School of Business, Social & Decision Sciences
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HABILITATION THESIS

Tokenization of Production & Supply chain systems: Transformation from XaaS toward a web 3 paradigm

By:

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Abstract

The paradigm of Cloud production and manufacturing system can be considered as one of the most dominant enablers of Industry 4.0 paradigm. The emphasize of this paradigm for realization of service-oriented production and manufacturing systems has established new perspectives for manufacturing business models toward globalized and distributed orientations. This thesis has proposed the evolution roadmap for realization of Cloud production and manufacturing system concepts. The thesis has proposed a roadmap of evolution which consists of three perspectives. The first perspective has contributed to platforms and architectures for globalized service-oriented production and manufacturing systems. The conducted research in this theme contributed for integration and interoperability of stakeholders and processes to enable the fulfillment of services. The second perspective has elaborated the idea of Cloud production and manufacturing systems by encompassing the transportation and logistics as service paradigm. The main contributions of the research studies in this theme can be interpreted as mutual and synergic production and transportation service alignment. Moreover, the research studies have contributed to the development of operations research (OR) models for Cloud service network management and planning. The third perspective has extended and contributed to the application of Blockchain and emerging Web 3 technologies in Cloud manufacturing networks. This research studies have accomplished the early steps for improving the effectiveness of the second perspective and have also provided an insight to the perspective of share economy and tokenization models in service-oriented networks. The studies emphasize the potential and capabilities of Web 3 for establishment of new business models in this network. The convergence of the research perspectives concentrates on more realization of service-oriented production and supply networks. The globalized interaction frameworks which operate with autonomous structures capable of resembling the preferences of Cloud stakeholders. From point view of sustainability pillars high research potentials can be of investigated. Moreover, the thesis proposes the future studies with motivation of more globalized, sustainable, and autonomous Cloud networks in form of tokenization paradigm.

Keywords Cloud production and manufacturing systems, service-oriented network, Globalized supply network, Blockchain, Web 3.

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List of Abbreviations

3PL	Third-Party Logistics
AD	Axiomatic Design
AP	Assignment Problem
APR	Alternative Process Routing
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CIM	Computer Integrated Manufacturing
CNN	Convolutional Neural Network
DA	Data Analytics
DApps	Decentralized Application
DICOM	Digital Imaging and Communications in Medicine
DLT	Distributed Ledger Technology
DT	Digital Twins
ERP	Enterprise Resource Planning
EVM	Ethereum Virtual Machine
IoT	Internet of Things
IT	Information Technology
ISO	International Organization for Standardization
MCOCS	Multi Criteria Optimization and Compromise Solution
MES	Manufacturing Execution System
ML	Machine Learning
MOM	Manufacturing Operation Planning & Management
OPC	Operation Process Chart
OR	Operations Research
PACS	Picture Archiving and Communication System
PLM	Product Lifecycle Management
PoA	Proof of Activity
PoW	Proof of Work
PoS	proof of Stake
CPDDN	Production-Distribution toward task Destination Nodes
QoS	Quality of Service
SCM	Supply Chain Management
SME	Small and Medium Enterprises
SOM	Service Oriented Manufacturing
VRP	Vehicle routing problem
XaaS	Everything as a Service

1. Introduction

Cloud manufacturing as a service oriented manufacturing paradigm has been introduced around one decade ago [1], [2], [3]. This paradigm introduced a XaaS (Everything as a Service) idea for production and manufacturing systems [4], [5]. This trend proposed new insights for transformation of manufacturing and production systems from "Product Oriented" [6], [7], [8] and "Process Oriented" [9], [10] to service oriented business models [11]. Through the last decades, there were various research orientations for the realization of Cloud manufacturing paradigm specially from point view of Industry 4.0 paradigm [12], [13]. This paradigm has the potential of shaping the globalized network of production and logistics service providers [14]. However this network creates complexities from point view of operations management [15], [16], inclusion of logistics [11], [17], [18] and global seamless communication of data and information [19], [20].

