International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:14, No:7, 2020

Using Axiomatic Design for Developing a Framework of Manufacturing Cloud Service Composition in the Equilibrium State

Ehsan Vaziri Goodarzi, Mahmood Houshmand, Omid Fatahi Valilai, Vahidreza Ghezavati, Shahrooz Bamdad

Abstract**—**One important paradigm of industry 4.0 is Cloud Manufacturing (CM). In CM everything is considered as a service, therefore, the CM platform should consider all service provider's capabilities and tries to integrate services in an equilibrium state. This research develops a framework for implementing manufacturing cloud service composition in the equilibrium state. The developed framework using well-known tools called axiomatic design (AD) and game theory. The research has investigated the factors for forming equilibrium for measures of the manufacturing cloud service composition. Functional requirements (FRs) represent the measures of manufacturing cloud service composition in the equilibrium state. These FRs satisfied by related Design Parameters (DPs). The FRs and DPs are defined by considering the game theory, QoS, consumer needs, parallel and cooperative services. Ultimately, four FRs and DPs represent the framework. To insure the validity of the framework, the authors have used the first AD's independent axiom.

Keywords**—**Axiomatic design, manufacturing cloud service composition, cloud manufacturing, Industry 4.0.

I. Introduction

MANY leading industries in the world have invested heavily in the development of manufacturing, innovation, and globalization. Many of these investments have led to the emergence of industry 4.0 in which enables smart and active manufacturing industries and factories. One paradigm that leads to the success of Industry 4.0 is CM [1]. Today, research on CM has been ongoing for more than eight years and much progress has been made. The significance of CM to the manufacturing industry has been increasingly realized by more and more people, and both academic research and industrial implementation of CM is undergoing rapid development [2]. It is noteworthy that CM is not restricted to the deployment of cloud computing in manufacturing. Indeed, the manufacturing businesses and related resources/capability should be described, componentized, virtualized and integrated into the form of manufacturing cloud (MCloud) [3]. One of the most important issues for improving CM and QoS is the manufacturing service management (MSM) and in particular the Optimal Service Selection and Composition [4]. Service composition, as well as optimal QoS, is of great importance in providing service to consumers, as this can enable them to emphasis on their main central business and outsource other activities in the CM [5]. QoS incorporates various metrics including cost, response time, reliability, availability, credit etc. [6]. As the CM settings imply, a massive number of services with similar manufacturing functionalities and a variety of QoS would be introduced in the cloud environment which only contributes to increasing the complexity of the service composition [5]. Concretely, cloud service selection and composition are categorized among the hardest problems in combinatorial optimization [6]. As massive MCloud services with similar manufacturing functionalities and a variety of QoS are emerging in the cloud environment, the service composition becomes increasingly complicated [5]. Simple cloud service selection and composition is a complicated and difficult process and NP-hard problem [6].

The main objective of this research is to develop a framework to satisfy the service composition system, the important factor of MSM in the CM environment. In this article, the customers' needs have been considered as the quality of service levels. The framework uses game theory as a tool. Previously, [4] and [7] recommended the use of game theory to solve the MCloud Service composition problem. This research extracted the measures of the MCloud service composition in the equilibrium state based on the conducted last researches and uses a well-known tool called AD to organize all measures for developing the framework. AD is used to design manufacturing systems [8]. Various researches have been conducted [8]-[14] to apply AD in CM environment. The main measure of the framework is composite services with acceptable consumers QoS which is capable of fulfilling the profit of MCloud service providers. In this research with the help of AD, the QoS is defined as the average of factors as, the time, cost, reliability value, the value of resilience and the system load-balancing value. To meet the customer's requirements, games are formed between MCloud service providers as players, based on the game theory.

The main purpose of the framework expresses in FR0. FR0 is a service composition system in the CM environment based on consumer's needs. DP0 is developed to satisfy FR0. DP0 can be described as "Provide an equilibrium system by using

Ehsan Vaziri goodarzi is with the School of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran (phone: +98-933-145-9209; e-mail: st_e_vaziri@azad.ac.ir).
Mahmood Houshmand is with the Department of Industrial Engineering, Sharif University of Technology, Tehran, Iran (phone: +98-912-104-2244; e-mail: hoshmand@sharif.edu).
Omid Fatahi Valilai is with the Department of Mathematics & Logistics, Jacobs University Bremen gGmbH, Bremen, Germany, (phone: +49-421-200-3077; e-mail: O.FatahiValilai@Jacobs-university.de).
Vahid Reza Ghezavati and Shahrooz Bamdad are with the school of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran (e-mail: v_ghezavati@azad.ac.ir, sh.bamdad2000@yahoo.com).

