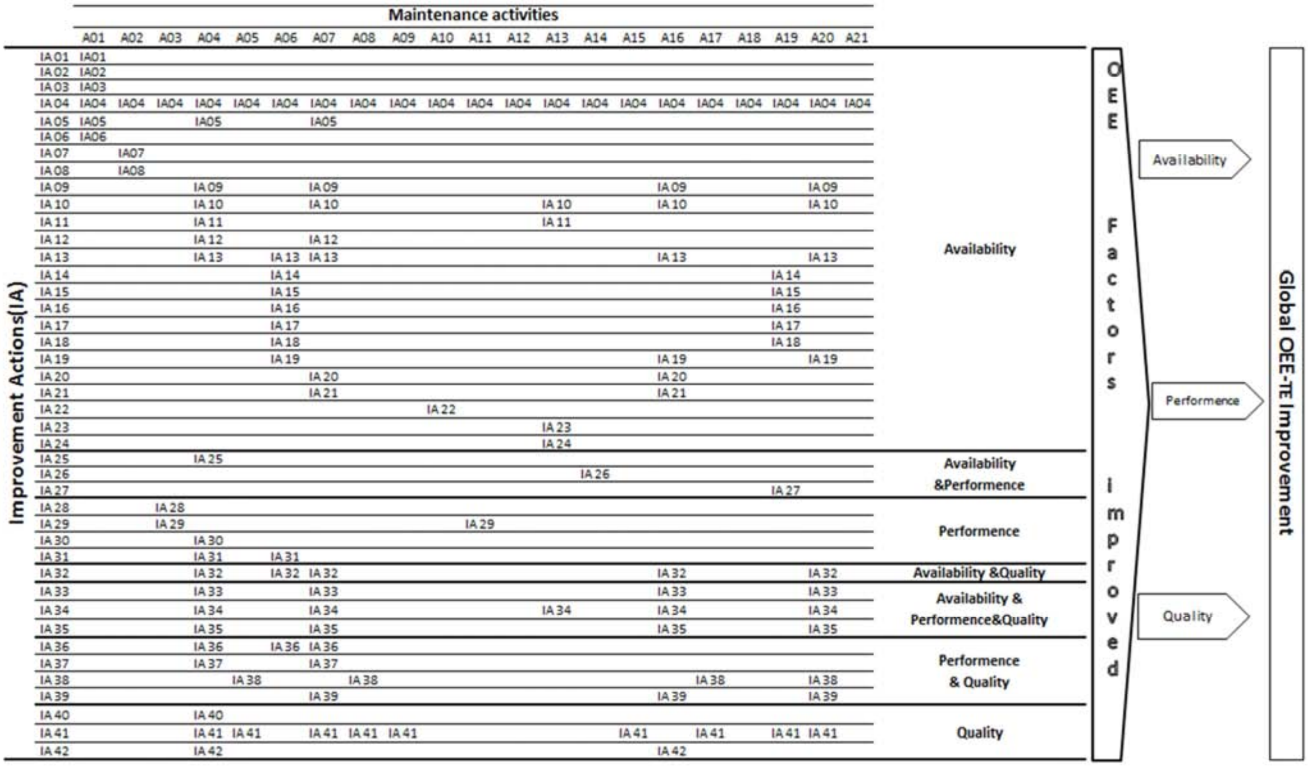

Figure 5. *Implementation area of actions and impact on OEE.*

4. Case Study

4.1. Company Information

The company chosen is an American automotive supplier specialized in the design and manufacture of interior trim parts (instrument panels, center consoles and door panels) and other disciplines, the company was recently established in Morocco, and it has 26000 employees around the world where an insistence of its distribution is done in four countries. Its main customers are BMW, Ford, GM and many others.