The realization of XaaS requires a transformation strategy for enabling the service-oriented production and manufacturing business models [6] [16]. Moreover, considering the globalized and network-based model of collaboration among the stakeholders, efficient IT (Information Technology) tools are required to support the operations management perspectives [21], [22] [23]. These tools should support decentralized mechanisms for handling the interactions among stakeholders. One of the recent paradigms for decentralized interactions is known to be Blockchain technology under the umbrella of Web 3 [24], [25]. This can shape a Tokenization ecosystem in which service-oriented interactions are handled autonomously and with a decentralized approach helping the more effective interaction management among stakeholders with a globalization characteristic [26] [27].

To achieve this transformation, this habilitation research suggests the realization of service-oriented production and supply chain systems [28] [29]. Shaping the network model of interactions, the thesis will suggest the realization of Blockchain technology to shape the tokenization model [30] [31] [32]. The requirements and trends of digital transformation for developing the Tokenization oriented model for production and supply chain networks will be investigated [33] [34].

The main objectives targeted to be fulfilled for tokenization of production and supply chain networks in this thesis can be categorized as:

- The transformational aspects of production and supply chain systems and their supply chains within the XaaS paradigm from points view of business models and operations management.
- The frameworks for mutual production operations and logistics services planning for XaaS paradigm.
- The decentralization of interaction management for production and supply chain networks by analysis of Web 3 capabilities.

1.1. Research roadmap

In this section, the thesis highlights the roadmap for analysis of the contributions to fulfill the proposed objectives. This roadmap has been illustrated in Figure 1-1 and demonstrates the connection of the research studies and the timeline. The roadmap highlights three perspectives which have been designed with interconnection to insure the transformation of XaaS architectures towards Web 3 enabled architecture.

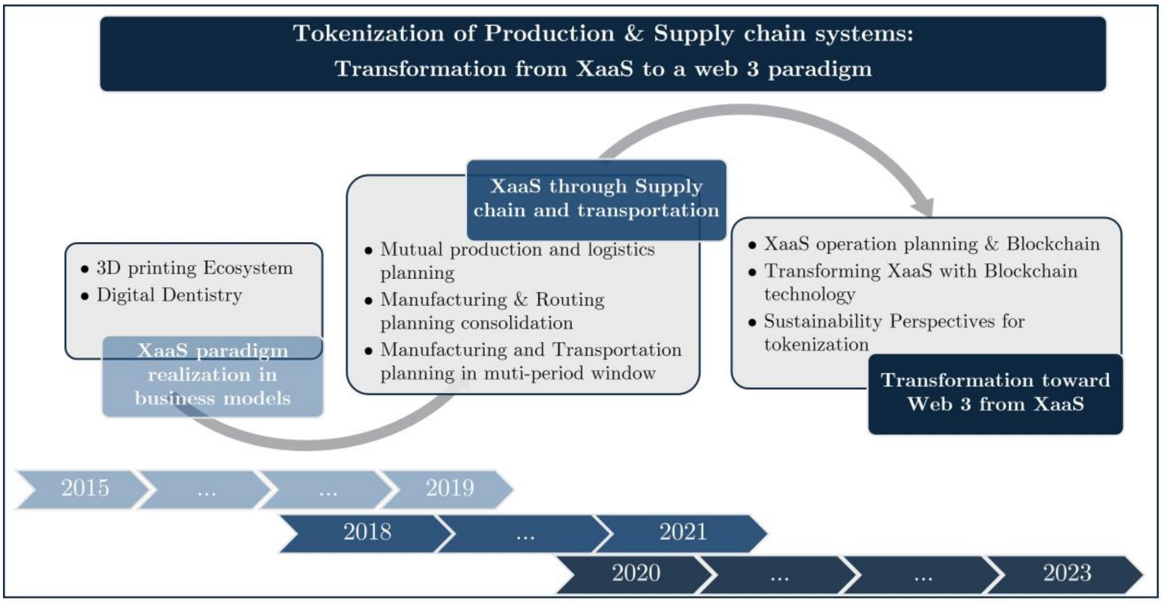


Figure 1-1. The roadmap of the thesis research contributions.