International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:14, No:7, 2020

game theory to fulfill the MCloud service composition" [23]. Applying the zigzagging process, eight FRs, as well as eight DPs, identify the framework of ESCM. According to AD rules, the design matrix is developed. This is a matrix in the type of couple, so that is not acceptable. FRs are being reviewed and new FRs and DPs are generated. The new one is a matrix in decouple type that is acceptable.

II. Literature Review

A. CM

CM benefits from the share-to-gain philosophy. In the CM environment, a wide number of manufacturing resources and capabilities are shared to provide consumer service. In competitive markets, given the high cost of product development considering the variety in the customers' demands, using the capabilities and resources of other manufacturing companies can be beneficial. In fact, the success of many enterprises depends on how much they can adopt distributed manufacturing capabilities around the world through their production processes [15]. CM is one of the industry 4.0 paradigms [1] and considers to be an essential technology in ubiquitous manufacturing [16]. Influenced by the definition of the National Institute of Standards and Technology (NIST) about cloud computing, we can define CM as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [10]. CM would reduce the system's costs and increase resource utilization rate [3]. CM is a solution to the changing manufacturing, in which everything can be considered as a service, and anyone in this system can be the service consumer or service provider [10]. The topic of CM is based on service-oriented network manufacturing systems as a brand-new [17] and state-of-the-art subject [18]. Some features of cloud services are providing services based on customers' demands, high security, usefulness, high quality, flexibility, customization, low cost, interoperability and communication capabilities, self-organizing, self-adaptive, self-matching and self-combination [19]. When a single Cloud service, on its own, cannot satisfy all the consumer requirements, the Cloud service composition of Cloud services is introduced. Cloud service composition consists of different capabilities such as definition, checking compatibility, nomination, and deployment. These capabilities are usually complex processes and many challenges arise when cloud users require to select the best service among the huge amount of service capabilities of possible compositions [20]. However, QoS should also be considered [21].

B. AD

The basic idea of AD was created in the mid-70s and later published in "The Principle of Design" by professor Nam Suh [41]. The name of the AD has been inspired by its utilization of Design Principles or Design Axioms (i.e. given without proof) which are governing the analysis and decision-making process. The idea of AD has been applied in many fields, especially for products, processes, and systems [14]. In AD, to establish a design problem, first, to satisfy the perceived needs, the design goals must be set. Second, the designs for the defined requirements would be provided among which the best design is chosen [22]. In designing, there are many FRs and physical components that rooted in the requirements of the customers. The physical components should be aligned with the FRs. According to this fact, AD considers four general domains which are named Customer Domain, Functional Domain, Physical Domain, and Process Domain. The sequential process of design in AD starts from Customer Domain with the definition of Customer Attributes (CAs). CAs are the customers' expectations and requirements. Then, the CAs are translated into the FRs in Functional Domain. The FRs express the requirements by engineering words. FRs express the term "what we want to achieve" clearly. Then, the FRs must turn to tangible terms. So, they are being mapped into the DPs in Physical Domain. DPs help to satisfy the related FRs. The recent process of mapping mostly is interpreted as the DPs. Finally, the DPs map into Process Variables (PVs) in Process Domain [14].

Decomposition in each domain cannot be performed autonomously of the developing hierarchies in the other domains and should follow a zigzag pattern between adjacent domains.

