Conceptual Maps of Reliability Analysis Applied in Reconfigurable Manufacturing System

Tian Zhang, Lazhar Homri, Jean-Yves Dantan, Ali Siadat

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Tian Zhang[1], Lazhar Homri[1], Jean-yves Dantan[1], Ali Siadat[1]

[1] LCFC laboratory, Arts et Metiers Institute of Technology, Metz, France

tian.zhang@ensam.eu
lazhar.homri@ensam.eu
jean-yves.dantan@ensam.eu
ali.siadat@ensam.eu

Abstract. Reliability has always been an important factor for any manufacturing companies. An appropriate level of reliability in a manufacturing system could mean less maintenance cost, higher efficiency and steadier production state. Because each machine in a manufacturing system has its individual level of reliability, reliability on the system level would depend largely on how the machines are configured. In traditional efforts on reconfigurable manufacturing system (RMS) reliability assessments, mean time between failure (MTBF) is usually adopted as reference index of reliability. Also, in existing research efforts of applying reliability analysis in manufacturing system, reliability is merely a single and over-simplified index in the framework. But there exist various forms of reliability inside a RMS, and the complexity of this concept would keep increasing with the development of new technology in manufacturing industry. To analyze reliability in RMS in a more comprehensive way, we built conceptual maps as first step for research agenda -- from the perspective of general layer, reliability analysis and RMS.

Keywords: Reconfigurable Manufacturing System, Reliability Analysis, Conceptual map, Mean Time Between Failure.

1 Introduction

Most of the existing research efforts on the reliability of manufacturing systems are analysis on system topology, and the reliability attributes of the components are relatively less considered. Analytical method and computer simulation method are the two main directions when analyzing reliability of a manufacturing system. Among various analytical methods, Fault tree analysis (FTA) and Failure mode and effect analysis (FMEA) are quite usually applied for systems with relatively smaller scale in earlier research [2]. With the development of modern industrial technology, more methods are gradually being proposed and applied into analyzing the reliability of the systems, such as Petri net and Markov chain [10][13]. In the system reliability assessment of large complexity, simulation method such as Monte Carlo combined with various algorithms plays an important role [9].

It is important to adapt reliability analysis to the specific case of Reconfigurable Manufacturing Systems (RMS) .RMS fits the current market trend, which is varying quite fast and cost limit. Although cost is a constraint, quality is a big issue at the same time. Taking china as an example, a national strategic plan "Made in China 2025" mentioned quality as a key focus [16]. Thus, to fit the fast-varying market with the cost and quality requirement, reliability analysis in RMS is important. Succinctly saying, when compared with regular manufacturing system, RMS would involve more module interactions/ interfaces due to the nature of the system. In an RMS, reliability not only matters on the modules of tools, machines and system, but also between these modules. Thus, it is more reasonable to distinguish the reliability of an RMS from a regular manufacturing system

RMS is a machining system which can be created by incorporating basic process modules including both hardware and software that can be rearranged or replaced quickly and reliably [6]. The basic features of an ideal RMS include modularity, integrability, customized flexibility, scalability, convertibility and diagnosability, in which diagnosability is the ability to automatically read the current state of a system for detecting and diagnosing the root-cause of output product defects, and subsequently correct operational defects quickly. Diagnosability has two application directions during manufacturing process. One is the diagnosability of machine failures, and another is the diagnosability of non-conforming products. The latter is quite necessary when one considers the frequent rearrangements happening in an RMS which causes higher uncertainties of product qualities than that happening in a traditional manufacturing system. Regarding the hardware equipment, fast diagnosability could be realized by reconfigurable inspection machine (RIM). Then control methods, statistic methods and signal processing techniques could be led-in for further analysis on sources of reliability and quality problems. Therefore, diagnosability – among the main 6 features mentioned above – has the strongest linkage with reliability analysis in RMS.

In traditional efforts on RMS reliability assessments, mean time between failure (MTBF) is usually adopted as the reliability performance reference index. Besides MTBF, several similar index such as failure rate (reciprocal of MTBF), mean down time and availability were also adopted in extensive research [7]. But there were doubts whether this is suitable for industrial applications. Calculation of MTBF requires that failure mode being based on exponential distribution, which does not always fit the real case, especially not for a RMS case.

For an RMS, the characteristic of reconfiguration could be realized in many forms. As shown in Fig. 1, reconfigurations could be on layout, machine tools or planning, either simultaneously or separately according to specific assumptions. Hence, reliability could be interpreted in many ways with different form of reconfigurations not limited to the only index – MTBF.

