A Model to Identify and Prioritise the Causes behind Losses in Company profit: Application Example

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Abstract

A production process includes several sub-processes (working areas) that are responsible for performing the different tasks required to accomplish the mission of the process. Thus, it is important to avoid a shortage of resources, unplanned stoppages and idle times that may arise. The problem addressed in this paper is: How should maintenance be considered in conjunction with plant activities, such as production, quality and personnel competence for easily and effectively identifying and quantifying company losses in profitability and eliminating underlying causes? In this paper, the interactions between major working areas have been introduced and discussed. The major result achieved in this study is the development of a new model (Maintenance Function Deployment (MFD), for an easy and effective identification and quantification of company losses in profitability. Four matrixes have been used for developing MFD model for effectively integrating maintenance with production, competence and quality. An application example is conducted to demonstrate the possibility of applying the model and its potential for enhancing production processes profitably. The main conclusion is: applying MFD gives an enormous opportunity to continuously maintain the quality of the working areas under consideration, which makes MFD one of the company's objective-driven tools for enhancing its profitability and competitiveness.

Keywords: Production Process; Vibration-based Maintenance; Maintenance Integration; Company profitability and competitiveness; Maintenance function deployment.

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INTRODUCTION

It is well known that the working areas such as production, quality, competence and maintenance in a production process interact with each other[1,2,3]To evaluate the condition of a production process/machine/component, production costs and other relevant data of high quality are needed [2]. A common database can be established where data from relevant working areas, such as production, quality, administration, maintenance and life cycle costs, are gathered without duplication in a common physical or virtual database[2,4,5]. These data are necessary for performing reliable, easier and faster mapping, following up and assessment of production cost, product quality, plant condition and performance[2,5]. The integrated information system provided by a common database enables the user to achieve more accurate and comprehensive holistic view and a sufficiently detailed description of the process condition, operating conditions, product quality, production cost factors, etc. [5,6].

Consequently, many primary potential benefits, such as more accurate diagnosis, prognosis, prediction and cost-effective decisions, can be obtained, which in turn can lead to secondary potential benefits;

1. increased certainty in the information acquired for enhancing quality of the decision-making process,
2. increased data availability that can be used for monitoring, mapping, analysis and decision-making,
3. better data coverage, which is required for modifying the available asset or for redesign it,
4. enhanced process stability, reliability and quality, machine and plant safety due to detecting damage at an early stage to reduce failures and failure-based accidents [3].
5. prolonged machine life length due to maintaining the quality of the machine via reduced failures
6. improved quality rate, due to the ability to detect and eliminate damage causes at an early stage,
7. better opportunity for reducing long-term operating costs through better optimization, [2,3,5,7].

1. Maintenance Role in the Production Process

The production personnel’s technical knowledge and experience in machine construction and functions influence production and maintenance costs as well as machine performance efficiency, because they affect the way of using and maintaining the machine quality (technical specifications). In [8] is cited that the amount of money spent company-wide on maintenance by du Pont in 1991 was roughly equal to its net income. Product quality, production cost, machine condition and its life length are usually influenced by the quality of the input elements involved in the production process, such as raw material, production tools, methods and procedures, operating and maintenance staff competence and operating conditions, and not just by the type of production machinery and maintenance policy [3]. Bad raw material or badly trained operating and maintenance staff often lie behind the initiation (or development) of damage in the component/equipment or cutting tool, which in turn results in production and financial losses (Ibid). Thus, the quality of the essential elements involved in production process is a key factor influencing overall equipment effectiveness (OEE). In general, neglecting maintenance and its role in the production process may lead to a faster degradation of machine and product quality [3]. It is well known that a process or machine in a bad condition cannot be expected to be capable of long-term high quality production delivered on time at a competitive price. The real status of maintenance in company culture has not yet properly been recognised, because of the lack of research highlighting the maintenance impact on company business [6].

A machine associated with failures often produces defective items [9]. From everyday experience, a machine with frequent failures that produces a high percentage of defective items increases the probability of delivery delay and high production costs, which in turn reduces profit and increases the risk of losing market shares and thus endangering the survival of the organisation in the long term. Reducing production losses and enhancing product quality always yield greater profit and improvement in the company's competitiveness, [3].