Maintenance department:

The maintenance department has as its missions: purchasing installation and maintenance of all plant equipment with maximum reliability and efficiency. Pillars of maintenance human resources are described as follows:

1 Maintenance manager

1 Method engineer

6 Maintenance technicians of which 2 Tool shop technician and 1 Spare-part agent.

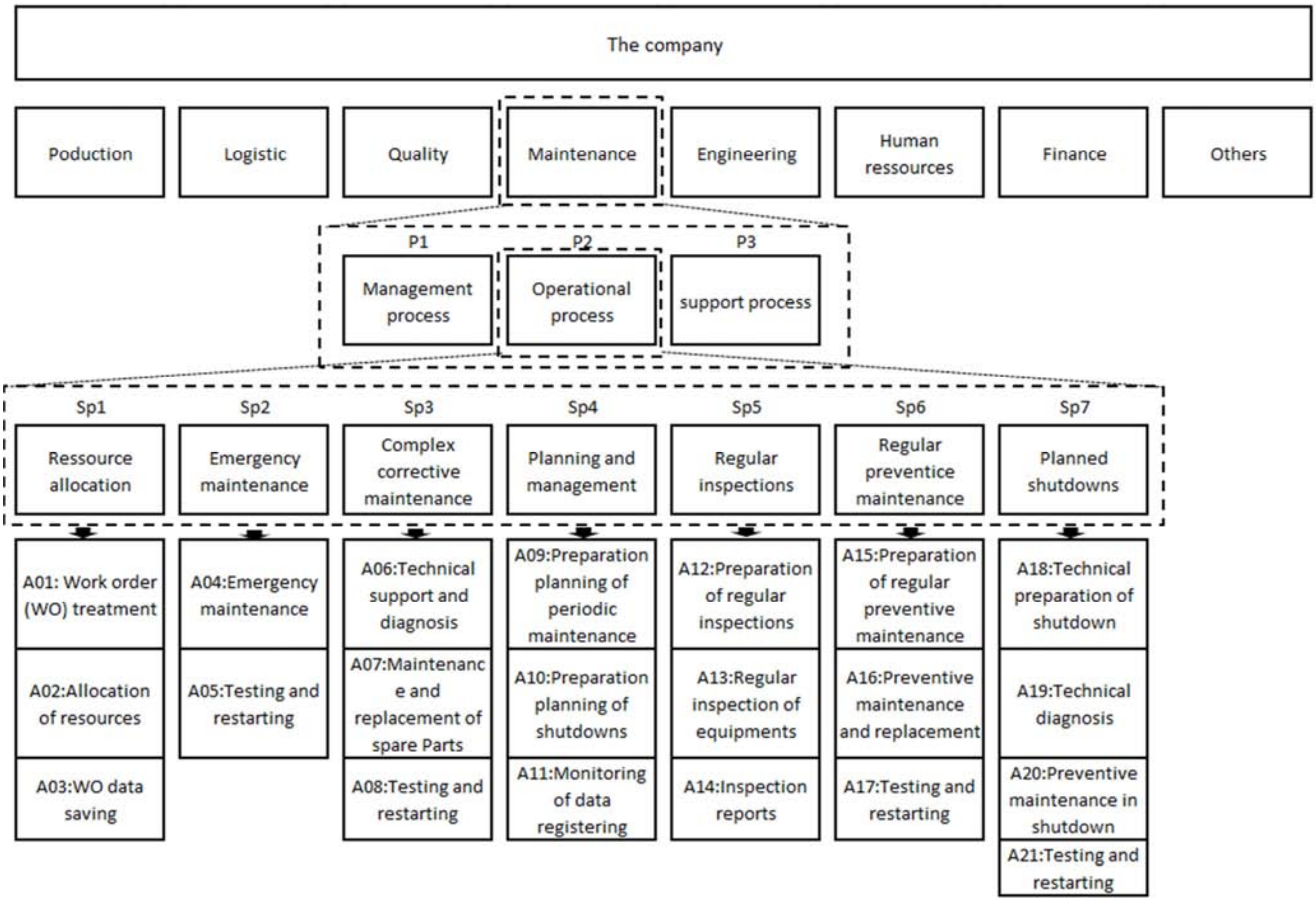

Figure 6. *Maintenance process and key activities.*

10 Trimmer machine and molding

Maintenance team is supported by 3 supervisors and production Manager

The main activity of the company is provided by 09 injection units which should be maintained by the presented maintenance department.