The relationship between FR and DP domains along with the design matrix (DM) to represent how a DP can satisfy an FR is illustrated in Fig. 1. The corresponding equation is expressed in (1) [22]:

$$AA_{i,j} = \partial FR_i / \partial DP_j \tag{1}$$

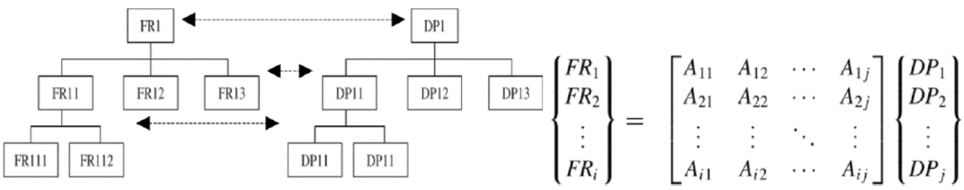

Fig. 1 Developing *DM* with FRs and DPs in AD

A good and principled process of AD must adhere to two principles of independence and information. In the independence axiom, each FR should affect one DP. If the DM is in the form of a diagonal and each FR just affects only one DP, this matrix is uncoupled. If the matrix is triangular and one FR communicates with a few DP or one DP communicates with a few FR, the DM is in decouple type. Both types of matrices are acceptable, but in the case of matrices that a few DP communicate with a few FR, this is a coupling matrix and it is not acceptable in the AD process. Also, information axiom is minimizing the information content of the design process. That information content of a design solution is closely related to the probability of fulfilling the design goal or goals [9]. Many researches have been conducted in this realm [14], [41]-[43]. Some researchers [44]-[47] touched the measures of the service composition system in CM, but none of them developed a system to consider all the measures together. Table I shows the related work on this research framework.

TABLE I
THE RELATED WORK ON THIS RESEARCH FRAMEWORK

	Scalability	Customization	Cooperation/ Collaboration	QoS	AD
[23]	No	No	Yes	Yes	No
[24]	No	No	Yes	Yes	No
[18]	No	No	Yes	Yes	No
[17]	No	No	Yes	Yes	No
[25]	No	No	Yes	Yes	No
[26]	No	No	Yes	Yes	No
[27]	Yes	No	No	Yes	No
[28]	No	Yes	Yes	Yes	No
[29]	No	Yes	Yes	Yes	No
[30]	No	Yes	Yes	Yes	No
[31]	No	Yes	Yes	Yes	No
[32]	Yes	Yes	Yes	Yes	No
[33]	No	Yes	Yes	Yes	No
This research	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

The main objective of this article is to develop a framework to organize the measures. The AD tool was used to develop the framework. Also, game theory was used in this framework to satisfy the framework's measures in the equilibrium state. Section III considers the development of the framework. The framework is developed based on AD and game theory. Game theory conducts the framework for implementing the MCloud service composition in real-world conditions. Finally, the validity of the framework is tested by AD's independent axiom.

III. THE FRAMEWORK FOR MCLOUD SERVICE COMPOSITION IN THE EQUILIBRIUM STATE

In order to achieve a framework by using the AD tools, three steps should be done: 1. FRs, 2. DPs, 3. DM. The measures interpret as FRs. Therefore, DPs are developed to satisfy FRs. Finally, to validate the framework, the related DM is analyzed by the first axiom of the AD.

A. Developing the Framework

This framework, based on game theory, has formed a game between MCloud service providers for fulfilling the related consumer requested service. MCloud service providers as players compete in this game to provide types as well as QoS. In this game, acceptable QoS's level is a strategy for players to increase their profits as the payoff. Developing a service as well as the best QoS based on customer request is problematic and sometimes inevitable. To develop the best QoS, move towards an interactive and cooperative environment is an undeniable subject. MCloud service providers in the cooperative environment obtain the capability of providing a composite service with better QoS. This environment adds more profit to MCloud service providers than they provide service individually.