Also, the role of maintenance has not been effectively and quantitatively highlighted. This is because the major

part of the profit that an effective maintenance may generate demands a big amount of effort to assess, whereas it is often easier to only measure maintenance costs, [3].

By applying effective maintenance, such as Total quality maintenance (TQMain), company profitability and competitiveness can be enhanced through the continuous cost-effective improvement of production and maintenance processes [2,3,6]. The latter can be achieved via maintaining and improving the quality of the elements involved in the production and maintenance processes continuously and cost-effectively, [3,6]. In this paper the role of effective maintenance is defined as: a means for detecting and controlling the deviations in the condition of a production process/equipment, production costs, working environment and product quality in order to interfere when it is possible to arrest or reduce the deterioration rate before the process condition and product characteristics are intolerably affected. Also, to perform the required action to restore the process or equipment/component to as good as before at continuously reducing cost per unit of quality product.

2. Model Development

The major characteristics specifying a production process that are of significance from the maintenance point of view are: failures, consequences, condition of producing machines, quality rate, economic losses per one-hour production stop and per one scrapped item, maintenance competence & experience available in the production department, type of production machines, production speed, loading frequencies and working environment. These characteristics influence the overall equipment effectiveness (OEE) and, consequently, the process of deciding the maintenance strategy or policy that should be implemented [3]. The major focus has been given are on the Whats and Hows in the model's four phases (matrixes) required to reflect how the main objectives of a production process/station are converted to specific actions necessary for eliminating losses and maintaining the quality of the elements involved in the production process cost-effectively. To avoid complexity in the model and to facilitate the understanding of its role and potential benefits the following elements are not considered in detail in MFD: Importance of each What and How, competitive assessment (for similar/equivalent machines), Target value that is different for different Whats (maximum losses allowed or the minimum capacity utilisation acceptable for the element in question), improvement direction, correlation matrix, sum of correlation and relationship matrix.The final outputs of the production process that are stated in the first phase as Whats, are considered as the reference for the outputs that should be provided by a production process to be able to fulfil its mission, see Figs 1 and 2a,b,c & d. For simplicity, we focus on one production station instead of a production line. The generalisation of the results of handling one production station to the rest of the production line, taking into consideration the essential differences, can then not be impossible. Also, we consider that all production stations' outputs should be achieved to fulfil the company's strategic goals.

The goals to be achieved by a production station are usually specified in technical terms, e.g. production rate, product characteristics expressed in; tolerances, surface finish and quality, as well as in economic terms, e.g. production cost, economic losses & profit margin. From industrial experience, maintaining the condition of production assets and reducing their share of pollution to the environment are considered as essential elements in the outputs of a production process & consequently of production stations. Achieving the planned outputs of the production

process/stations is necessary to preserve the continuity in the production process at the pre-determined specifications; otherwise it will not be easy in the long term to maintain a profitable business. In Fig.1 the bold-style arrow is used to indicate the direction of the model development, i.e. the model is developed backwards from the company's strategic goals towards the factors required to support the integration of maintenance with plant activities. The reverse arrow is used to indicate the direction of applying the model (starting from the factors required to support maintenance integration with plant activities forward to achieve the company's strategic goals).

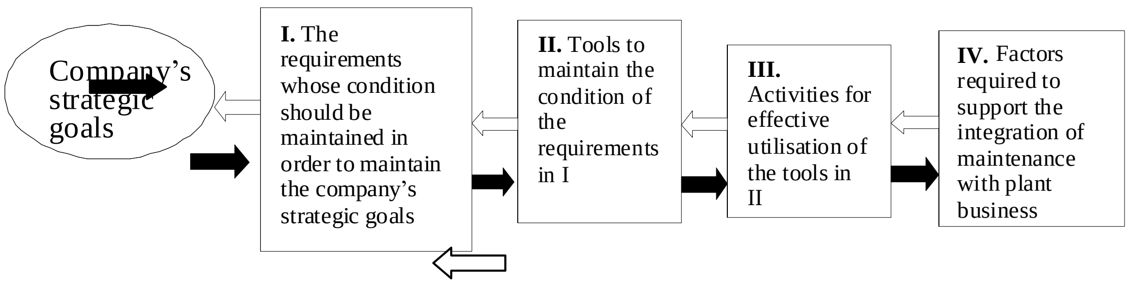

Fig.1. Schematic description of the model's four phases

2.1. Model Construction

The outline of the model Maintenance Function Deployment (MFD) consists of four phases, Fig.1a,b,c,d:

I. Phase One: It starts by identifying the objectives/goals that should be achieved. In this paper, we specified five objectives, which are common for companies/production processes or stations in a very wide range of branches:

(1) High quality (technical specifications) of the item/product.

(2) Delivery on time.

(3) Competitive price. To enhance company competitiveness the profit margin should be big enough to enable the company to offer its customers a competitive price. It can be achieved through reducing production economic losses continuously, [10].

(4) Environment-friendly production process and product, (ibid).

(5) A production machine in a reliable condition. It provides the company with a reliable opportunity to sell the machine after its designed life instead of paying scrapping fees, [11].

These objectives, i.e. the Whats, are stated as the goals that every production station strives to achieve. They are highly influenced by the elements involved in the production process, e.g. machine condition, working environment, personnel competence, maintenance policy, raw material, production method and procedures, cutting tools and quality system, etc. To achieve, maintain and improve the mentioned goals, the requirements needed (Hows) should be specified using a technical analysis of the company's strategic goals, production process and the production station in question.

In Fig.2a we identify the most important requirements for achieving, maintaining and improving; product quality, delivery on time of production that is accepted by the society at a competitive price and maintaining the manufacturing machine in a reliable condition. These requirements are; reliable quality and production logistics systems, working environment, machine and tool condition, staff competence, production rate. Maintaining the high quality of these requirements will ensure the production of high quality products at a competitive price and delivered on time [6]. If the elements; raw material, energy and operator, are available at the required quality, one or more of the following causes can result in a stoppage and probably a delivery delay: machine and tool condition, disturbances in the production logistic system that influence its availability, variations in the production rate, machine capability of producing high quality products, [10]. The price of a product is usually decided on the basis of internal and external factors.

The internal dominating factors influencing product price include: machine and production station unavailability, bad quality cost, quality system malfunction, incompetent personnel, bad machine condition, energy consumption, waste of raw material, the insurance premium, material flow problems, etc., [3]. The external factors are mainly dominated by raw material cost, market demands, competition, crises, wars and currency value. In this paper, we consider only the internal factors, because they are of major interest for maintenance. External factors lie outside the context of the maintenance influential area, [3]. Focusing on the internal factors, we realise that the control of production losses has an influential impact on the profit margin and consequently on the product price giving that all the production can be sold [10].

Taking into consideration the increasing number of people who are conscious of environment problems, a production that does not expose society and the global environment to unacceptable hazard, pollution and harm is more acceptable nationally and internationally. The requirements that help to achieve a better environment are those, for instance, which are related to the condition of the machine, losses in material and production and rational use of machines & energy. Also, these requirements increase the probability of preserving the producing machines in a reliable condition, [10]. For simplicity, the lateral interactions between the columns, i.e. Hows, are ignored in this paper.

In each of the four phases, the model provides a possibility to allocate the accumulated share (importance) of the Whats and Hows in developing the accumulated effect for each What and the current situation experienced by each of the Hows. For example, the share of every column (Hows) in the economic losses is generated by bad quality production, additional production expenses due to delivery delay or environment damage penalties, etc. Besides, the accumulated effect of each of the Whats is generated by the shares of all the participating Hows in that What. This will be described in the example introduced in Figs 2a, 2b, 2c and 2d. In this application example we assumed that the losses in a company’s profit are generated due to bad quality, delivery delay, failures, violation of environment and bad machine condition. The shares of these losses are divided focusing mainly on availability. The same thing is done when the losses are divided according to the Whos in all the model phases. For example, to determine the impact of machine condition on production cost, the economic losses due to failures & disturbances should be assessed [3].