Based on the considerations and discussions above, we proposed to interpret the idea of reliability in a more reasonable and comprehensive way. The problem formalization is as follows:

To address the increasing complexity of manufacturing systems, we try to include various forms of reliability inside a reconfigurable manufacturing system, its machines and products during the whole period of time: from the beginning of manufacturing to product's end of life. In this paper, our main contribution is constructing conceptual maps as an informational basis for an issue we proposed.

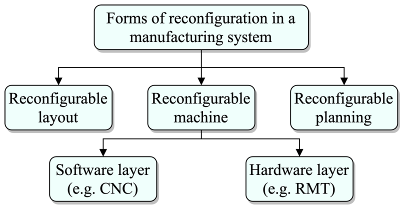

Fig. 1. Reconfiguration in various forms

To clarify the proposed research issue, we made an example with automobile for illustration as shown in Fig. 2. The whole life of the automobile, from manufacturing to usage were included in our research time span. When the automobile order arrives, the production requirements would occur automatically, thus we make selection of the configurations, which could be presented as the period called "usage of RMS". During this step, performance index of a system such as scalability is also renewed. Then the manufacturing process starts, during which the state of the system is diagnosed, along with the reliability such as MTBF for a maintainable automobile manufacturing system. After the automobile has been verified by the quality control and put into usage, environmental factors such as road quality, maintenance of the engine and usage weather etc. could all influence the final reliability of the automobile.

In the following part of this paper, chapter 2 includes the discussion of existing related works and highlighted two firmly related papers to our research issue; chapter 3 presents the conceptual maps we built for the research issue; and chapter 4 includes conclusion and future research perspectives.

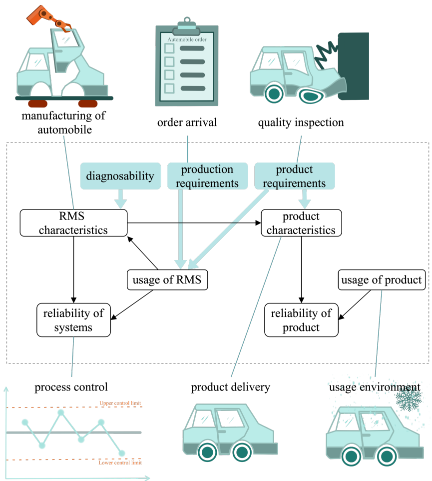

Fig. 2. Research issue with automobile as an example

2 Relevant research

After formalizing our problem, we did a literature searching in Web of Science. The searching condition was set very strictly, and we applied snowballing method for more related papers. We ended up with 25 papers as the review paper database, in which there were 2 papers highly related to the issue we proposed. This number proves the scarcity of reliability analysis in RMS, in which reliability is taken as a main criterion. Yet as we have mentioned in chapter 1, reliability plays a rather important role in current manufacturing systems, especially in systems with reconfigurable characteristics. Therefore, it is quite important to build conceptual maps for this issue as a start.

Papers highly related to the proposed issue:

–《A multi-objective reliability optimization for reconfigurable systems considering components degradation》 [14]

The authors proposed an integrated method to improve reliability of the reconfigurable manufacturing system, with cost-efficiency as constraint. The problem in this paper is a multi-objective optimization, in which objectives are to maximize system reliability and minimize total cost or performance lost. In this article, reconfiguration is realized through rearranging and replacing components, which accords to the reconfigurable layout branch in Fig. 1.

–《Research and optimization of reconfigurable manufacturing system configuration based on system reliability》 [12]

The authors presented a hybrid parallel-series model with waiting system characteristics, in which reliability is set as the criterion. Also, other system performances including productivity, and cost by combining system engineering theory are adopted for evaluation. Same as the former paper, reconfiguration form also accords to the reconfigurable layout branch in Fig. 1 in this research.

These two papers share the same form of reconfiguration, and both worked on algorithms to solve the performance optimization. But the difference is in the 1st research, the optimization is multi-objective but in the 2nd research, reliability is the only objective in optimization.

3 Construction of conceptual maps

A conceptual map is a graphical tool that depicts suggested relationships between concepts [4]. It is commonly used by instructional designers, engineers, technical writers, and others to organize and structure knowledge. It could help organize the complicated relations between concepts, which fits our need since the definition of the reliability and quality in our research is of multiple layers. Reliability analysis and quality control enable a manufacturing company to precisely control the manufacturing process from two key aspects.

The advantage of CM is its stimulation of idea generations, which could aid in brainstorming of potential research topics. But as the same time, it can only be seen as a first step in a scientific research and there could be individual differences when it comes to the definition of one same word. This often happens when the researchers are from different countries, or even sometimes different labs.