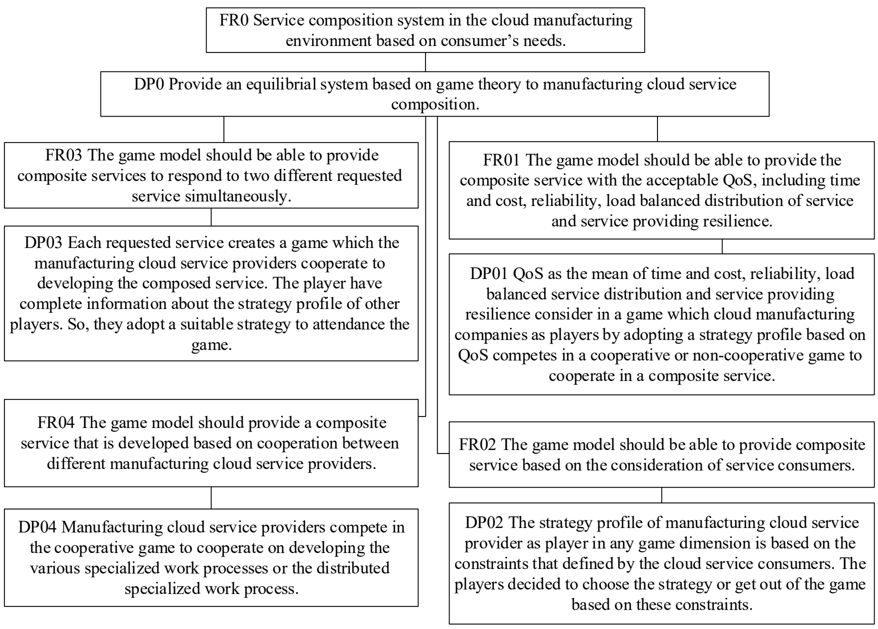

Fig. 2 Modified AD flowchart to developing a framework for ESC

$$
\begin{array}{c|cccc}
 & DP\,01 & DP\,02 & DP\,03 & DP\,04 \\
\hline
FR\,01 & 1 & 1 & 1 & 1 \\
FR\,02 & 0 & 1 & 1 & 1 \\
FR\,03 & 0 & 0 & 1 & 1 \\
FR\,04 & 0 & 0 & 0 & 1
\end{array}
$$

Fig. 3 DM of modified AD flowchart

According to AD rules, the primary framework is developed. Based on the measures, FRs are developed. The main objective of the framework is stated in FR0 in the first level of FR. To satisfy FR0, the framework proposes DP0 as the first level of DP.

- FR0: *Service composition system in the CM environment based on consumer's needs.*
- DP0: *Provide an equilibrial system based on game theory to MCloud service composition.*

By using the zigzagging process, the second level of FRs and DPs has been developed. Eight FRs and DPs are developed. Then, in order to observe the independence axiom, the DM is extracted. The matrix is a coupling matrix. This type of matrix is not acceptable by AD's rules.

In order to improve the framework based on the DM, the FRs and DPs have been redesigned. After the second zigzagging process between FRs and DPs, the framework has been modified with the new second level of FRs and DPs, as shown in Fig. 2. Therefore, the modified framework has four FRs and DPs. Also, the DM has been redesigned and shown in Fig. 3. This DM is triangular and decoupled, so it is acceptable based on AD's rules.

B. Validation Study of the Framework

According to [8], AD can be applied to design manufacturing systems. Also, as mentioned in Section I, some other researchers used AD in related CM system researchers. In this paper, the framework's measures are developed based on related last researches, [3], [6], [12], [18], [19], [26], [28], [34]-[38]. These researches are used to develop DPs for satisfying FRs. Also, based on the models that have been developed in different researches, using game theory to solve the service composition problem in the CM system has been recommended by [4], [7], [12], [39], [40].

The valid framework has been developed and shown in Fig. 2. The related DM is acceptable because that is triangular and decouple, as shown in Fig. 3. Based on the DM in Fig. 3, the dependencies of FRs and DPs are analyzed and shown in Fig. 4. Therefore, the framework configuration is not complex and it is acceptable based on the AD's rules.

