Knowledge-based estimation of maintenance time for complex engineered-to-order products based on KPIs Monitoring: a PSS Approach

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Abstract

Maintenance is the most common product-oriented Product Service System (PSS) offering, as well as a core activity of the manufacturing system lifecycle, since it accounts for as much as 60 to 70% of its total costs. Commonly, in the Small Medium Enterprises (SMEs), the maintenance activities of customised engineering-to-order (ETO) products highly depend on the experience of engineers and shop-floor experts, without considering specific tools and algorithms that can capture the knowledge and reuse it in an efficient way. Moreover, the estimation of the maintenance time for a new maintenance project, which is among the main offerings in the maintenance, is solely based on the engineer’s experience and knowledge. Aiming to support the knowledge capturing and its reuse in the maintenance activities, as well as to improve the performance of the provided maintenance PSS, the present work proposes a methodology for knowledge-based estimation of maintenance time based on Key Performance Indicators (KPI) monitoring. Data captured through the KPIs monitoring tool were collected in a knowledge repository, and were processed using a Case-Based Reasoning (CBR) technique, estimating the required maintenance time. A validation of the proposed methodology was performed based on real-life data from a mold-making European Small Medium Enterprise (SME). Preliminary results indicated a significant reduction in the number of iterations between customers and the engineering department, compared to the traditional approach followed by the company, and improved accuracy of maintenance time estimation, which led to increased customer satisfaction.

1. Introduction

Most industrial sectors strive to find methods to reduce costs, time-to-market, as well as to improve quality, customer experience and expand market opportunities [1][2][3]. Nowadays, Product-Service Systems (PSS) have been established as the prominent business strategy for adding value to the company, and for selling more services instead of products. Towards that end, a significantly increased interest is observed from an academic and industry perspective, as PSS promise sustainability [4]. Our interest will be focused on the knowledge-based maintenance time estimation of a mold-making EU SME, using a data repository built from a KPIs Monitoring System [5]. Knowledge-based is called the system, which is able to, track, recall, and use historical production data. The extraction of the knowledge of experienced engineers or experts has a large impact on a SME, significantly improving its efficiency and its competitiveness [6].

Business Intelligence, in terms of analyzing historical and current data, system behavior, and performance estimation, needs further investigation and exploitation to offer a company competitive advantages [7]. Thus, the exploitation of detailed historical data transaction is crucial regarding the improvement of maintenance PSS, leading the company towards Servitization. To this end, the proposed method exploits the Case-Based Reasoning (CBR) technique [8] for the generation of a successful estimation on the expected maintenance time, for a maintenance process of the ETO
product. ETO is an approach in which a company designs and manufactures a product based on very specific customer requirements and only after the receipt of the order by a customer like molds [9]. In this type of production paradigm, every mold is unique, and may have completely different lead and maintenance times. Contrary, in the MTO there are no or minor changes between the orders’ specification, then the estimation of the lead and the maintenance times are easily predictable if one of them is known. Consequently, the present methodology aims to address the aforementioned issue of an ETO company, which is the difficulty on the estimation of required time for a new maintenance task, which inserted into the system.

Maintenance time has an implicit relationship with the Business customer, as it is undoubtedly connected to the delivery time of the repaired mold to them. Knowing when the mold will be ready for use is of great importance for the correct arrangement of the production plan. Currently, the maintenance time estimation is empirical, without a structured methodology and detection tools, consequently driving to questionable accuracy and significant deviations from the actual state. Taking into consideration that the mold industry commonly follows a Business to Business (B2B) strategy, any deviations from the promised delivery time of a mold can create disturbances at the upstream supply chain (customers and buyers of a company’s products/services). Consequently, customer’s loyalty is decreasing. Therefore, it is necessary to accurately estimate maintenance time, especially considering the cost level of a mold.

Summarizing, the present work aims to address the aforementioned identified gaps, which mainly comprise: (i) limited studies on the ETO methodologies for time estimation, (ii) nonexistence of structured and accurate way for the maintenance time estimation in the real life of ETO companies, (iii) limited adoption of the PSS business model by the SMEs. The added value flow for a SME by adding more services to the product plays an important role for its sustainability within the current intensive global competitive environment [10]. To this end, the present methodology aims to guide a mold making SME towards Servitization, by providing a very quick and effective estimation of maintenance time. The data which has been used in the implementation of the approach, are retrieved through a KPI monitoring system designed for PSS evaluation [11]. This methodology, apart from the improvement of the existing PSS, could be provided as a service to the customers.

2. State of the art

Knowledge reuse in manufacturing remains an open issue in need to be addressed, regarding not only how the data collection could be effectively and rapidly performed but also the pre-processing, the analysis, and the sharing of these data [1]. High repetitiveness and the generation of vast amount of data characterize manufacturing activities. There is significant research focusing on Knowledge Management (KM) with a view to identify, represent and distribute information, knowledge, know-how, expertise and other forms of knowledge for leverage, utilization, reuse, and transfer of knowledge across the industry. The reuse of stored data is a difficult subject, and holds significant potential for manufacturing [12]. Thus, interest is focusing on knowledge-based systems for the estimation of crucial metrics such as cost, which have been implemented following a hybrid methodology, utilizing case-based reasoning and regression analysis. Reuse of past knowledge can guide the decision-making, the design, the planning, and the operation activities of past and new projects [13]. In modern manufacturing, the reuse of expert human knowledge constitutes a key factor for improving manufacturing performance during the design, the planning, and the operational phases [14]. Yet, the expertise and the knowledge of the engineers lie in tacit form with them, and are not shared. Thus, passing from tacit to explicit knowledge by means of recording data and actions, will offer numerous improvement effects to the company [15].

Knowledge repositories and reasoning mechanisms have been employed to assist knowledge reuse about product design and development at various stages of the product lifecycle [5], [16]. Maintenance procedure is a typical and the most important PSS offering of ETO industries, once the wear and the life extension of a mold is directly related to its use-cycle. Indicatively, for many types of molds, their usage in three shifts means, 1/3 of actual time before returning to the manufacturer for repair compared to a similar mold that operates in a single shift. The current maintenance procedure concerns the repair of molds in order to bring them back to their original operating condition. Maintenance time is affected by many factors including: capacity, loading, batching, and scheduling. Those factors affect many aspects of cost and control. Owing to the fact that maintenance PSS has only recently been studied in the literature in terms of improvement, there is little research background in this field.

There is a variety of methodologies for time estimation including: Simulation, Logistic Curves, Queueing Theory, Statistics, Stochastic Analysis, Artificial Intelligence and also Hybrid Systems. Artificial Intelligence (AI) is the most robust method for time estimation. Artificial intelligence methods for time estimation are Data Mining, Expert Systems, Neural Network, Genetic Algorithms, Fuzzy Logic and CBR [17]. From the Artificial Intelligence (AI) Methods the one, which best matches to our case, is CBR a methodology in which knowledge and/or inferences are derived from historical cases [8].

CBR, which focuses on solving problems by adapting acceptable solutions and comparing differences and similarities between previous and current products, has been utilized for maintenance time estimation. Knowing that the sample number is small, CBR is the most appropriate technique among the Artificial Intelligence Techniques [8]. In essence, CBR is how people reason from experience. More specifically, CBR adapts solutions for old problems to create solutions for new problems. CBR finds cases of solved problems similar to the current one, and adapts the previous solution or solutions to fit the current problem, while considering any difference between the two situations; relevant work can be found in [18], [19], and [20].

Maintenance PSS is the main provided offering from the mold section, considering that in molding, small tolerances are required. In these terms, the mold needs to be operating as if
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