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A Knowledge-Enriched Problem Solving Methodology for the Design Phase of Manufacturing Equipment

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Abstract

During the design phase of large-scale industrial engineering projects, numerous problems usually arise, which are related to the project analysis and methods used in each phase. Such projects are undertaken by multi-disciplinary teams of expert designers and planning managers that often communicate these problems to the members of their team via emails and telephone calls. However, the alignment of efforts towards solving these problems cannot be achieved effectively though these inherently limited communication and collaboration means. In parallel, the operation of manufacturing systems is evolving towards structures that are similar to social networks. The trend is to automatically connect to web-based collaboration platforms in order to search for the appropriate experts to deal with the problem in question. Towards this end, the proposed research work focuses on the development of a knowledge-based method, which is developed into a mobile app, and focuses on providing a collaboration space for reporting, tracking, and solving project-related problems. The methodology adopts concepts from the Root Cause Analysis method, which is further enriched with knowledge reuse features. Already reported and potentially solved problems, as well as other historical data are retrieved from a knowledge repository through advanced indexing techniques in order to support the identification of solutions for newly experienced problems. Results from the interpretation of the natural language that is considered to be used in the problem reporting phase and the accuracy of retrieved solutions are further discussed. Finally, the methodology is validated through a real-life case study obtained from the die construction department of an automotive industry.

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1. Introduction

A key success factor in an increasingly competitive market, is the ability to bring new products to market and meet customer demands [1]. Additionally, the growing scarcity of natural resources requires an examination of the complete life cycle of a product aiming its valorization in end of life. Launching a new product is therefore among the most critical aspects of sustainability for companies [2]. The product release cycle is a complex, time consuming process that is based on experience and knowledge. It involves multi-disciplinary technological specialties and a great management capacity, as well as, huge volumes of information and resources from all factory departments. Efficient management of this process is both a challenge and key to competitive advantage in the market [3].

Towards that end, the proposed approach aims to support manufacturing problem solving during the design of die construction projects. A Root Cause Analysis concept is proposed enhanced with knowledge reuse features. Already faced problems constitute the knowledge that is reused and every new problem is queried against this stored knowledge to discover solutions that can be applied to the new situation.

2. State of the Art

The complexity of an application domain makes the building of a conceptual model from scratch extremely expensive especially in manufacturing domain [4]. Nowadays a large number of very comprehensive reference models are available for understanding significant relationships among the entities of a domain and support the development of consistent standards or specifications. Consequently, the ability to effectively and efficiently reuse them plays a crucial role. Reusability has been intensively studied in areas like software engineering [5, 6]. This topic has been partially explored in the field of knowledge

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engineering, where initiatives take a deeper look at evaluation and models comparison for knowledge reuse [7, 8].

Once the set of reusable reference models has been identified, a customization process is applied extending or simplifying the initial model. Then, models covering similar domains are collected and merged into one model. Finally, the conceptual models, that cover different domains, are combined into a final application. In this regard, a study is conducted in [9], which analyses the above process of knowledge reuse from a methodological viewpoint. The methodology comprises of several phases and activities, the most important, also summarised in [10], are: (i) Feasibility study, (ii) Decomposition of the domain into thematic conceptual clusters (modules), (iii) Identification of a preliminary list of ontological primitives to be included in each module, (iv) Selection of a set of candidate reference models, (v) Analysis of the candidate relevant sources, (vi) Choice of source reference models, and (vii) Integration of reference models. Once the reference framework has been set, it can be exploited as a common ground for various engineering tasks, like collaborative problem solving, storytelling, fault tree analysis, events and causal factors charting and root cause analysis [11]. The latter has its origins in the aerospace industry and has been widely used to identify and resolve occurring problems.

The Root Cause Analysis (RCA) is a well-structured process to identify the causes that led to the occurrence of an undesirable event. As a process, it has been used in many case studies. In [12], RCA is used to identify the key failure characteristics of an ignition switch and determine a response function to present the failure modes after the proper mapping of the key product characteristics. Another application is presented in [13], which uses rough set theory to find the relevance between the product's pedigree attributes and the repair actions required for a specific failure. Consequently, decision rules can be created that would classify the repair actions according to terms of product pedigree. In [14], an RCA methodology is presented that focuses on the sustainability of biodiesel processes depicting how important such an analysis can be for the domain of chemical engineering. Furthermore, in [15], a combined method of RCA and inference mechanisms is presented. It is used for a start-up failure analysis in automobiles and offers better handling of the data versus conventional methods. Finally, RCA can be used to identify the causes and prevent any possible reoccurrence of serious events such as explosions, as described in [16]. An identification of every failure and its analysis for a number of parts is emphasized in [17], where the challenge for an OEM is to detect already used patterns in problem solving in order to improve the RCA process.

In this research work, a knowledge reuse methodology is coupled with the RCA process. This novel coupling of the two methods allows the reuse of knowledge regarding already faced and dealt with problems to handle newly experienced situations in the design phase of manufacturing equipment. Consequently, already made analyses can be reused when new similar failures occur, saving time and effort. Every newly experienced problem or situation is firstly checked against a database of already tested cases. Only in case no similar situation is found, the new case needs to be analyzed from scratch.

3. Methodology Description

In comparison with the conventional process where RCA starts with analyzing the new occurring problem and search for its symptoms, causes, and appropriate solutions, similar solved past problems, their causes and solutions are extracted from a knowledge base. This knowledge is then reused and shared among teams of experts during the design phase of construction of manufacturing equipment. The aim is to enable the knowledge diffusion among the engineers and improve the process of solving important engineering problems that emerge on a daily basis.

3.1. Root Cause Analysis process

The procedure to resolve a problem according to RCA contains four basic steps [18]: Define, Investigate, Verify, and Ensure. The time spent among the four stages is depicted in Fig. 1. The proposed research work supports primarily the first two steps that take up 70% of the time for conducting an analysis. The process is improved in ways shown in the right hand-side of the figure: (i) similar past solutions are retrieved through natural language processing of the queries of the engineer, (ii) potential root causes are suggested, (iii) co-workers are notified that a new problem has emerged, and (iv) solutions are validated by teams of experts.

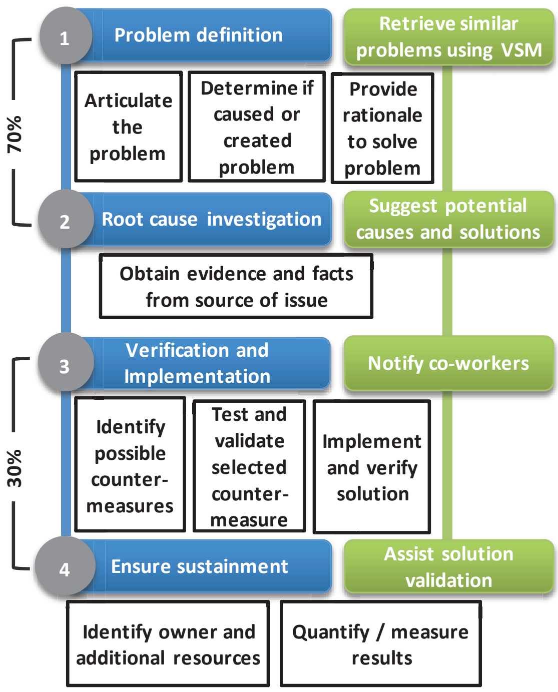

Fig. 1. Root Cause Analysis process [18] and the proposed work.

Moreover, a simple workflow design for a trouble-shooter is adopted similar to the one of Fig. 2. The symptoms are taken into consideration for the right solution to derive from the analysis process as proposed in [19].