By constructing conceptual maps, we intended to aid researchers by increasing clarity of reliability analysis and RMS concepts and thus, the probability of successful implementation. At the same time, it will help clarifying for our own research topic in the later works. CM is preferred to be built with reference to a few particular questions that researchers would like to answer as a start. The focus question we ask is consistent to the research issue we proposed: How do we conduct reliability analysis on RMS in a more reasonable and comprehensive way?

The elements in CM are concepts, propositions, cross-links and hierarchical frameworks [8]. Concept is defined as a perceived regularity in events or objects, or records of events or objects, designated by a label. Cross-links helps connect two concepts from various segments of the CM, it is often where the creative leaps would occur. Propositions are statements about some object or event in the universe, either naturally occurring or constructed. Propositions contain two or more concepts connected using linking words or phrases to form a meaningful statement.

In the following parts, we are going to present the CM of the 2 concepts “reliability analysis ” and “”reconfigurable manufacturing system” separately and then combine the two concepts for a more general CM. The former two CMs are buit the 2 main questions: why and how? “Why” leads to the concepts that’s related to the reason why this main concept is built and “how” leads to the concepts those are more related to the methods and approaches.

As shown in Fig. 3, reliability analysis could be broadly interpreted as analysis on the ability for a system to perform its intended function [11]. As discussed in the former contents, the importance of reliability in a system is nonnegligible, especially with the increasing of size and complexity of systems. With functionality of manufacturing operations becoming more essential, there is also a growing need for reliability analysis. Definition of reliability could be adapted into many forms based on the essence of the systems. Reliability could be presented by many indexes, the common definition of reliability function is R(t), and also there could be MTTF, maintainability– which could also be presented by mean time to repair (MTTR), mean time between failure (MTBF), failure rate and availability. The techniques in RA that's quite often applied are reliability block diagrams, network diagrams, fault tree analysis (FTA) and Monte Carlo simulation. FTA has the advantage of describing the fault propagation in a system, but it might not come into effect in a system with high-complexity and maintenance characteristic. Monte Carlo simulation could be applied to evaluate MTBF when the possible distribution function is already given.

It is noteworthy that the concepts in Fig. 3 could keep unchanged or change according to the system type (regular/ reconfigurable manufacturing system). To identify those concepts which might be significantly impacted by system type, we highlighted them in Fig. 3 by deep color. (When one concept is highlighted, all the concepts located on its branches could be affected by system type logically.) When a system is reconfigurable rather than dedicated, there would certainly involve more possible **failures** due to its higher system complexity. Yet when compared to overly complicated flexible manufacturing system, it could contain less failures – either in law of the failure, causes of failure or consequences of failure. Thus, the **reliability** for regular and reconfigurable manufacturing system would vary identically. And as shown in Fig. 3, the **hardware system**, **software system** and **machines** for processing could all be special for a reconfigurable manufacturing system when compared with regular ones.

