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Co-design of products and systems using a Bayesian Network

Mohmmad Hanafy and Hoda ElMaraghy*

Intillegent and Manufacturing Systems Centre (IMSC), Industrial and Manufacturing Systems Engineering, University of Windsor, Windsor, Canada

* Corresponding author. *E-mail address:* hae@uwindsor.ca

Abstract

Complexity in manufacturing arises due to the intertwined relationships between products and their manufacturing systems. If the system/product relations can be retrieved automatically and efficiently, complex systems would be better designed and utilized to manufacture more products effectively. In this paper, a comprehensive method is used to explore the inter-relationships in the products domain and machines domain, and map the relations between products and systems. The method uses structure learning by Bayesian Networks to capture and analyze these relations, hence facilitating synthesis of new systems and product. A case study of parts and respective machines for producing them is used to demonstrate the method. Results show that the dependency relations among products and systems features can be extracted by analyzing existing instances of related entities such as machines/products and specifications without explicitly identifying the relations between them, which is akin to reverse engineering. Using Bayesian Networks and the most probable algorithm, a new composite part is obtained for a 3-axis machine with a tool magazine. This new information is based on the inferred Bayesian Network that links products and machines. Thus, future manufacturing systems and parts/machines co-design can be done robustly without much human interference.

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1. Introduction

In the world of manufacturing, systems are developed and/or modified in response to changing products and increased variety. Often these systems continue to evolve and change rapidly without the complete utilization of their capabilities. A new method for mapping/modelling the dependency relations between products and manufacturing systems is proposed. Should these relations be discovered, then co-design of products and corresponding machines is facilitated. The proposed method approach discovers the different relations that link products with systems and predicts the maximum possible features that a part can have given the machine capabilities. The relations between products and machines are generally not clearly understood except by the experts. Hence, a model capable of extracting information and simplifying the different relations that exist between features of products and the capabilities of machines is needed. Such model would be used for assigning new parts' to machines for processing. In the context of manufacturing, the concept of Evolving Parts/Products families has opened a new and promising area of research [1]. Extracting as much information as possible from the relations that exist between complex systems and products would facilitate the application of this

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concept. Generally, the problem of designing new artefacts, whether they are products or systems, is divided into two known domains: analysis and synthesis. Analysis entails decomposing bigger wholes into smaller parts that can be better understood and manageable. Synthesis is the integration of small parts to form one big whole that performs a certain function or requirement. classified classes of Problems to be synthesized are classified into three categories [2]:

- Problems with complete description
- Problems with incomplete environment description
- Problems with incomplete specifications and environment description

Ueda proposed a framework to achieve emergent synthesis in products' design, manufacturing systems and relational emergence between customers and artefacts, but did not include a mathematical algorithm to achieve that emergence.

It was proposed to capture the relations between elements of conceptual design of a fluid power circuit using different techniques such as Artificial Neural Network (ANN), CN2 algorithm, and COBWEB algorithm, but the latter three did not provide satisfactory results unless the relations were very clear and could be deduced from the data [3]. ANN only dealt with numerical values and the weights were vague and not indicative of comprehensible physical meaning. In CN2, the rule learning is not sufficiently comprehensive to deal with all design situations, meaning that its maturity in inferring relations is not robust. The COBWEB algorithm classifies qualitative and categorical values into similar regions in a hierarchical manner [3]. Although the COBWEB algorithm developed a full representation of the fluid circuit design based on the considered cases in the designer archive, no further information was deduced and no conclusions were drawn about the causations and relations between different elements to help in inferring future circuit designs.

Cladistics, a hierarchical classification technique extensively used in biology, and trees reconciliation was used in comparative biological data analysis, combined with associated product features and manufacturing capabilities matrices reduction, to infer relations and associations between products and their manufacturing systems [1]. This method - Cladistics - was applied to a case study of machine tools and products. It was able to infer direct relations between different elements with good representation. If a machine capability appeared in the machine cladogram, then a corresponding feature would appear in the products cladogram and vice-versa. However, Cladistics method cannot determine inverse relations. This is because Cladistics does not depend on probabilities which may provide direct or inverse correlation. This new concept of inverse relations in the manufacturing systems and products domains will be elaborated in the proposed method for integrating products and systems dependency modelling, analysis and synthesis. The main objective is to relate elements in the product-systems domain to each other. This necessitates the use of intelligent tools for discovering causations and correlations. In the following section, application of Bayesian networks will be discussed within the context of engineering and manufacturing. Although the method depends on extracting useful relations from existing products and systems, but it can be used to deduce future relations when new combination of products' features is required. Each product feature can have different states (on/off, no surface/complex surfaces …etc.), on the other side, the examined products' features do not contain every possible combination. Therefore, the designer will be provided by automated intelligent insight, to better select the machine capabilities that can efficiently produce the required product.

2. Bayesian Network in Engineering and Manufacturing

A Bayesian Network is a directed acyclic graph used to describe uncertainty in representing variables or hypotheses [4]. The graph consists of nodes; each node represents a discrete or continuous variable. The edges are the relations between nodes. The direction of the edge indicates the causation, where if A→B, then A causes B.

In Fig. 1, there are two groups of nodes, parents and children. These names are relative, because, for example, the x6 node is the parent of both x11 and x14. The same node is the child of x1. The causal relation may be direct or inverse.

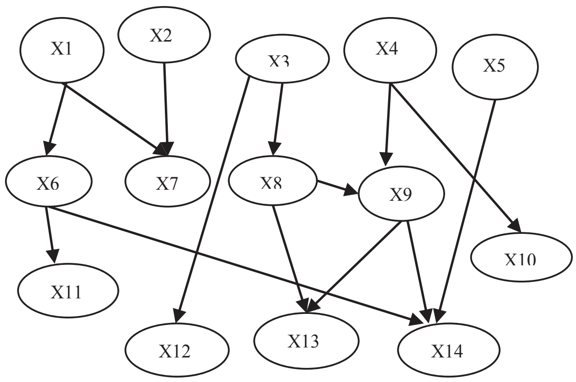

Fig 1. A Bayesian Network

The Bayesian Network can be built in one of two ways using: 1) expert knowledge or 2) structure learning from data. Expert's 'knowledge is often difficult to obtain, filter and analyze and is often very detailed. Comprehensive questionnaires have to be conducted to capture this knowledge. Bayesian Networks (BN) and Bayesian analysis have been used for a limited number of applications in