Mapping processes and key activities of maintenance department

As described before, the maintenance department is chosen to be mapped in order to experiment the proposed model in part 3. As presented in figure 6, the focus is allocated to the operational process by describing the 9 sub-processes, as emergency maintenance and preventive maintenance in shutdowns, so as to correlate the 21 associated activities.

After definition of key activities, time and cost of each activity were determined based on TDABC approach (Meddaoui and Bouami 2013) [13], see table 4.

Table 4. *Plant maintenance data (activity's time and cost) for Feb- 2014.*

Process	Act. ID	Cost (MAD)	Time (Min)
Corrective maintenance (CM)	A01	42 941.79	6 472
	A02	39 037.99	5 860
	A03	54 876.26	8 307
	A04	61 568.49	9 917
	A05	13 942.14	2 222
	A06	8 922.97	1 352
	A07	80 306.72	12 852
	A08	10 038.34	1 481
Preventive maintenance (PM)	A09	2 230.39	332
	A10	1 022.26	164
	A11	861.95	148
	A12	5 878.01	999
	A13	16 100.65	2 572
	A14	1 765.73	265
	A15	3 345.59	533
	A16	19 515.93	2 951
	A17	1 686.73	270
	A18	360.12	59
	A19	499.51	82
	A20	115 736.46	19 414
	A21	2 090.99	309

4.2. Data Before Improvement

OEE-TE is calculated for the nine presented injection units and consolidated for the entire plant. Availability and Performance factors are based on 'hours' except for the third factor Quality, which is based on bad and good produced parts. As described in part 3, in order to obtain final results of OEE-TE, factors are weighted by injection unit's specific ACP. Technical and Economic efficiency is calculated for the month of February 2014 as a first step before the establishment of lean maintenance improvement, Table 5.

In order to give the calculating procedure of ACP, Table 6 below describes the link between cost elements CE, the three factors (F1, F2 and F3) and budgeted/actual CDR.

Table 5. *OEE-TE calculation before establishment of lean maintenance improvement.*

Machines	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**TOTAL Plant February'14**
ACP	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Availability	71.5%	72.0%	68.5%	68.7%	72.8%	69.8%	79.4%	67.3%	68.0%	70.9%
Machines	M1	M2	M3	M4	M5	M6	M7	M8	M9	TOTAL Plant February'14
ACP	96.8%	96.8%	96.8%	96.8%	96.8%	96.8%	96.8%	96.8%	96.8%	96.8%
Performance	87.9%	70.3%	90.3%	25.6%	85.7%	49.3%	73.1%	44.4%	39.4%	65.7%
Machines	M1	M2	M3	M4	M5	M6	M7	M8	M9	TOTAL Plant February'14
ACP	96.9%	96.9%	96.9%	96.9%	96.9%	96.9%	96.9%	96.9%	96.9%	96.9%
Quality	95.2%	92.8%	94.2%	94.8%	95.3%	80.1%	93.9%	91.6%	86.6%	93.4%
OEE-TE February '14	59.8%	47.0%	58.3%	16.7%	59.4%	27.5%	54.5%	27.4%	23.2%	43.6%

4.3. Implementation and Results

A versatile team is formed in cooperation with external stakeholders to constitute a piloting committee of lean maintenance improvement. Implementation is started at the end of February 2014 with involved stakeholders in maintenance and plant finance controlling department.

Improvement actions are preselected in a first step with the aim of killing time and delaying wastes recurrent problems in maintenance activities as well as its adaptation to the experimented case study.

Improvement actions implemented for each maintenance activity are detailed below, Figure 7.

Numbers in Figure 7 represent improvement points for each interconnection binomial by using improvement action's weighted percentage allocated to saving time.