The roadmap includes following perspectives:

1.1.1. XaaS paradigm realization in production and manufacturing business models

The thesis starts with contributions which enable the architectures and frameworks for realization of service oriented models in manufacturing and production systems. The main contributions in this theme focus on the required Information Technology (IT) features in terms of computational and communicational technologies to enhance the information exchange through different disciplines and layers of production and manufacturing functionalities. The XaaS should be realized both through digital transformation of business models aligned with service-oriented approach and also should be equipped with operations research models for Manufacturing Operation Planning & Management (MOM). Also, the innovative technologies referred in Industry 4.0 paradigm like 3D printing and their roles in realization of service-oriented production and manufacturing systems should be elaborated. For this perspective, two research contributions conducted which are:

- "*Depicting additive manufacturing from a global perspective; using Cloud manufacturing paradigm for integration and collaboration*", Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., Bd. 229, Nr. 12, S. 2216–2237, Dez. 2015, doi: 10.1177/0954405414546706 [35].

  This research contributes to the realization of Cloud manufacturing and XaaS for 3D printing. The contributions focus on integrated design, process planning and fabrication with a service-oriented structure.

- "*A novel digital dentistry platform based on cloud manufacturing paradigm*", Int. J. Comput. Integr. Manuf., Bd. 32, Nr. 11, S. 1024–1042, Nov. 2019, doi: 10.1080/0951192X.2019.1686170 [36].

This research elaborates the Cloud manufacturing and XaaS theoretical and practical solution for digital dentistry. This highlights an application domain example for transforming a traditional value chain of design, process planning and fabrication for an XaaS orientation.

1.1.2. Service oriented manufacturing & Supply chain networks with transportation integrated models.

Considering the research studies which emphasize on the realization of service-oriented manufacturing systems, the necessity of considering logistics and transportation in manufacturing operation service models for shaping the globalized supply chain networks will be inevitable. This is essential as due to the nature of service-oriented models; globally distributed manufacturing facilities will be enabled which accomplish the production operations through their available services. The proposal of models for facilitation of transportation and logistics services and their integration in terms of mutual production and manufacturing service and transportation service matching will be essential to promote the service-oriented paradigm to a wider area including the Supply Chain Management (SCM) interaction level. These studies also focus on Operations Research (OR) perspective of service-oriented networks. The contribution for targeting the operations management perspectives of the models and facilitation of practical aspects of service definition, composition, and matching will be discussed. For this perspective, three research contributions conducted which are:

- "*Mutual manufacturing service selection and routing problem considering customer clustering in Cloud manufacturing*", *Prod. Manuf. Res.*, Bd. 6, Nr. 1, S. 345–363, Jan. 2018, doi: 10.1080/21693277.2018.1517056 [37].

  This research contributes to consideration of manufacturing and logistics services for service composition problem. The research emphasizes the effects of customer locations and selects the required manufacturing services with focus logistics related costs.

- "*Alternative process routing and consolidated production-distribution planning with a destination-oriented strategy in cloud manufacturing*", *Int. J. Comput. Integr. Manuf.*, Bd. 34, Nr. 11, S. 1162–1176, Sep. 2021, doi: 10.1080/0951192X.2021.1972459 [38].

  This research contributes to distribution and transportation services in Cloud manufacturing paradigm. The optimization of the service composition is considered to enable cost efficient and reliable fulfilment of services while fulfilling the required QoS (Quality of Service).

- "*Dynamic mutual manufacturing and transportation routing service selection for cloud manufacturing with multi-period service-demand matching", PeerJ Comput. Sci.,* Bd. 7, S. e461, Apr. 2021, doi: 10.7717/peerj-cs.461 [18].

  This research contributes to enabling the service composition for realistic dynamic characteristics of Cloud manufacturing and transportation systems.

The complexity of multiple service providers for both manufacturing and transportation systems are addressed. It enables an optimization model for distribution of manufacturing and transportation services over the globe and analysis the complexity in XaaS system in a cloud network.

