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Review

Data quality assessment of maintenance reporting procedures

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ABSTRACT

Today's largest and fastest growing companies' assets are no longer physical, but rather digital (software, algorithms...). This is all the more true in the manufacturing, and particularly in the maintenance sector where quality of enterprise maintenance services are closely linked to the quality of maintenance data reporting procedures. If quality of the reported data is too low, it can results in wrong decision-making and loss of money. Furthermore, various maintenance experts are involved and directly concerned about the quality of enterprises' daily maintenance data reporting (e.g., maintenance planners, plant managers...), each one having specific needs and responsibilities. To address this Multi-Criteria Decision Making (MCDM) problem, and since data quality is hardly considered in existing expert maintenance systems, this paper develops a maintenance reporting quality assessment (MRQA) dashboard that enables any company stakeholder to easily – *and in real-time* – assess/rank company branch offices in terms of maintenance reporting quality. From a theoretical standpoint, AHP is used to integrate various data quality dimensions as well as expert preferences. A use case describes how the proposed MRQA dashboard is being used by a Finnish multinational equipment manufacturer to assess and enhance reporting practices in a specific or a group of branch offices.

1. Introduction

Data and information quality is one of the most competitive advantages for an organization in today's digital age, for example, with the rapid evolution of Internet of Things, Industry 4.0, Big Data and Cloud Computing (Chen, Mao, & Liu, 2014; Xu, He, & Li, 2010). Companies are trying hard to find out relevant strategies to make their products (physical or virtual) standout with respect to their competitors. Quality improvement of products, processes and services requires the collection and analysis of data to solve quality-related problems (Köksal, Batmaz, & Testik, 2011; Li, Tao, Cheng, & Zhao, 2015). Companies need to provide after-sales services such as maintenance and warranty services to ensure that the delivered product is reliable and in full accordance with the customer requirements. Nonetheless, providing such services inevitably generate costs for businesses (Fang & Huang, 2008). As indicated by Mobley (2002), one third of all maintenance costs is wasted as the result of unnecessary or improper maintenance practices. More recent studies have confirmed that maintenance is a major cost issue, with a ratio between maintenance costs and added-value higher than 25% in some sectors (Sophie et al., 2014). In fact, data quality practices – *including maintenance reports* – have a considerable impact on maintenance tasks, risks and business performance since poor data quality results in losses across a number of fronts (Arputhamary & Arockiam, 2015), and reciprocally, high data quality fosters enhanced business activities and decision-making.

A successful maintenance program often relies on a detailed planning and intelligent decision-making support systems. This is all the more true given that planning maintenance involves managing a set of complex tasks and resources to guarantee the maximum possible operational availability of equipment (Parida, 2007). Various stakeholders with different responsibilities are involved in this management, such as (i) maintenance planners who are responsible for scheduling planned maintenance activities; (ii) plant managers who are responsible for cost reporting and savings; (iii) maintenance managers who are responsible for the execution of planned/unplanned maintenance activities, and so on. All these experts have a common goal: reducing maintenance downtime to increase productivity. In this respect, they usually make use of maintenance reports as decision support tools, which contain useful record information such as technical maintenance logs, asset location, description of defect location codes, scheduled maintenance date, *etc.* It is thus of importance to develop and implement strategies for enhanced reporting practices, data quality control

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and management (Jones-Farmer, Ezell, & Hazen, 2014). Nonetheless, requirements related to the data and associated quality attributes are tightly coupled with the stakeholder's needs and responsibilities. For example, maintenance managers pay more attention to technical log records for their daily decision-making, whereas plant managers rather use defect and asset location-related information to manage their inventory. All this provides irrefutable evidence of the complexity of developing a flexible, intelligent and integrated decision-making support system for data quality assessment and maintenance management; it implies to take into consideration various stakeholder roles, needs, quality dimensions, and other technical and organizational aspects (Shafiee, 2015; Vujanović, Momčilović, Bojović, & Papić, 2012). Given the Multi-Criteria Decision Making (MCDM) nature of the problem, this paper investigates and develops a maintenance reporting quality assessment (MRQA) tool, whose underlying framework relies on AHP. The primary goal of this tool is to help companies to dynamically assess quality of daily maintenance data reporting activities, while taking into account specific needs or role of the end-user (i.e., a company stakeholder).

The summary of the paper is as follows: Section 2 conducts a thorough literature review of both (i) existing expert maintenance systems making use of MCDM techniques, and (ii) existing data quality frameworks, against which our research is motivated. Section 3 provides insight into the research methodology underlying the MRQA framework/tool development. Section 4 thoroughly details the MRQA framework and underlying mathematical theory. Section 5 describes a use case that shows how the proposed MRQA decision-making support dashboard is being used by a Finnish multinational Original Equipment Manufacturer (OEM) company to assess and rank company branch offices in terms of maintenance reporting quality. Conclusions, implications, limitations and future research are discussed in Section 6.

