



# Development of a maintenance performance measurement framework—using the analytic network process (ANP) for maintenance performance indicator selection



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## ABSTRACT

The competitiveness and performance of manufacturing companies depend on the availability, reliability and productivity of their production equipment. This recognition has led to a drastic change of perception on maintenance over the past decades, evolving from a “necessary evil” to a “value adding” activity. In order to ensure a good performance of the production plant, maintenance managers need a good overview of maintenance processes and achievements. This can be attained by a rigorously defined maintenance performance measurement (MPM) system and maintenance performance indicators (MPI). Many performance measurement frameworks and indicators are presented in literature; however some major issues remain unresolved. Many papers discuss the development of generic maintenance performance frameworks and corresponding indicators; however none of the publications considers the selection of relevant MPI for a specific business context and consequently in relation with the company’s maintenance objectives. Moreover, the link with the manufacturing and corporate strategy should be established in order to establish an MPM system useable throughout the entire company. In this way, maintenance performance measurement should be defined on all management levels (i.e. strategic, tactical and operational). To overcome these problems, the objective of this paper is to develop an MPM framework that aligns the maintenance objectives on all management levels with the relevant MPI used. In order to assist the maintenance manager on selection of the relevant MPI, an analytic network process (ANP) model and methodology is presented which is based on the designed MPM framework. The methodology is applied to several case studies considering companies from different types of industry. The results illustrate the applicability and capability of the presented MPM framework and ANP model to assist maintenance managers in the definition and selection of MPI in line with the maintenance and corporate objectives and strategy. The ANP approach enables the decision maker to better understand the complex relationships in the decision problem, which improves the reliability of the corresponding decisions.

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## 1. Introduction

In the face of the economic downturn, current global competition and increasing demands from stakeholders, there is a distinct need to improve manufacturing performance. Furthermore, as a consequence of the implementation of advanced manufacturing technologies, the increase in automation and the reduction in buffers of inventory the pressure on maintenance is increased [1]. In this way maintenance management becomes centrally relevant for a company to stay productive and profitable. Within this maintenance management function, maintenance performance measurement (MPM) is perceived as an important function to

achieve sustainable performance of any manufacturing plant [2,3]. In order to achieve this, maintenance managers need a good track of maintenance process performance, which can be achieved by a rigorously defined performance measurement system (MPM) and indicators (MPI) that are able to measure maintenance function performance. This is reflected and supported by the many proposed MPM approaches in literature. Recently, extensive literature reviews on the implementation of performance measurement systems [4] and maintenance performance measurement [5] are published. Despite the extensive research on maintenance management and performance measurement, still some major flaws in the available methodologies remain unsolved. The link between the strategic objectives of the company and the corresponding MPI is lacking. Together with the lack of a methodological approach to select business specific MPI based on the corporate strategy and derived maintenance

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objectives, these form the major directions of future research necessary to improve currently available MPM systems.

MPM systems need to be aligned with the corporate or organizational strategy [6–8]. In order to accomplish the top-level objectives of the maintenance strategy, these objectives need to be translated to the lower levels of the organizational structure [9]. Crespo Marquez and Gupta [1] propose to align maintenance management with all actions at the three levels of business activities (i.e. strategic, tactical and operational). Maintenance priorities in order to derive and track maintenance performance must be set according to criticality functions directly linked to the company's business goals. The authors mention that a main concern for business management is establishing the parameters influencing the criticality function and their relative weight, which changes according to the current business environment. Moreover, there is little literature available on the development of a systematic approach that embraces every level of business activities (i.e. strategic, tactical and operational) [10]. Parida and Chattopadhyay [11] presented a multi-criteria hierarchical maintenance performance measurement framework to resolve this issue; however their framework does not provide any guidance on the selection of business specific MPI. This brings us to the second major flaw in MPM systems identified from literature.