1.1.3. Cloud Manufacturing Paradigm & Web 3 paradigm.

This perspective has been focused on the complexities for globalized Cloud manufacturing service composition and the solutions for finding decentralized methods for handling the Cloud manufacturing and supply chain networks. So, this perspective is focused on the application of Web 3 (also called Blockchain technology) in service-oriented paradigm of production and manufacturing systems. The main motivations of contributions in this theme will solve the problems of service-oriented production and manufacturing operation planning and management from a global perspective. As the operations research aspects of the Cloud manufacturing systems are known to be categorized as NP-hard [14], [39], [40], [41] problem which introduces challenges for time efficient solution providing. On the other hand, considering the global collaboration among different firms together, the centralized operations management paradigm would not be an efficient solution. The contributions in this theme will elaborate the capabilities of technologies in Web 3 and Blockchain for efficient realization of Cloud production networks. For this perspective, three research contributions conducted which are:

- "*A novel cloud manufacturing service composition platform enabled by Blockchain technology*", Int. J. Prod. Res., Bd. 58, Nr. 17, S. 5280–5298, Sep. 2020, doi: 10.1080/00207543.2020.1715507 [39].

This contribution focuses on enabling the service composition problem through a Blockchain architecture. The decentralization method for creating the clusters of services and demands has been elaborated. Moreover, the performance of the Blockchain based model in comparison with traditional state of the art model has been discussed.

- "*Blockchain-based cloud manufacturing platforms: A novel idea for service composition in XaaS paradigm*", PeerJ Comput. Sci., Bd. 7, S. e743, Dez. 2021, doi: 10.7717/peerj-cs.743 [42].

This contribution enables a mapping between XaaS service composition framework and Blockchain enabled service matching model. This contribution discusses the possibility of defining new consensus mechanisms with a focus on the optimality of service matching model. The details about the motivation-related mechanisms for service matchers have also been discussed.

- "*Blockchain-Based Architecture for a Sustainable Supply Chain in Cloud Architecture*", Sustainability, Bd. 15, Nr. 11, Art. Nr. 11, Jan. 2023, doi: 10.3390/su15119072 [43].

This research contributes more to the idea of Blockchain based architecture for Cloud manufacturing systems. Moreover, the research proposes the idea of tokenization of model for inclusion of sustainability perspectives for composition and creation of Cloud manufacturing networks.

1.2. Timeline of research studies

As illustrated in Figure 1-1 the research studies timeline started from 2015 with focus on the first perspective “XaaS paradigm realization in production and manufacturing business models” and continued for almost 4 years and preparing the grounds for second perspective. The second perspective of research “Service oriented manufacturing & Supply chain networks with transportation integrated models.” started from 2018 and elaborated models for inclusion of transportation and logistics. The last perspective “Cloud Manufacturing Paradigm & Web 3 paradigm.” started from 2020 and continued for almost 3 years until 2023.

2. XaaS paradigm realization in production and manufacturing business models

As mentioned earlier, this theme contributes to the research studies which have proposed frameworks and architectures to enable the service-oriented production and manufacturing paradigm. Using the Industry 4.0 paradigm and its related emerging technologies, it was mainly intended to elaborate the functional frameworks in which the realization of the service-oriented production and manufacturing systems would be possible. These architectures are contributed to enable the interoperability and integrity of data and information among collaborating firms in production and supply chain networks. Also, the issue of application of emerging technologies and their applications from a global perspective has been focused.

2.1. Depicting additive manufacturing from a global perspective; using Cloud manufacturing paradigm for integration and collaboration

2.1.1. Summery

This paper has considered the globalization as one of the requirements of Cloud manufacturing and considered the additive manufacturing potentials and its application trends in Industry 4.0 paradigm besides its characteristics for fulfilling the quick design to manufacturing were investigated. The research has discussed the requirements and necessities of additive manufacturing with respect to a Cloud manufacturing and globalized production systems. Two major requirements were demonstrated as the integration of manufacturing operations and enabling collaboration through the distributed manufacturing service providers. A framework for enabling additive manufacturing in the global paradigm was introduced. The framework applied the Cloud manufacturing paradigm for considering the 3D printing services through the network for communication of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) data among distributed firms. The integration of processes for transition of data from design to fabrication phase over the globe has been discussed and a framework was proposed by the study.

2.1.2. Bibliography information

O. Fatahi Valilai* und M. Houshmand, "*Depicting additive manufacturing from a global perspective; using Cloud manufacturing paradigm for integration and collaboration*", Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., Bd. 229, Nr. 12, S. 2216–2237, Dez. 2015, doi: 10.1177/0954405414546706 [35].

2.1.3. Author contributions and roles

Please find CRediT author statement for our paper entitled "Depicting additive manufacturing from a global perspective; using Cloud manufacturing paradigm for integration and collaboration", Published in , Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, http://doi.org/10.1177/0954405414546706.