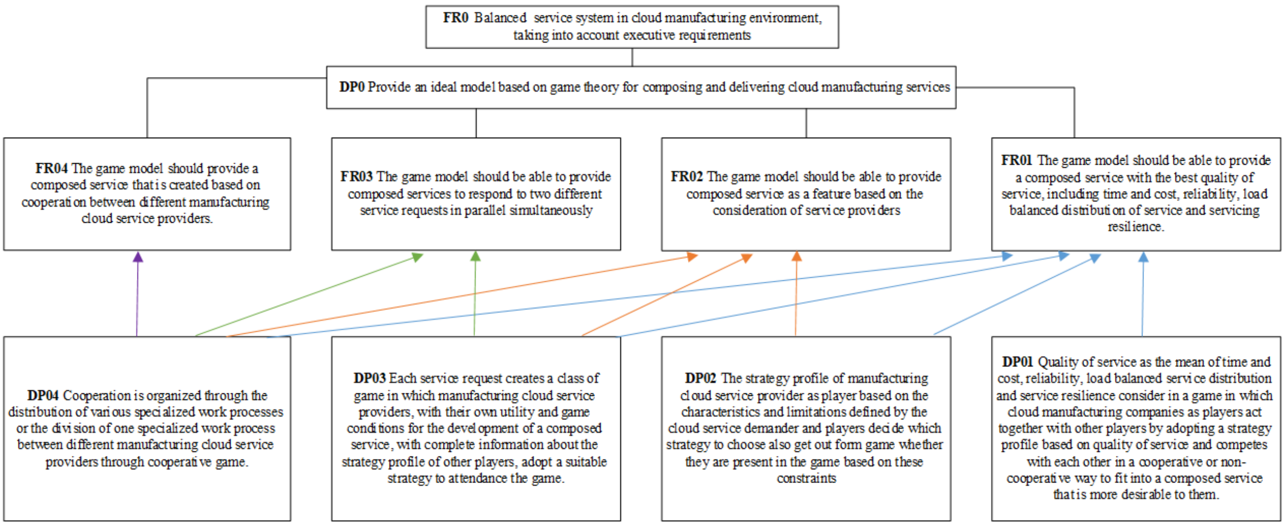

Fig. 4 Dependencies of FRs and DPs based on the related DM

IV. Conclusion

CM is one of industry 4.0's paradigms. In CM, each MCloud service provider can be used as a service according to its capacity. The CM system has some characteristics such as resilience and flexibility. In this system, it is possible to develop a product based on consumer's considerations. Therefore, this system enables the development of the product as well as acceptable QoS based on the customer's requested service. One of the most important subjects in CM is MCloud service composition. According to a large number of service providers in the CM system, selecting the best MCloud service providing to develop a composite service is an important problem. In this problem, the QoS must be attracted as a constraint to developing the composite service.

Developing a framework to MCloud service composition system is an essential issue for solving the problem of MCloud service composition system in an equilibrium state. This framework should take into account the essential measures of the MCloud service composition system. In this research, the framework has been developed with the help of game theory and AD to achieve the proposed MCloud service composition in the equilibrium state. According to conducted research by various researchers [23], [37], [39], the measures of the MCloud service composition in the equilibrium state have been extracted. The framework has been developed with the help of the AD tool. Also, game theory has been used to achieve the framework equilibrium state. Finally, the framework has been developed with four FRs and DPs based on the requirements of the AD tool, after two zigzagging levels and one redesign level. Accordingly, the related DM is in decouple type, so it is acceptable. For future work, it is recommended fo the improvement of this research framework, taking into account separate QoS's factors such as time, cost and reliability of service.

REFERENCES

[1] Thames, L. and D. Schaefer, Software-defined cloud manufacturing for Industry 4.0. Procedia CIRP, 2016. 52: p. 12-17.

[2] Liu, Y., et al., Cloud manufacturing: key issues and future perspectives. International Journal of Computer Integrated Manufacturing, 2019: p. 1-17.

[3] Wang, X.V. and X.W. Xu, An interoperable solution for Cloud manufacturing. Robotics and Computer-Integrated Manufacturing, 2013. 29(4): p. 232-247.

[4] Tao, F., et al., Manufacturing service management in cloud manufacturing: overview and future research directions. Journal of Manufacturing Science and Engineering, 2015. 137(4): p. 040912.

[5] Wang, X., S. Ong, and A. Nee, A comprehensive survey of ubiquitous manufacturing research. International Journal of Production Research, 2017: p. 1-25.

[6] Jula, A., E. Sundararajan, and Z. Othman, Cloud computing service composition: A systematic literature review. Expert Systems with Applications, 2014. 41(8): p. 3809-3824.

[7] Zeng, W., Y. Zhao, and J. Zeng. Cloud service and service selection algorithm research. in Proceedings of the first ACM/SIGEVO Summit on Genetic and Evolutionary Computation. 2009. ACM.