The available literature mainly proposes common lists of MPI but lacks an agreed-upon methodological approach of selecting or deriving business specific MPI from the listed indicators in literature [2,12]. Therefore, maintenance managers are left to select relevant MPI for their specific business situation. As it is definitely not feasible to monitor or measure all of the available indicators due to the increase in number and type of measures [13], selection of MPI in line with the business environment and maintenance strategy is crucial. Swanson [14] identifies the formulation and selection of MPI that reflect a company's organizational strategy as a major issue. Moreover, Muchiri et al. [2] mention that an operational level based maintenance measurement model that links maintenance objectives to maintenance processes and results is lacking. The development of such a model could provide a basis to identify business specific MPI for the maintenance function. The study performed by Muchiri et al. [12] revealed a lack of direct alignment between the maintenance objectives and the maintenance MPI used, while one would expect that the MPI used in a company are directly influenced by the maintenance objectives and in accordance with the needs of its manufacturing environment. Moreover, only a minority of the companies have a high percentage of decisions triggered by the defined MPI. These results definitely raise doubts on the effectiveness and efficiency of currently defined and implemented MPM systems. Among the issues proposed in future research is the establishment of a methodological approach of deriving MPI from maintenance objectives. Such an approach can potentially support maintenance managers in deriving business specific MPI. Performance measurement, when used properly, should highlight opportunities for improvement, detect problems and derive corresponding solutions [15]; which is currently not the case according to the study of Muchiri et al. [12].

As a conclusion, it can be summarized that most models, methodologies and frameworks on MPM are generic, without considering the business specific environment of the company where these tools should be applied. Therefore, the link between the corporate strategy and the used MPM and corresponding MPI is not established in a proper way. A second major flaw in the available literature on MPM is the lack of methodological approach to select or derive business specific MPI. The objective of this paper is to tackle these issues by proposing a new MPM framework which is based on the corporate and maintenance

strategy, by incorporating all organizational levels (i.e. strategic, tactical and operational). Furthermore, an ANP model to determine business specific maintenance objectives and corresponding MPI based on the developed MPM framework is presented. The link between corporate strategy, maintenance objectives, MPI, decision making and continuous improvement is concretized. In this way, a customized MPM with corresponding MPI that fits the business specific environment and needs of a company is derived. The methodology assists decision makers and more specifically maintenance managers in the selection of MPI in line with their specific maintenance and manufacturing strategy. The developed methodology is applied to five industrial case studies to illustrate and validate the proposed approach. An overview and short description of the case studies is given as follows:

- Company A: manufacturer of wind turbine components
- Company B: manufacturer of industrial systems and provider of additional service contract
- Company C: medium size hospital
- Company D: large university hospital
- Company E: military aircraft operator

The remainder of this paper is organized as follows. Section 2 of this paper describes the developed maintenance performance measurement (MPM) framework and applied methodology in detail. An overview of the ANP methodology applied to one specific case study is given in Section 3. Section 4 discusses the selection of business specific MPI. Finally, a discussion and managerial implications are given in Section 5 and Section 6 states the major conclusions.

## 2. Maintenance performance measurement (MPM) framework

This section presents in detail the developed maintenance performance measurement (MPM) framework. Furthermore, based on a literature review, an overview of the maintenance objectives and criteria considered on the different organizational levels (i.e. strategic, tactical and operational) is given.

### 2.1. General framework and methodology

Availability of maintenance performance frameworks and indicators may not necessarily guarantee performance improvement [2]. The main reason for this is that the developed maintenance performance frameworks in literature are too generic, as MPM frameworks can be seen in most cases as a list of maintenance objectives and MPI. Consequently, as stated in Section 1, they do not provide any guidance on the selection of relevant maintenance objectives and corresponding MPI for a specific business environment. The objective of the proposed MPM framework (Fig. 1) is to link the generically defined MPM frameworks with the business environment and corporate strategy of an organization and in this way develop a customized MPM system. The proposed methodology and steps that need to be followed to achieve this are shown in the framework of Fig. 1. As can be seen the proposed ANP model, discussed into more detail in the next sections of this paper, is the enabler to define and develop a customized business specific MPM system. This is performed by defining and prioritizing maintenance objectives on all organizational levels in a first phase and deriving the corresponding MPI in a second phase. In this way, the selection of MPI is based on a prioritization of business specific maintenance objectives. The ANP model allows to analyze maintenance objectives tailored

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