ARTICLE IN PRESS
JID: KNOSYS [m5G;November 11, 2017;9:40]
Knowledge-Based Systems 000 (2017) 1–12
Contents lists available at ScienceDirect
Knowledge-Based Systems
journal homepage: www.elsevier.com/locate/knosys

Data-driven decision making for supply chain networks with agent-based computational experiment

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A R T I C L E I N F O

Article history:
Received 5 April 2017
Revised 4 November 2017
Accepted 8 November 2017
Available online xxx

Keywords:
Data-driven decision making
Supply chain network
Business analytics
Data-granularity model
Four-dimensional-flow model
Agent-based computational experiment

A B S T R A C T

The complicated micro structures, macro emergences and dynamic evolutions in a supply chain network pose challenges to decision making for solving operational problems for the network's performance improvement. Most of these problems are complicated since various factors and their complicated relationships are involved. Success of this decision making relies on efficient business analytics based on the comprehensive and multi-dimensional data related to the static attributes and dynamic operations of the network. To confront the challenges, this paper proposes to explore a methodology of data-driven decision making for supply chain networks. In this methodology, a data-granularity model of a supply chain network is developed to standardize the data form for decision making. A four-dimensional-flow model of a supply chain network is proposed to satisfy the data requirements for decision making that are defined in the data-granularity model. Agent-based computational experiment is employed to support the generation of a comprehensive operational dataset of a supply chain network and to verify the solutions generated in decision making. Integrating these models, a data-driven decision-making framework for supply chain networks is proposed. In the framework, a new decision-making mode of "problem definition - business analytics - solution verification - parameter adjustment" is proposed. Oriented towards domain knowledge in supply chain networks, two approaches of business analytics—mapping analysis and correlation analysis—are presented. Finally, a case of a five-echelon manufacturing supply chain network is studied with the methodology. The findings indicate that the proposed methodology, models and framework are effective in supporting the data-centric decision making for solving complicated operational problems in supply chain networks and provide the networks' managers or member enterprises with an effective tool to generate unbiased and efficient decisions for the networks' performance improvement.

1. Introduction

Currently, decision support nowadays is increasingly targeted to large-scale complicated systems and domains [24]. A supply chain network is a typical complex system with features of complicated micro structures, macro emergences and dynamic evolutions [4, 26]. These features bring challenges to decision making for the network. Referring to Power's definition [18] of a decision support system, decision making for a supply chain network is intended to use communications, technologies, data, documents, knowledge, and/or models to identify and solve problems in the network domain, complete decision process tasks, and make decisions. There is a large volume of diverse data related to the static attributes and dynamic operations of a real supply chain network. These diverse data include, but are not limited to, micro entities' representations and structural relations, basic operational specifications, customer demands, product knowledge, and operational time series information. These data, reflecting the status and performance of the supply chain network, provides sufficient evidence for decision making. Data become the most valuable resources for an enterprise and even a supply chain network.

Decision making for supply chain networks focuses on how to generate unbiased and efficient decisions for the networks' performance improvement. In practice, a large proportion of the decisions are made based purely on domain knowledge or long experience of decision makers in their supply chain network fields [19]. The subjective decision making becomes inefficient and/or more biased, due to the subjectivity of the experts or the pre-assumptions of certain ideas or algorithmic procedures [24]. Additionally, the combination of subjective experience and objective data analysis is widely used for decision making [19]. With a large and complex supply chain network, subjective decision making is greatly challenged. In the past decades, model-driven decision

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https://doi.org/10.1016/j.knosys.2017.11.006

making played a dominant role. This decision-making paradigm uses assumptions or constraints to simplify the problems in a supply chain network for building precise partial mathematical models and employs algorithms to solve the models to obtain insights for decision making [29]. Although model-driven decision making requires rigorous models and solving processes, the assumptions or constraints on which the models depend are less rigorous and objective. In addition, the complex features of supply chain networks pose great challenges to model-driven decision making. The model-driven paradigm for supply chain networks is bound to be changed. Today, with the rapid development of computer technologies, the capabilities of data collection and processing have been greatly advanced, for example, big data analysis, business intelligence and data mining. A comprehensive and multi-dimensional data analysis can enhance the efficiency of decision making. Therefore, the data-driven decision-making paradigm becomes prevalent [25]. This paradigm refers to the practice of basing decisions on the analysis of data rather than purely on intuition [19]. This decision-making paradigm for a supply chain network, focusing on the problems in the network, conducts business analytics based on data in a special decision domain for solutions generation. The data required by this paradigm are derived from the operational practice of a supply chain network, which directly describes the emergences and evolutions of the network. Thus, the data-driven paradigm well fits the research of complex systems such as supply chain networks. Data-driven decision making can involve comprehensive and multi-dimensional business analytics for supply chain networks without any assumptions or constraints. The obtained decisions are unbiased and objective. Therefore, data-driven decision making has obvious advantages over model-driven decision making.