By using the Matrix, time and delay are reduced for each maintenance activities. By consequence contribution factors are respectively improved:

Availability: +3.68Pt,

Performance: +7.46Pt,

Quality: +1.1Pt.

Systematically global OEE-TE improvement is +8, 3Pt by using adequate interconnection between activities and improvement actions.

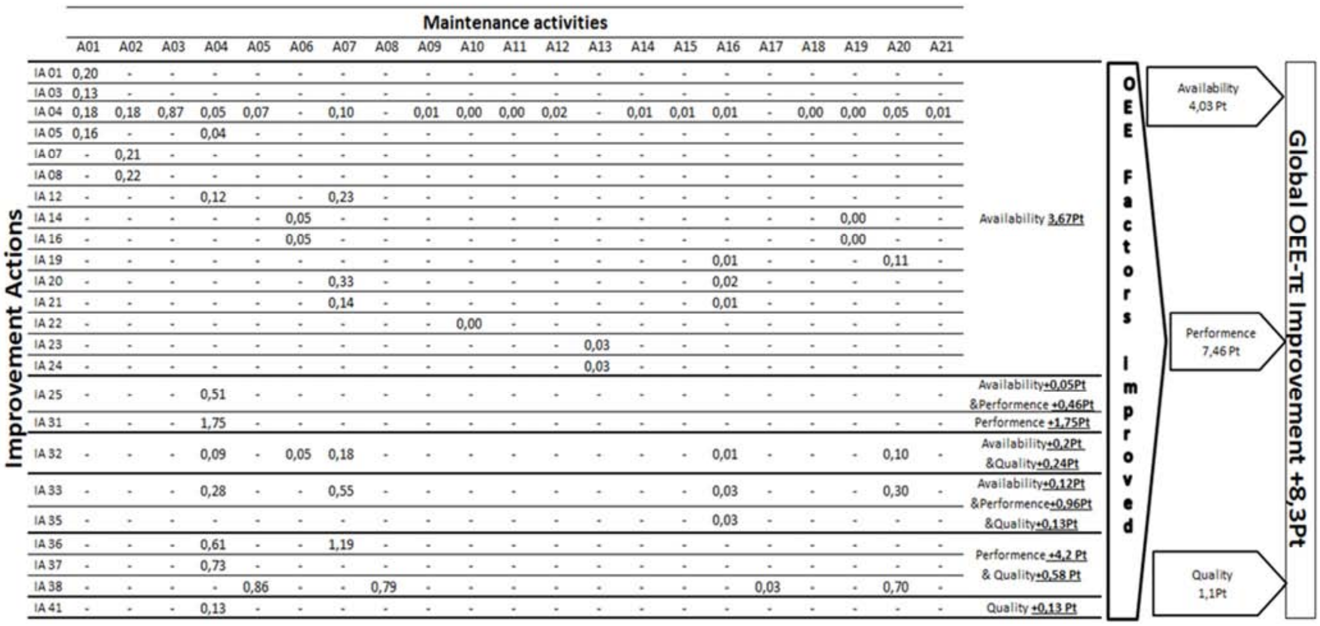

Figure 7. *Global scheme of effectiveness improvement.*

***Table 6.** ACP Calculating procedure.*

CPG Cost pool generator	CDR Budget Bugeted unit Cost driver rate	F1 Availability	F2 Performance	F3 Quality	CDR Actual Actual Unit Cost driver rate	CPP Cost Performence	ACP Average Cost performence
Labor cost : Trimmer	29	*			31	93%	
Labor cost : Maintenance Manager	13	*			13	100%	
Labor cost : Production Manager	16	*			16	100%	
Labor cost : Supervisor	20	*			20	100%	
Labor cost : Mainatenance Technician	23	*			24	93%	
Ovehads costs : Maintenance cost	90	*			95	95%	96%
Direct Labor costs	37		*		38	97%	97%
Other indirect labor costs	29			*	28	104%	
Salaried costs	74			*	72	103%	
Overheads costs	371			*	390	95%	
Depreciation	86			*	86	100%	97%