[8] Rauch, E., D.T. Matt, and P. Dallasega, Application of axiomatic design in manufacturing system design: a literature review. Procedia CIRP, 2016. 53: p. 1-7.

[9] Gonçalves-Coelho, A.M. and A.J. Mourao, Axiomatic design as support for decision-making in a design for manufacturing context: A case study. International journal of production economics, 2007. 109(1-2): p. 81-89.

[10] Xu, X., From cloud computing to cloud manufacturing. Robotics and computer-integrated manufacturing, 2012. 28(1): p. 75-86.

[11] Wang, X.V. and X.W. Xu, ICMS: a cloud-based manufacturing system, in Cloud manufacturing. 2013, Springer. p. 1-22.

[12] Wu, D., D. Schaefer, and D.W. Rosen. Cloud-based design and manufacturing systems: a social network analysis. in DS 75-7: Proceedings of the 19th International Conference on Engineering Design (ICED13), Design for Harmonies, Vol. 7: Human Behaviour in Design, Seoul, Korea, 19-22.08. 2013. 2013.

[13] Valilai, O.F. and M. Houshmand, A manufacturing ontology model to enable data integration services in cloud manufacturing using axiomatic design theory, in Cloud-Based Design and Manufacturing (CBDM). 2014, Springer. p. 179-206.

[14] Delaram, J. and O. Fatahi Valilai, An architectural solution for virtual computer integrated manufacturing systems using ISO standards. Scientia Iranica, 2018.

[15] Fatahi Valilai, O. and M. Houshmand, A collaborative and integrated platform to support distributed manufacturing system using a service-oriented approach based on cloud computing paradigm. Robotics and computer-integrated manufacturing, 2013. 29(1): p. 110-127.

[16] Wang, X.V., et al., Ubiquitous manufacturing system based on Cloud: A robotics application. Robotics and Computer-Integrated Manufacturing, 2017. 45: p. 116-125.

[17] Liu, Z.Z., et al., An Approach for Multipath Cloud Manufacturing Services Dynamic Composition. International Journal of Intelligent Systems, 2017. 32(4): p. 371-393.

[18] Liu, B. and Z. Zhang, QoS-aware service composition for cloud manufacturing based on the optimal construction of synergistic elementary service groups. The International Journal of Advanced Manufacturing Technology, 2017. 88(9-12): p. 2757-2771.

[19] Zhang, S. and X. Hu, Game analysis on logistics cloud service discovery and combination. International Journal of u-and e-Service, Science and Technology, 2015. 8(10): p. 193-202.

[20] Dastjerdi, A.V. and R. Buyya, Compatibility-aware cloud service composition under fuzzy preferences of users. IEEE Transactions on Cloud Computing, 2014. 2(1): p. 1-13.

[21] Wang, D., et al., QoS and SLA Aware Web Service Composition in Cloud Environment. KSII Transactions on Internet & Information Systems, 2016. 10(12).

[22] Mokhtar, A. and M. Houshmand, Introducing a roadmap to implement the universal manufacturing platform using axiomatic design theory. International Journal of Manufacturing Research, 2010. 5(2): p. 252-269.

[23] Lei, Y. and Z. Junxing, Service composition based on multi-agent in the cooperative game. Future Generation Computer Systems, 2017. 68: p. 128-135.

[24] Li, Y., X. Yao, and J. Zhou, Multi-objective optimization of cloud manufacturing service composition with cloud-entropy enhanced genetic algorithm. Strojniški vestnik-Journal of Mechanical Engineering, 2016. 62(10): p. 577-590.

[25] Xu, W., et al., An improved discrete bees algorithm for correlation-aware service aggregation optimization in cloud manufacturing. The International Journal of Advanced Manufacturing Technology, 2016. 84(1-4): p. 17-28.

[26] Zheng, H., Y. Feng, and J. Tan, A fuzzy QoS-aware resource service selection considering design preference in cloud manufacturing system. International Journal of Advanced Manufacturing Technology, 2016. 84.

[27] Liu, Y., et al., An Extensible Model for Multitask-Oriented Service Composition and Scheduling in Cloud Manufacturing. Journal of Computing and Information Science in Engineering, 2016. 16(4): p. 041009.