The production cost consequently influences company ability in offering its customer a competitive price. In the same way we can assess the impact of machine condition on the production delivery schedule. When these shares are clearly determined, it would be possible to develop a priority list of the tasks, indicating which of the Whats based on its importance should be considered for deeper analysis for achieving a cost-effective improvement.

II. Phase Two: The requirements (Hows) needed for achieving, maintaining and improving the outputs described in Phase One, are moved to the column of Whats in the Phase Two matrix. To describe the new Hows, a spectrum of the tools that are necessary to preserve the condition of the requirements shown in Phase One should be specified. It is important to treat every requirement individually to facilitate the tracking of the cause-result links for each particular area. Using this systematic analysis, a large number of tools of different correlations and impact importance will be approached. In this paper, we focus on the most essential tools related to maintenance and its impact on company business to avoid unnecessary and unmotivated difficulties in the model development.

In general, it is possible to identify the major sub-Hows required for determining the tools that are needed for maintaining the condition of any of the requirements. For example, the sub-Hows needed for selecting a cost-effective and comprehensive maintenance policy for a component/ equipment are summarised by:

(1) Identifying and quantifying production cost, failure rate and consequences.

(2) Identification of significant elements in the production process.

(3) Assessment of economic losses per one-hour production stoppage.

(4) Available knowledge of and experience in maintenance.

(5) Criteria for selecting the most cost-effective maintenance strategy/policy.

(6) Quantification of failures impact on the working environment, [2,3,6].

Furthermore, a cost-effective and continuous improvement policy consists of several sub-hows, e.g. failures and their consequences, staff competence training programs, failure impact on the working environment and deficiencies in the maintenance policy. Keep in mind that traditional never-ending improvement policy would not assure a cost-effective continuous improvement of the product quality and process profitability without realising the cost-effectiveness of every effort has been done in improving the process, [3,6].

For simplicity, we considered only the Hows that are necessary for maintaining the condition of the requirements needed for achieving, maintaining and improving company strategic goals and neglecting their sub-hows. Developing and applying the model on this level allows us to better understand its role in integrating maintenance with the other working areas in the plants, and to easily generalise it to the other requirements and sub-Hows later. To maintain the condition of a significant component in a production machine, it is necessary to apply a relevant maintenance policy fulfilling the expectations. Also, to achieve the predetermined results, this maintenance policy cost-effective and comprehensive [7]. In general, applying any maintenance technique except a breakdown strategy demands a suitable measuring and analysis system for providing maintenance staff with relevant information. Furthermore, maintenance policies demand measuring and analysis systems of different architecture and contents [5]. For example, when applying age-based maintenance, the age of the component/equipment is the most important. But when using CBM, measurements and analysis from CM parameters are demanded, which in turn demands different database architecture to cover a wider data surface and make it easily accessible.

The database required for TQMain includes a wider range of data (from CM systems, operating condition, organisational and accountancy systems). A clear and obvious measuring and analysis policy can be considered as a separate tool or as a tool included in the comprehensive maintenance policy. It eases maintaining the quality of the elements involved in a production process. The maintenance standard and instructions for applying high quality maintenance can be very important for avoiding faulty and irrelevant actions to reduce the losses and increase process profitability. The tools for maintaining the condition of the requirements, e.g. maintenance policy, cost-effective continuous improvement policy, measuring and analysis system and a standard for doing maintenance properly, are specified in Fig. 2b as the new Hows.

Losses category according to the outputs to be achieved, maintained and improved (Whats)	**Target value (Max. losses)**	**Requirements necessary for achieving, maintaining and improving the**	Production machine condition	Machine tool condition	Working environment	Production rate, e.g m /min	Quality system condition	Competence of the staff	Condition of the production logistics system	**Importance of Whats (Total)**	**Priority list of the actions required for improvement**
Bad quality			3%	1%	0	0	3%	2%	0	9%	Third priority
Delivery delay			5%	1%	1%	3%	0	1%	2%	13%	Second priority
Lost profit margin (due to failures)			30%	4%	7%	13%	0	6%	5%	65%	First priority
violation of the Environment			4%	0	2%	0	0	0	0	6%	
Bad machine condition			7%	0%	0%	0%	0%	0%	0%	7%	
Importance of Hows (Total)			**49%**	**6%**	**10%**	**16%**	**3%**	**9%**	**7%**	**100%**	

Fig.2a. Shares of How's in generating the losses are classified according to the company strategic goals.