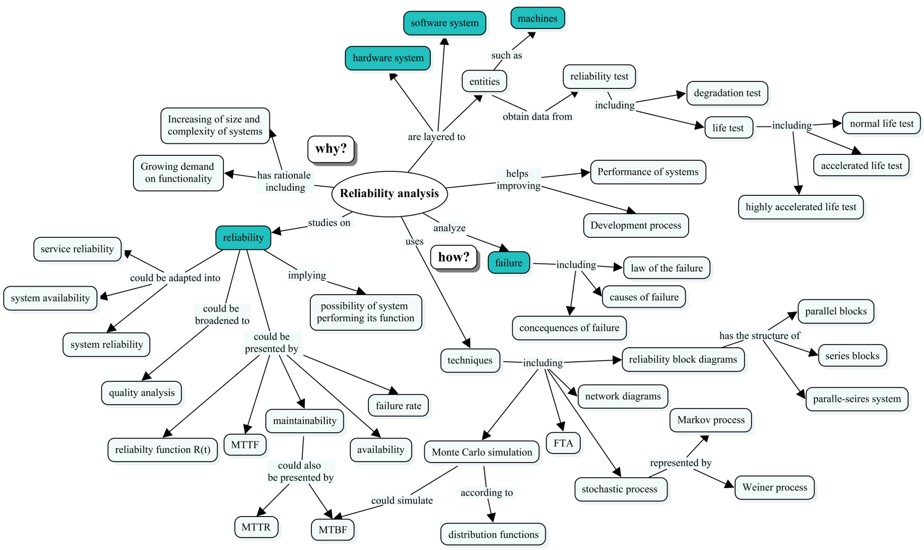

Fig. 3. Conceptual map of reliability analysis in a system

We constructed the CM of RMS as shown in Fig. 4. The parts where RMS is different from a regular manufacturing system have been highlighted by darker color in the figure. RMS was introduced as a response to volatile global markets that instigated large uncertainty in product demand [5]. RMS has the reconfigurable characteristics, and they are commonly concluded to 6 features for enabling rapid responsiveness [1]. The feature customized flexibility enables the system to manufacture part families. One of the main reason RMS is different from dedicated manufacturing system (DMS) or flexible manufacturing system (FMS) is its focus on producing part families. Integrability could be realized either on the system level or machine level. At the machine level, reconfigurable machine tools (RMT) could be applied; at the system level, machines are seen as modules that could be integrated through transport systems. Diagnosability is the feature closely related to reliability, it could be detection on either product quality or system reliability. In the phase of problem formalization, both these two elements are taken into consideration in the model. Typically, RMS contains computer numerically controlled (CNC) machines and in-line inspection stations. RMS could be the study object in many applications: configuration selection, planning and scheduling, product family formation, layout configuration analysis and configuration design. In configuration design, it could be applied to level of systems, machines or other modules such as transportation/controlling equipment etc. [3], which concords with the feature of integrability.

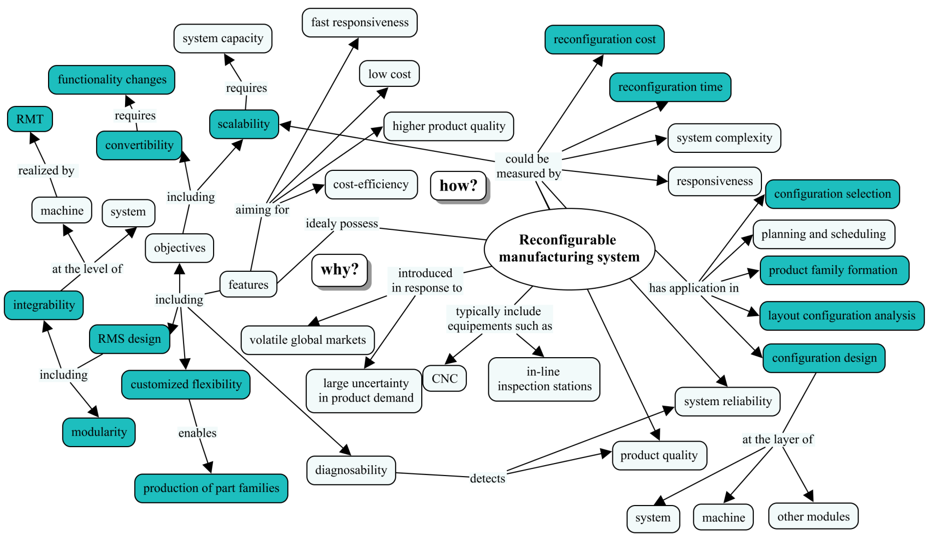

Fig. 4. Conceptual map of reconfigurable manufacturing system

As show in the Fig. 5, combination of the conceptual maps includes general concepts for our research issue – applying reliability analysis in reconfigurable manufacturing system, in which we show the factors that attributes to the comprehensive research characteristics. Attributions to comprehensiveness of our research have two parts: the variety of reliability indexes and the variety of the studied layers. And the scope of time, which has not been added into the map, is also an attribution to comprehensiveness.

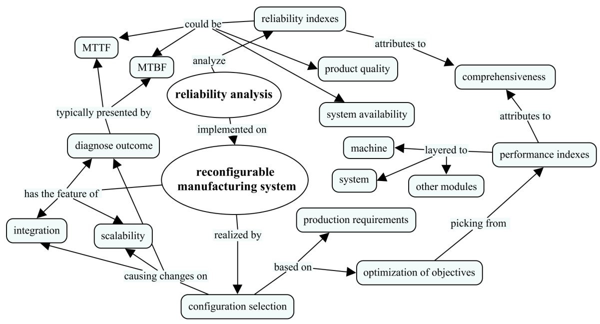

Fig. 5. Combination of the conceptual maps

4 Conclusion

The conceptual maps we have developed are based on the study literatures of RMS and reliability. The validation of the conceptual map could be realized in 2 ways in future work. One way is to validate by comparing conceptual maps generated by others. The other way is to observe the behavior in a relevant situational context. This could be summarized as application validity approach [15].

The aim of this study was to clarify the conceptual ambiguity when applying reliability analysis in reconfigurable manufacturing systems. In support of this aim, we provided a visual representation of this topic in the form of conceptual maps in chapter 3. While the map provides a necessary first step towards clarification, the results could be continuously improved based on up-to-date findings in those fields.

The construction of the conceptual maps is a basis for our research agenda. In future work, we could keep developing the methodology and models for the research issue we proposed. As mentioned in chapter 3, each cross-link in the conceptual maps could imply a potential research topic. Besides the issue we proposed, how the usage period together with manufacturing period impact on the reliability of products could also be an interesting direction for researching.

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