[28] Zhou, J. and X. Yao, A hybrid artificial bee colony algorithm for optimal selection of QoS-based cloud manufacturing service composition. The International Journal of Advanced Manufacturing Technology, 2017. 88(9-12): p. 3371-3387.

[29] Zhou, J. and X. Yao, DE-caABC: differential evolution enhanced context-aware artificial bee colony algorithm for service composition and optimal selection in cloud manufacturing. The International Journal of Advanced Manufacturing Technology, 2017. 90(1-4): p. 1085-1103.

[30] Zhou, J. and X. Yao, Multi-objective hybrid artificial bee colony algorithm enhanced with Lévy flight and self-adaption for cloud manufacturing service composition. Applied Intelligence, 2017: p. 1-22.

[31] Zhou, J. and X. Yao, Hybrid teaching–learning-based optimization of correlation-aware service composition in cloud manufacturing. The International Journal of Advanced Manufacturing Technology, 2017: p. 1-19.

[32] Zhou, J. and X. Yao, Multi-population parallel self-adaptive differential artificial bee colony algorithm with application in large-scale service composition for cloud manufacturing. Applied Soft Computing, 2017. 56: p. 379-397.

[33] Zhou, J. and X. Yao, A hybrid approach combining modified artificial bee colony and cuckoo search algorithms for multi-objective cloud manufacturing service composition. International Journal of Production Research, 2017: p. 1-20.

[34] Wang, S., et al., Towards network-aware service composition in the cloud. IEEE Transactions on Cloud Computing, 2016.

[35] Huang, B., et al., Cloud manufacturing service platform for small-and medium-sized enterprises. The International Journal of Advanced Manufacturing Technology, 2013: p. 1-12.

[36] Putnik, G., et al., Scalability in manufacturing systems design and operation: State-of-the-art and future developments roadmap. CIRP Annals-Manufacturing Technology, 2013. 62(2): p. 751-774.

[37] Esposito, C., et al., Smart cloud storage service selection based on fuzzy logic, theory of evidence and game theory. IEEE Transactions on computers, 2016. 65(8): p. 2348-2362.

[38] Huang, J., et al., Converged Network--Cloud Service Composition with End-to-End Performance Guarantee. IEEE Transactions on Cloud Computing, 2015.

[39] Fontanini, W. and P. Ferreira, A game-theoretic approach for the web services scheduling problem. Expert Systems with Applications, 2014. 41(10): p. 4743-4751.

[40] Li, H., et al., Geo-information processing service composition for concurrent tasks: A QoS-aware game theory approach. Computers & Geosciences, 2012. 47: p. 46-59.

[41] Suh, N.P., Complexity in Engineering. CIRP Annals - Manufacturing Technology, 2005. **54**(2): p. 46-63
[42] Delaram, J. and O.F. Valilai, An architectural view to computer integrated manufacturing systems based on Axiomatic Design Theory. Computers in Industry, 2018. 100: p. 96-114.
[43] Valilai, O.F. and M. Houshmand, A Manufacturing Ontology Model to Enable Data Integration Services in Cloud Manufacturing using Axiomatic Design Theory, in Cloud-Based Design and Manufacturing (CBDM). 2014, Springer. p. 179-206.
[44] Aghamohammadzadeh, E. and O.F. Valilai, A novel cloud manufacturing service composition platform enabled by Blockchain technology. International Journal of Production Research, 2020: p. 1-19.
[45] Aghamohammadzadeh, E., M. Malek, and O.F. Valilai, A novel model for optimisation of logistics and manufacturing operation service composition in Cloud manufacturing system focusing on cloud-entropy. International Journal of Production Research, 2019. 6(1): p. 345-363.
[46] Valizadeh, S., O. Fatahi Valilai, and M. Houshmand, Flexible flow line scheduling considering machine eligibility in a digital dental laboratory. International Journal of Production Research, 2019: p. 1-19.
[47] Assari, M., J. Delaram, and O.F. Valilai, Mutual manufacturing service selection and routing problem considering customer clustering in Cloud manufacturing. Production & Manufacturing Research, 2018. 6(1): p. 345-363.