2. Data quality in expert maintenance systems

To understand how crucial and complex it is to properly address data quality in maintenance settings, Section 2.1 discusses the key maintenance business levels, along with previous research works that have used MCDM techniques to address challenges at each of these levels. Section 2.2 discusses existing frameworks for data quality analysis and management in maintenance processes.

2.1. Expert maintenance systems

Maintenance is a complex process that is usually triggered by an equipment failure or planned repair. This process requires planning, scheduling, controlling as well as deploying maintenance resources to perform the necessary maintenance actions (Duffuaa, Ben-Daya, Al-Sultan, & Andijani, 2001). Adopting an efficient approach to organize maintenance management (MM) activities is a prerequisite to its success. Several MM frameworks have been developed and applied for this purpose, one of the earliest being put forward by Pintelon and Gelders (1992) who pointed out three important business levels in the decision-making process, including the *(i) operational level*: decision regarding marketing and finance; *(ii) planning & control level:* decisions regarding resource and scheduling management, and performance reporting; *(iii) managerial level:* decisions regarding how to optimize actions and policies to be performed on-site. Later on, Levrat, Iung, and Crespo Marquez (2008) proposed a similar three business level-based MM framework, namely:

- *Strategic level:* strategic axis are expressed in quantitative and qualitative terms, and organizational maintenance strategies are defined such as corrective and preventive maintenance, risk-based or condition-based maintenance, *etc.*;
- *Tactical level:* maintenance actions such as scheduling and resource planning are planned;
- *Operational Level:* actual work is carried out in addition to access performance and future equipment conditions.

Making decisions at each of these three levels implies dealing with multiple, conflicting, and incommensurate criteria and/or objectives, as well as human judgments. Research on human judgements and decision making shows that the human brain is able to consider only a limited amount of information at any one time (Simpson, 1996), which makes it unreliable to take decisions when facing complex problems. MCDM techniques, such as AHP, TOPSIS, ELECTRE, PROMETHEE, Fuzzy MCDM, *etc.*, have been proven to be of great value in supporting decision-makers at each MM level, as summarized in Table 1.

At the "strategic level", MCDM techniques are considered for various purposes, including (i) maintenance policy selection, (ii) tool/contractor selection, and (iii) cost estimation. Table 1 provides an "at a glance" overview of scientific papers that have made use of MCDM techniques for each of these purposes. Bevilacqua and Braglia (2000); Fouladgar, Yazdani-Chamzini, Lashgari, Zavadskas, and Turskis (2012); Tan, Li, Wu, Zheng, and He (2011); Wang, Chu, and Wu (2007) developed MCDM-based maintenance policy selection frameworks taking into account maintenance cost, added-value and safety dimensions. Shahin, Pourjavad, and Shirouyehzad (2012) rather focused on the selection of appropriate (optimum) maintenance strategies, paying special attention to reliability, availability and maintainability criteria and potential interdependencies (via ANP). Durán (2011); Gomez and Carnero (2011) developed a similar approach, considering the same criteria, but rather applying ELECTRE II and FAHP respectively. Selecting appropriate tools and/or contractors for outsourcing activities plays also an important role at the strategic level, as it affects the whole maintenance management process. In this respect, (Bertolini, Bevilacqua, Braglia, & Frosolini, 2004) developed an AHP-based outsourcing service selection model considering maintenance-related criteria. Maintenance budgeting and cost estimation are other important strategic decisions that need to be properly managed. To this end, (Chou, 2009) and (Chen, Weng, & Zhang, 2005) develop two distinct utility-based assessment approaches, respectively relying on AHP and ELECTRE II, which enable decision-makers to estimate – *based on historical data of similar projects* – pavement and pipeline maintenance costs.

Looking at the "tactical level" now, MCDM techniques are mainly applied for maintenance work planning purposes, which includes (i) task prioritization, (ii) task scheduling, and (iii) resource planning. Table 1 reports some scientific papers that have made use of MCDM techniques for each of these purposes. Cafiso, Di, Kerali, and Odoki (2002); Farhan and Fwa (2009); Moazami, Behbahani, and Muniandy (2011); Ouma, Opudo, and Nyambenya (2015) and Babashamsi, Golzadfar, Yusoff, Ceylan, and Nor (2016) have all studied prioritization of road maintenance with the objective to reduce the overall cost (criteria considered in this studies being traffic volume, road safety, pavement width...). Other studies such as Monte and de Almeida-Filho (2016); Trojan and Morais (2012a, 2012b) developed MCDM-based frameworks for maintenance prioritization in the context of water supply networks, looking at strategies for reducing costs and water losses. Taghipour, Banjevic, and Jardine (2011) developed a framework in the context of healthcare maintenance management for medical equipment prioritization, considering mission criticality, age, risk, recall and hazard alerts as main prioritization criteria. Resource planning is also a very critical aspect to be tackled at the tactical level, as resources can be either human or non-human in nature. For example, (Van den Bergh, De Bruecker, Beliën, De Boeck, & Demeulemeester, 2013) develop a three-stage