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Development of data-driven technology roadmap considering dependency: An ARM-based technology roadmapping

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ABSTRACT

The active incorporation of business data has become a vital process in the recent business environment. Despite the potential utility of massive database, technology roadmap, a well-known strategic planning method, still remains a subjective and qualitative method conducted by some experts. Even if some studies have tried, previous research lacks a dependency measure that can be used between layers, which is a critical part of technology roadmaps. This paper therefore suggests an association rule mining (ARM)-based technology roadmap to identify the relationship between different layers. The use of ARM fits the purpose, in terms of capturing the dependency information. Two types of roadmap are developed: a keyword portfolio map and a keyword relational map. In the keyword portfolio map, four types of keyword pairs are identified according to their support and confidence. In the keyword relational map, a 2-dimensional map is developed using support as an intra-layer affinity relationship and confidence as an inter-layer dependency relationship.

1. Introduction

We live with data all around the world. With the help of information technology (IT), many kinds of business transactions occur in electric form, which causes a massive database to be generated and consumed [17,19]. With the rise of the Internet, streams of logs and user data generated from many information systems give insight not only into the operation of a system itself, but also into the behavior patterns of users [5]. In online marketplaces, customer needs and requirements are represented in the form of customer reviews or forums [3]. In addition, the products and services of a firm can be identified in many types of documents, such as service descriptions in a mobile open market, or product/service manuals.

Quite naturally, the active incorporation of these massive databases becomes an imperative and vital process for recent business environment [4,13,20]. Data can be utilized in two ways. The first usage is related to the reactive process such as a bibliometric analysis, analyzing historical patterns based on the statistical approach. The second usage deals with more prominent issue, the proactive process. The proactive process is related to the forecasting and planning process in which firms forecast future trends and plan their strategies. This means that current planning methods should actively incorporate business data into their planning procedures. The technology roadmap, which is a representative and prominent tool for the strategic planning [14,22], is no exception.

However, the development of technology roadmaps still remains a subjective and qualitative task conducted by only some experts [15]. Expert knowledge, of course, still plays a decisive role, and may be more desirable due to the strategic

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nature of technology roadmaps [11]. However, the active incorporation of business data cannot simply be neglected since it can deliver essential, unexpected, and effective information [10,15].

Responding to the needs of data-driven roadmapping, there has been some research into the analytic approach to technology roadmapping, measuring the relationship between layers in the technology roadmap [15,16,24,26,27]. The discussion in these studies has mainly focused on the quantification of relationships between planning elements, which is a critical step in technology roadmapping.

However, previous studies on the quantification of relationships in the technology roadmap surprisingly converged on a common limitation: the lack of dependency measurement. Previous studies have focused on measuring the relationship using keyword similarity, by simply calculating the frequency of keyword occurrence [15,16,24,26,27]. However, the tenet of technology roadmaps stems from identifying links among the market, service, product, and technologies of a specific firm — in other words, links between different layers. This means, measuring "causal" relationships between layers, i.e., measuring "dependency" is the core and critical information to be incorporated.

The use of association rule mining (ARM) fits the purpose. The essence of ARM is the identification of relationships and potential associations from huge amounts of data [1,9,23]. The rules used can be effective in uncovering unknown relationships which can be an inspiration for further decision making [9]. ARM is particularly capable of capturing dependency information using the confidence measure, which can be effectively implemented in the technology roadmap.

In response, this paper suggests an association rule mining (ARM)-based technology roadmap to identify the relationship between different layers, facilitating the development process of a data-driven technology roadmap. Using ARM, two types of associations are measured and employed: support and confidence. Support measures the ratio of the number of transactions that include two specific items, which can be expressed as item affinity. Confidence measures the ratio of the number of transactions containing a specific item, given in transactions containing another item, which can represent the dependency relationship. The advantage of expressing the dependency relationship in ARM is that it provides an excellent methodological sufficiency for the technology roadmap, whose core value stems from the dependency relationship between each layer.

The remainder of this study is organized as follows. A literature review deals with the theoretical and methodological background of this paper: the era of big data, technology roadmap, and ARM. The proposed approach considers how the data-driven technology roadmap can be developed and how ARM is used for this purpose. The overall process and detailed procedures are introduced. To illustrate how the proposed approach works, a simple case study is conducted. Finally, the contributions and limitations of this paper are provided in the conclusion.

2. Related works

2.1. Technology roadmap

The technology roadmap has long been considered a prominent tool for the strategic planning of technology [14,22]. It enables a firm to carry out its R&D activities in a systematic manner, laying out explicit plans about what technologies to develop, when and how. Fig. 1 illustrates the generic structure of a technology roadmap as a time-based chart, comprising a number of layers [22].

Some researchers view a technology roadmap as a visualization tool for the strategic management of technology. Although there are various definitions of the term 'roadmap', the key features and benefits typically relate to visualization and communication [26]. Many practitioners and researchers visualize or summarize such information to achieve a variety of benefits. Yoon et al. [27] present four techniques to structure technological information for technology roadmapping: summarization, information extraction, clustering and navigation.

There have been several attempts to find the most effective way to build technology roadmaps. Bray and Garcia [2] suggested three phases: preliminary activity, roadmap development, and follow-up activity. Groenveld [6] developed a seven-stage process. The development of 'T-Plan' supports the swift initiation of roadmapping in three stages: planning, roadmapping and roll-out [21], and a modified T-Plan process has also been introduced with five key modules [8]. Lee and Park [14] suggested a framework for customizing the technology roadmapping process according to its specific purposes, suggesting eight formats of roadmaps.

These roadmapping processes commonly include an important step: identifying the relationship between layers. Since the technology roadmap is a multiple-layered chart including market, product and technology layers, identification of relationships between layers is of importance for identifying the "when and how" strategy. Kostoff and Schaller [10] noted the need for measuring functional relationships in technology roadmaps. Due to the inherent uncertainties and evolving requirement changes in large programs, the structure of technology roadmap should be flexible enough to incorporate the dynamics. This denotes the importance of linked functional relationships that reflect changes at any node of technology roadmap to the whole layers of the technology roadmap [10]. The task of identifying relationships between layers, however, is mostly dependent on expert judgment [10,15]. Due to the rise of big data, a proactive process of incorporating the data is becoming increasingly important.

2.2. ARM

ARM is one of the most important and well researched techniques of data mining. It identifies associations among a

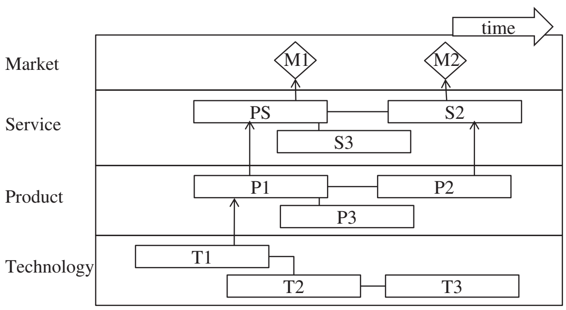

Fig. 1. Structure of technology roadmap.