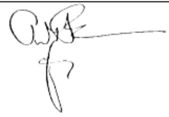
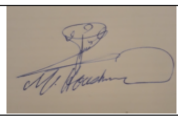
	Author	Description	CRediT Statement	Signature
1.	Fatahi Valilai, Omid	Corresponding author	Conceptualization, Methodology, Software, Writing original paper, Visualization, Investigation, Data curation, Methodology, Validation	
2.	Houshmand, Mahmoud	Co-Author	Supervision, co-writing original draft and revising the paper, Validation	

Figure 2-1. CRediT certificates for research contribution with doi: 10.1177/0954405414546706.

2.2. A novel digital dentistry platform based on cloud manufacturing paradigm

2.2.1. Summery

While the main aspects of Cloud based production and manufacturing systems were elaborated through research and studies, there have been opportunities to propose new business models with the application of the service oriented and Industry 4.0 based production and manufacturing systems. From one point of view, the service-oriented perspectives of production and manufacturing systems enabled the offer of services for fabrications of prosthetics or oral scanning services for CAD files and from other perspectives technologies like 3D printing and their capabilities for rapid and agile fabrication of customized products. The research proposed the digital dentistry paradigm and elaborated the digital dental workflow in terms of phases including scan, design, production planning and fabrication. In each phase the application of variety of software solutions and digital technologies were investigated. The service-oriented approach in terms of intensive collaboration of dentists, dental laboratories, imaging, and production centers were discussed. The facilitation of interoperability among digital components was also considered and the application of Digital Imaging and Communications in Medicine (DICOM) standard for integration of data was suggested. Moreover, the application Picture Archiving and Communication System (PACS) concept for fulfilling the design, implant planning, process planning, and production workstations was considered. This study can be considered as one of the transformation production business models which benefits from the service-oriented production network.

2.2.2. Bibliography information

S. Valizadeh, O. Fatahi Valilai*, M. Houshmand, und Z. Vasegh, "*A novel digital dentistry platform based on cloud manufacturing paradigm*", Int. J. Comput. Integr. Manuf., Bd. 32, Nr. 11, S. 1024–1042, Nov. 2019, doi: 10.1080/0951192X.2019.1686170 [36].

2.2.3. Author contributions and roles

Please find CRediT author statement for our paper entitled "A Novel Digital Dentistry Platform Based on Cloud Manufacturing Paradigm", Published in **International Journal of Computer-Integrated Manufacturing**, http://dx.doi.org/10.1080/0951192X.2019.1686170.

	Author	Description	CRediT Statement	Signature
1.	Valizadeh, Siavash	Ph.D. Candidate	Conceptualization, Methodology, Software, Writing original paper, Visualization, Investigation.	[signature]
2.	Fatahi Valilai, Omid	Co-Supervisor Corresponding author	Data curation, Methodology, co-writing and revising the paper, Validation	[signature]
3.	Houshmand, Mahmoud	Supervisor	Supervision, co-writing original draft, Validation	[signature]
4.	Vasegh, Zahra	Consulting advisor	Supervision, Validation	

Figure 2-2. CRediT certificates for research contribution with doi: 10.1080/0951192X.2019.1686170.

3. Service oriented manufacturing & Supply chain networks with transportation integrated models

The realization of Cloud based production and manufacturing systems insists on consideration of whole production and manufacturing processes as available services distributed over the globe. Although the composition of the services for fulfilling the requirements of production operation provides great opportunities for different business models, the distribution of operation service providers requires the consideration of transportation and logistics among the operation service providers. This theme encompasses all the research studies which contributed to the form of transportation and logistics models and integrating them into service-oriented Cloud production and manufacturing systems. Special focus also has been devoted for the integrity of process and information from supply chain management perspectives. This includes considerations for the raw material procurement and the inbound logistic operations as well as distribution and dispatching operation for last middle delivery of produced products to the end consumers and their effects on the management and planning of fabrication services.