Currently, data-driven decision making for supply chain networks is in its infancy and some gaps remain. As a new paradigm, its decision-making mechanism, which is oriented toward the domain knowledge of supply chain networks, needs to be further explored and identified. The way in which the dataset is collected for comprehensive and multi-dimensional business analytics in data-driven decision making for supply chain networks still needs to be seriously considered. The specific business analytics approaches in data-driven decision making for supply chain networks are required. The systematic and comprehensive frameworks or methodologies for data-driven decision making for supply chain networks are ignored in the current literature. To bridge these gaps, this paper tries to explore the data-driven decision making for supply chain networks. This paper proposes a methodology of data-driven decision making for supply chain networks. In this methodology, a data-granularity model of a supply chain network is developed to standardize the data form for decision making. A four-dimensional-flow model of a supply chain network is proposed to satisfy the data requirements for decision making defined in the data-granularity model. Agent-based computational experiment is employed to support the generation of a comprehensive operational dataset of a supply chain network and verify the solutions generated in decision making. Integrating these models, a data-driven decision-making framework for supply chain networks is proposed. In the framework, a new decision-making mode of "problem definition - business analytics - solution verification - parameter adjustment" is proposed. Oriented to domain knowledge in supply chain networks, two approaches of business analytics—mapping analysis and correlation analysis—are presented. Finally, a case of a five-echelon manufacturing supply chain network is studied to verify the proposed methodology, models and framework. The findings indicate that the proposed methodology, models and framework are effective in supporting the data-centric decision making for solving complicated operational problems in supply chain networks and provide the networks' managers or member enterprises with an effective tool to generate unbiased and efficient decisions for the networks' performance improvement.

The rest of this paper is organized as follows: Section 2 presents a series of related work. Section 3 gives a methodology and related models for data-driven decision making for supply chain networks. Section 4 puts forth a framework for data-driven decision making for supply chain networks and specifies the decision-making mode and business analytics approaches. Section 5 conducts a case study for verifying the proposed methodology, models and framework. Section 6 presents conclusions.

2. Related work

Recently, some research focused on data-driven decision making. Wong and Wang [24] presented a fundamental data-driven framework based on pattern discovery toward intelligent decision support by analyzing a large amount of mixed-mode data to bridge the subjectivity and objectivity of a decision support process. Zhang et al. [29] investigated big-data-driven operational analysis and decision-making methodology in an intelligent workshop and proposed a new "correlation, forecast and regulation" decision-making pattern. Hu [6] proposed a data-driven feed-forward decision framework for building clusters operation under uncertainty. Meng et al. [16] developed a data-driven modeling and simulation framework for material handling systems of coal mines to support various decisions in coal mining such as equipment scheduling. Nay and Gilligan [17] outlined a method for automatically generating models of data-driven dynamic decision making. Han van der [23] presented an approach that automatically derives process models for data-driven decision-making processes given the structural data-flow relations underlying a workflow. Power [18] emphasized that it is important for managers and information technology professionals to understand data-driven decision support systems and how such systems can provide business intelligence and performance monitoring. Provost and Fawcett [19] discussed the relationship between data science and data-driven decision making. The discussions show that data science not only supports data-driven decision making, but also overlaps with it. In the discussions, a study was recently conducted by economist Erik Brynjolfsson and his colleagues from MIT and Penn's Wharton School [3] on how decision making affects firm performance. The report of the study shows that the more data-driven a firm is, the more productive (a 4–6% increase) it is; data-driven decision making is also correlated with higher return on assets, return on equity, asset utilization, and market value, and the relationship seems to be causal. As mentioned above, data-driven decision making has been becoming a widely used new decision paradigm with obvious advantages.

Data-driven decision making has also begun to be applied in supply chain networks. Qiu et al. [20] applied a data-driven approach to derive a robust coordination strategy in a two-stage supply chain. A numerical calculation shows that the data-driven approach can effectively cope with the supply chain risk deriving from demand uncertainty. Hedgebet [5] discussed the business intelligence applications in data-driven decision making for the enterprise. The discussions show that the use of business intelligence applications aids a knowledge enterprise by promoting efficiency within an organization, particularly by using analytical methods to provide valuable decision-making knowledge to minimize operating costs and to accurately forecast market trends. Long [10] creatively proposed a flow-based three-dimensional collaborative decision-making model for supply chain networks based on data-driven theory. This model: (i) clarifies both the domain and the space of collaborative decision making; (ii) sets up mapping relationships of decision spaces in different decision domains and elaborates their formal descriptions systematically; (iii)