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A rough DEMATEL-based approach for evaluating interaction between requirements of product-service system

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ABSTRACT

Requirements analysis and understanding play a key role in the successful development of Product-Service System (PSS). Some PSS requirements may interact with others and even with the environment due to different stakeholder's preference and PSS heterogeneity. Thus, it is necessary to understand the dependencies and correlations between the underlying PSS requirements. However, there are few researches on requirement interaction evaluation and analysis in the early planning phase of PSS development. Besides, PSS requirement interaction evaluation often involves much vagueness due to the subjective judgments. To solve these problems, a systematic method for assessing and analyzing PSS requirement dependencies under vagueness is proposed. The proposed method integrates strength of group DEMATEL (Decision-Making and Trial Evaluation Laboratory) in assessing interaction relationship and merit of rough set theory in manipulating subjective judgments. To demonstrate the potential of the approach, an application in an air compressors system is also illustrated.

1. Introduction

Manufacturers today are facing challenges of increasingly competitive pressure and environmental issues. It is difficult for them to provide only physical products to differentiate themselves from competitors (Kuo, 2013). Moreover, customers need personalized solutions to solve their own problems. Therefore, many manufacturers begin to offer integrated bundle of product, service, and software, which are known as product-service systems (PSS) (Mont, 2002; Song & Chan, 2015; Van Halen, Vezzoli, & Wimmer, 2005). The basic idea of PSS is not to separately sell products and services but to sell a defined result, a system's availability or just functionality.

The goal of PSS development is to satisfy stakeholders' requirements as well as to meet the company strategy (Szwejczewski, Goffin, & Anagnostopoulos, 2015). To achieve this goal, it is important to well understand the customer requirements and other stakeholders' requirements (Peruzzini, Marilungo, & Germani, 2015; Song, Ming, Han, Xu, & Wu, 2015; Song, Wu, Li, & Xu, 2015). Requirements analysis and understanding play a key role in the successful development of PSS (Cao, Jiang, & Wang, 2016; Zheng, Xu, & Xie, 2016). PSS development projects typically involve a large number of stakeholders with different views and expectations regarding the PSS, such as operators, maintenance personnel, and energy managers, etc. Beside, PSS lifecycle covers different stages of the equipment procurement, installation and commissioning, operation, maintenance, recycling and disposal. In this respect, PSS requirement is diverse, and one PSS requirement may interact with other requirements and with the environment. The satisfaction of one requirement can aid or detract from the satisfaction of another, and the environment can also increase or reduce requirement satisfaction. For example, industrial customers always highlight the "availability of repair service", and this requirement can be satisfied by expanding the "coverage of service center". However, expanding "coverage of service center" may increase the "cost of the service delivery" from the side of service provider. Therefore, it is necessary to figure out such requirement interactions for successful PSS development projects.

Requirements interaction evaluation is directed toward the discovery, management, and disposition of critical relationships among sets of requirements, which has become a critical area of requirements engineering. The main objective of requirements interaction evaluation is to analyze and manage dependencies among requirements to obtain a good requirements specification. However, previous approaches have not handled requirement interactions (Zhang, Harman, & Lim, 2013), and the PSS

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requirement interactions is always not clear due to the PSS characteristics of heterogeneity, stakeholder participation and service experience, etc. Thus, evaluation of PSS requirement interactions involves much ambiguous human perceptions and subjective judgments, which will lead to the inaccurate requirement specification and priority. However, there is a lack of systematic methods for evaluating and analyzing interactions among PSS requirements under vague environment in past research.

Therefore, in this paper, an integrated evaluation method for PSS requirement interaction is developed based on DEMATEL and rough set theory. The DEMATEL is a useful approach to visualize the structure of complex causal relations with direct-relation matrices or digraphs (e.g., cause and effect diagram, interaction map) which describes a contextual relation between different system elements (Fontela & Gabus, 1976). In this respect, DEMATEL is a suitable method to explore the PSS requirement interactions, because it cannot only reveal the strength of the interaction between PSS requirements, but also graphically portray the cause and effect relationship between requirements. However, Different with the previously used DEMATEL (Shieh, Wu, & Huang, 2010), this research integrates group DEMATEL and rough logic together to deal with the vague and subjective judgments of PSS requirement interaction. It integrates strength of group DEMATEL in revealing interaction relationships and merit of rough set theory in manipulating subjective PSS requirement interaction judgments. In this respect, the proposed rough group DEMATEL is new. Compared with the conventional group DEMATEL, the proposed method is more accurate in discerning interactions between PSS requirements to make preparations for PSS development without much prior information. Besides, it is new to focus on the PSS requirement interaction and analyzing the causal and effect relationships among requirements. To our knowledge, there are no such researches in the past to help to explore the requirement interactions with vagueness for PSS development.