III. Phase Three: In this phase the Hows represent the activities necessary for effective utilisation of the tools used for maintaining the condition of the requirements expressed in Phase Two are introduced. Due to deterioration, tools should be continuously maintained and improved to be accommodated to the changes in the production process and operating conditions. Therefore, a reliable training programme, new experience, edge knowledge and instrumentation, for enhancing the competence of the staff is necessary to prevent the recurrence of problems and eliminate their root-causes [3]. Also, this reduces the efforts required for maintaining the quality of the input elements in the production process. Furthermore, it will enhance the precision of the repeatability of the procedures of applying maintenance actions, which in turn reduces the probability of bad quality maintenance actions, e.g. the adjustment, replacements and repair of the deteriorated components, and consequently increases the probability of maintaining the processes/machine/cutting tools at an acceptable level. From everyday experience, training and re-training of the staff can be done effectively if there is a special training programme.

However, keep in mind that selecting and applying the best cutting tools, methods, machines, etc. will not guarantee keeping them best in time without a clear and well stated policy for cost-effective and continuous improvement, see also Fig. 3c. Techniques for monitoring the performance of a production process, e.g. production rate, are significant for achieving the productivity and consequently the profitability level demanded. Also, using technical and economic measures for mapping the performance of the whole process provides a reliable opportunity for analysing and judging the effectiveness and productivity of the production process

[3]. Mapping of production and maintenance processes for following-up and analysis of the

situation to detect deviations and perform improvements cost-effectively can normally not be done properly without a reliable data- and knowledge base. The latter provides a wide coverage of relevant data, knowledge and experience concerning these processes (Ibid).

Requirements for achieving, maintaining and improving the outputs (Whats))	Target value (Max losses)	Tools necessary to preserve the condition of the requirements	Lack of or inefficient maintenance policy	Lack of or inefficient & measuring analysis system	Lack of or inefficient & cost effective continuous improvement policy	Lack of or inefficient & standard instruction in maintenance	Importance of Whats (Total)	Priority list of the actions required for improvement
Production machine condition			21,0%	8,0%	13,0%	7,0%	**49,0%**	First priority
Machine tool condition			2,0%	2,0%	1,0%	1,0%	**6,0%**	
Working environment			3,0%	2,0%	3,0%	2,0%	**10,0%**	
Production rate, e.g. m/min			7,0%	4,0%	4,0%	1,0%	**16,0%**	Second priority
Condition of the product quality system			1,5%	0,5%	0,5%	0,5%	**3,0%**	
Competence of the operating and maintenance staff			5,5%	1,5%	1,0%	1,0%	**9,0%**	
Condition of the production logistics system			3,0%	2,0%	0,5%	1,5%	**7,0%**	
Importance of Hows (Total)			43,0%	20,0%	23,0%	14,0%	**100,0%**	

Fig.2b. The shares of the tools in causing problems for the requirements.

Tools that are necessary to preserve the condition of the requirements (Whats)	Target value (Max losses)	Activities necessary for effective utilisation of the tools in phase two (Hows)	Lack of or inefficient training program to improve staff competence	Lack of or inefficient technique for monitoring and adjusting production rate and working environment	Lack of or inefficient measures for monitoring process performance and cost-effectiveness	Lack of or inappropriate data and knowledge base	Importance of Whats (Total)	Priority list of the actions required for improvement
Lack of or inefficient maintenance policy			26,0%	3,0%	8,0%	6,0%	43,0%	First priority
Lack of or inefficient measuring and analysis system			7,0%	3,0%	2,0%	8,0%	20,0%	Third priority
Lack of or inefficient cost-effective and continuous improvement policy			11,0%	1,0%	2,0%	9,0%	23,0%	Second priority
standard and instruction for doing maintenance properly			5,0%	0,0%	0,0%	9,0%	14,0%	Fourth priority
Importance of Hows (Total)			**49,0%**	**7,0%**	**12,0%**	**32,0%**	**100,0%**	

Fig. 2c. The shares of the activities in causing problems for the tools.