***Table 7.** OEE-TE September after improvement actions establishment.*

Machines	M1	M2	M3	M4	M5	M6	M7	M8	M9	TOTAL Plant September'14
ACP	95.8%	95.8%	95.8%	95.8%	95.8%	95.8%	95.8%	95.8%	95.8%	95.8%
Availability	73.0%	73.0%	73.4%	70.7%	77.3%	75.4%	85.6%	75.4%	70.3%	75.0%
ACP	97.0%	97.0%	97.0%	97.0%	97.0%	97.0%	97.0%	97.0%	97.0%	97.0%
Performance	96.2%	77.5%	92.5%	41.2%	91.3%	40.9%	79.1%	56.6%	46.0%	73.2%
ACP	97.3%	97.3%	97.3%	97.3%	97.3%	97.3%	97.3%	97.3%	97.3%	97.3%
Quality	95.4%	95.8%	94.6%	96.4%	95.5%	83.0%	95.2%	93.0%	88.1%	94.5%
OEE-TE September'14	67.0%	54.2%	64.2%	28.1%	67.4%	25.6%	64.4%	39.7%	28.5%	51.9%
OEE-TE February'14	59.8%	47.0%	58.3%	16.7%	59.4%	27.5%	54.5%	27.4%	23.2%	43.6%
OEE-TE Improvement	7.2%	7.2%	5.9%	11.4%	8.0%	-1.9%	9.9%	12.3%	5.3%	8.3%

In parallel, questions of: how much is cost saving due to improvement actions in each OEE-contribution factor and how much is one point of the OEE-TE could be answered.

Total savings per month is calculated by using CDR for each contribution factor improvement hour:

Availability: 185h*200 MAD=39 KMAD

Performance: 329h*38 MAD=13 KMAD

Quality: 314h*576 MAD=181 KMAD

Total OEE-TE: 238 KMAD with 1pt=29 KMAD

As presented in Table 7, the global OEE-TE improvement for each machine and total plant.

Global OEE-TE is improved for all studied machines due to implemented actions except for machine (M6).

4.4. Return on Experience

Results:

OEE-TE February: 43.6%

OEE-TE Septembre: 51.9%

Improvement rate: 8.3 %

Global Saving cost: 238 KMAD

Cost of one point OEE-TE = 29 KMAD

The proposed approach is very helpful for companies looking for performance improvement of their operational processes. In this case study, OEE-TE was improved by 8.3 points (43.6% in February VS 51.9% in September) with a global savings of 238Kmad per month (One point=29 Kmad).

Improvement actions must be maintained and monitored, in parallel a new target is defined to reach higher improvement points and explore total opportunities presented in the case study. So OEE-TE target can be fixed to 85% for both injection and assembly lines, and opportunities are 33.1 Pts to be reached by an exhaustive use of improvement actions.

5. Conclusion

The basic contribution of this paper is to propose a new tool of maintenance performance measurement and improvement based on the combination of Lean and Overall equipment effectiveness approach. Firstly, maintenance activities were mapped and improved via smart improvement actions, then the actual OEE was criticized and improved by taking into consideration technical and economic factors. Proposed factor OEE-TE was associated to lean improvement actions to establish a global effectiveness increasing scheme. It could be easily employed by all maintenance engineers and researchers involved in the problematic of maintenance process.

Process approach is used to describe key activities of maintenance operational processes: preventive and corrective maintenance. Discussed application gives an idea about impact of lean actions on the Overall Equipment Effectiveness, and also the equivalent of quantitative aspect of one point of OEE in term of cost saved.

The proposed tool could be used by researchers and practitioner to have both technical and financial information about maintenance process.

Certainly the proposal can be improved. However the limitation of the proposed model is linking and restricting the study of maintenance process to two main processes, preventive and corrective.

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