The structure of the rest of this paper is organized as follows. In Section 2, some of the prior literature relating to PSS, PSS requirement and methods for analyzing requirement interactions is reviewed. In Section 3, the proposed method based rough group DEMATEL is described. In Section 4, a case study of elevator PSS requirement interaction evaluation is illustrated. Finally, according to the findings of this research, conclusions and suggestions are presented.

2. Literature review

2.1. PSS and PSS requirement

Product-service system (PSS) is bundles of physical technological elements and service elements that are integrated to solve customer problems. With the help of PSS, manufacturers extend their businesses around the products to related services, such as personal customization, process support, repair and maintenance, upgrading and recycling, product lifecycle management (Belvedere, Grando, & Bielli, 2013; Shokohyar, Mansour, & Karimi, 2014; Williams, 2007). Both product and service shares are included in one system. The PSS enables companies to provide customers with offerings that continuously deliver value and create a strong competitive advantage (Tan, McAloone, & Gall, 2007). Different with the traditional standardized product or service offerings, PSS are supposed to be integrated, lifecycle-oriented and customized service solutions to flexibly meet customer's requirements (Long, Wang, Zhao, & Jiang, 2015; Song et al., 2015), which are "sold" as one package. In this respect, PSS offer personalized solutions, and create added value for customers by offering more functionalities and flexibility (Van Halen et al., 2005). To integrate the PSS into the organization, it is necessary to make an overall determination of the customer's business processes, the company's support processes and usage of the PSS (Berkovich, Leimeister, & Krcmar, 2011). In this way, PSS providers can identify and analyze the requirements resulting from the business processes.

The key to successful solutions is, in particular, the satisfaction of wishes and expectations of the customer and stakeholders that are described in the different requirements (Nuseibeh & Easterbrook, 2000). A requirement is a defined behavior, characteristic or property, to be assumed for an object, a person or an activity which has to assure a certain result in a value creation process (Kruse, 1996). PSS requirements include different kind of requirements, such as product requirements, service requirements and software requirements. Moreover, different interactions may exist between these heterogeneous PSS requirements, e.g. relations of enhancements, synergies, substitutions and conflicts (Song, 2017). Song and Sakao (2016) believe that the requirements conflicts may lead to the difficulty of PSS concept generation, increase of service delivery failure, and eventually the decrease of customer satisfaction. To concretize PSS requirements, Berkovich, Leimeister, Hoffmann, and Krcmar (2014) propose a requirements data model (RDMod). Durugbo (2013) utilizes the Systems Modelling Language (SysML) as a technique for analyzing PSS requirements. Although some research has explore the requirement identification, analysis, prioritization (Akasaka, Hosono, Nakajima, Kimita, & Shimomura, 2010; Berkovich et al., 2011; Song, Ming, Han, & Wu, 2013; Zhu, Gao, & Cai, 2015), requirement interaction evaluation and analysis is still an emerging research field.

2.2. Methods for analyzing requirement interaction

It is well acknowledged in practice as well as in research that requirements are related to each other and that these relationships affect product development work in various ways (Papinniemi, Hannola, & Maletz, 2014). Paja, Dalpiaz, and Giorgini (2013) consider that requirements are inherently prone to conflicts, for requirements originate from stakeholders with different, often opposite, needs. Carlshamre, Sandahl, Lindvall, and Regnell (2001) believe that roughly 20% of the requirements are responsible for 75% of the interdependencies. Therefore, it is necessary to focus more on the critical requirements which influence others. Some researches on analyzing requirements dependencies have been done conducted.

Schuh and Gudergan (2009) use the qualitative interdependence analysis method to show the mutual dependence between PSS requirements. To obtain the consistent service requirements, the requirements for the service from the perspective of the customer are confronted and compared with those from the perspective of the company in a matrix. After that, the service requirements are prioritized with pair wise comparison method. Kim and Yoon (2012) use the questionnaire method to obtain car-sharing service requirements and their priorities. However, these qualitative methods neither take into consideration judgment vagueness nor interdependent requirements. The interdependencies are particularly crucial, since it can influence the final importance of the requirement. Some researchers omit the interdependencies when prioritizing requirements. Lin, Wang, Chen, and Chang (2008) apply the analytic hierarchy process (AHP) to evaluate the relative overall importance of customer requirements. Perini, Ricca, and Susi (2009) propose that the AHP is more accurate than case-based ranking method in requirements prioritization. But the human assessment on requirements is always subjective and imprecise. The conventional AHP is inadequate to determine the importance and interdependency for user requirements. To solve this problem, Nepal, Yadav, and Murat (2010)