IV. Phase Four: In this phase, the Hows from Phase Three become the Whats of Phase Four, Fig. 2d. The new Hows are the factors required to support the integration of maintenance with plant business, which can in many cases be considered crucial to achieve the strategic goals. It is well known that the application of overall concepts, e.g. TPM and TQM, demands among others the commitments of the Company Board and chief manager, [12]. Thus, the commitment of the chief manager confirmed by a special budget for highlighting maintenance role in the company's business and promoting its integration with other activities is required for enhancing maintenance performance. The budget considered for integrating the maintenance strategy with the strategies of other relevant working areas may be considered as a risk capital, it is regarded as an investment to improve the production process output.

Activities necessary for effective utilization of the tools in pahse two (Whats))	**Target value (Max Losses)**	**Factors required to support integrating maintenance with plant business (Hows)**	Lack of or inefficient strategic plan for integrating maintenance with plant business	Lack of or insufficient risk capital for integrating maintenance with plant business	Lack of or irrelevant experience in the production machines/process	Lack of or inefficient managerial and organisational tools	Lack of or insuitable criteria for selecting tools, methods & policies (most informative CM, most cost-effective maintenance)	**Importance of Whats (Total)**	**Priority list of actions required for improvement**
Lack of or inefficient training program to improve staff competence			15,0%	13,0%	10,0%	11,0%	0,0%	49,0%	First priority
Lack of or inefficient monitoring & adjusting technique for production rate & working environment			3,0%	2,0%	2,0%	0,0%	0,0%	7,0%	Fourth priority
Lack of or inefficient measures for monitoring process performance & cost-effectiveness			4,0%	3,0%	2,0%	2,0%	1,0%	12,0%	Third priority
Lack of or inappropriate data & knowledge base			10,0%	10,0%	3,0%	5,0%	4,0%	32,0%	Second priority
Importance of How's (Total)			**32,0%**	**28,0%**	**17,0%**	**18,0%**	**5,0%**	**100,0%**	

Fig.2d. The shares of the factors for causing problems for the activities.

Therefore, the new output should always justify the investment, which is generally possible [2,3]. Technical and economic criteria for objectively selecting cost-effective methods, policies and tools are necessary, [7]. Personnel special training programme is important after doing the

selection properly. Developing and improving the tools expressed in Phase Two should be done with respect to both technical feasibility and cost-effectiveness; otherwise it might be easy to achieve high technological solutions albeit at very high and unacceptable costs. Technical knowledge of and experience in the behaviour, failure rate and consequences of the essential elements in the production process under consideration are necessary for performing a successful selection of the relevant measuring and analysis system, maintenance policy and training programme, [3].

DISCUSSION AND CONCLUSION

Applying maintenance function deployment (MFD) gives an enormous opportunity to make significant improvements in the quality of the working areas considered in the integration. It can assist the achievement of an easy and effective identification, quantification and elimination of company losses in profitability and competitiveness. The example conducted in this paper reveals and describes the way of application and the potential of the model in identifying, quantifying and possibly eliminating the root causes behind technical and economic deviations. MFD can also be utilised to justify the investments required for enhancing company profitability when planning for eliminating the root-causes. The investments suggested for the actions in the prioritised list can be compared with the anticipated savings that can be achieved by better performance when the root causes behind the deviations have been eliminated. In other words, MFD functions can be utilised as a decision support tool for judging the cost-effectiveness of the investments in advance, which can be controlled accurately after the improvements have been done. The analysis and improvement of production and maintenance processes may be carried out effectively if the causes behind deviations can be classified with respect to the strategic goals and the requirements for maintaining and improving these goals.

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