Moreover, this theme of the research studies has focused on operations research aspects of XaaS production and manufacturing systems. The main pillars of contributions are related to mathematical models for encompassing more realistic Cloud based ecosystems operational models. The main challenges for Cloud production and manufacturing systems are due to global perspective of the model which with the NP-hard nature of these problems which necessitate the effective solving approaches for practical aspects. So, the studies in this theme are contributing to both mathematical model structure and the solving approaches.

3.1. Mutual manufacturing service selection and routing problem considering customer clustering in Cloud manufacturing

3.1.1. Summery

This study focused on the mathematical models for operation and transportation service assignment problem using the operation process chart (OPC) of product for efficient transportation service assignment in Cloud manufacturing. The structure of mathematical model fulfils the clustering of customer for product delivery for shared logistic aspects. The possibility of using shared logistics services for cluster of operations services is considered. The objective function considers the profit in terms of sales befits and the operation and transportation costs. The dependencies among the operation service fulfilment and also the sequences of the operation service fulfillment were also embedded thought the model structure. The model was developed with linear structure for efficient solving time and was solved in large scale sample cases with genetic metaheuristic algorithm. This study has contributed to the service composition models with customer orientation service composition which highly decrease the transportation costs for global manufacturing. The study considers single-product supply network in Cloud manufacturing. The service selection model benefits from the layered structure of transportation and production services with clustered.

3.1.2. Bibliography information

M. Assari, J. Delaram, und O. Fatahi Valilai*, M. Houshmand, und Z. Vasegh, "*Mutual manufacturing service selection and routing problem considering customer clustering in Cloud manufacturing*", *Prod. Manuf. Res.*, Bd. 6, Nr. 1, S. 345–363, Jan. 2018, doi: 10.1080/21693277.2018.1517056 [37].

3.1.3. Author contributions and roles

Please find CRediT author statement for our paper entitled "Mutual Manufacturing Service Selection and Routing Problem Considering Customer Clustering in Cloud Manufacturing", Published in **Production & Manufacturing Research Journal,** http://dx.doi.org/10.1080/21693277.2018.1517056.

	Author	Description	CRediT Statement	Signature
1.	Assari, Mozhgan	M.Sc. Student	Conceptualization, Methodology, Software, Writing original paper, Visualization, Investigation	
2.	Delaram, Jalal	M.Sc. graduate	Methodology, Writing original paper, Investigation.	
3.	Fatahi Valilai, Omid	M.Sc. Supervisor, Corresponding author	Supervision, Data curation, Methodology, co-writing and revising the paper, Validation	

Figure 3-1. CRediT certificates for research contribution with doi: 10.1080/21693277.2018.1517056.

3.2. Alternative Process Routing and Consolidated Production-Distribution Planning with a Destination Oriented Strategy in Cloud manufacturing

3.2.1. Summery

To progress the mutual transportation and manufacturing service orientation, this study extended the ideas in terms of using the operations services with a strategy to produce the final product near to final customer delivery location. So, the operation services can be selected with orientations for geographical locations near to their targeted delivery locations. This enables the paradigm of Cloud manufacturing to overcome the crises for transportation more efficiently for using distributed manufacturing resources while using the opportunities to decrease the logistics and production costs. The study proposed a structure model for decomposing ordered tasks to several subtasks and then considering them as services which should be allocated to distributed manufacturing resources. Form the implementation aspects, the paper also developed an operational planning model for evaluation of Cloud manufacturing performance. The proposed decomposition models for services created the alternative process routing concept. So, the decomposition of operation tasks to several manufacturing plans enabled the flexibility of Cloud system for proper service assignment which was offered as consolidated production-distribution toward destination nodes strategy.

3.2.2. Bibliography information

M. Zeynivand, H. Ranjbar, S.-A. Radmanesh, und O. Fatahi Valilai*, "*Alternative process routing and consolidated production-distribution planning with a destination-oriented strategy in cloud manufacturing*", *Int. J. Comput. Integr. Manuf.*, Bd. 34, Nr. 11, S. 1162–1176, Sep. 2021, doi: 10.1080/0951192X.2021.1972459 [38].

3.2.3. Author contributions and roles

Please find CRediT author statement for our paper entitled "Alternative Process Routing and Consolidated Production-Distribution Planning with a Destination Oriented Strategy in Cloud manufacturing" Published in **International Journal of Computer Integrated Manufacturing,**
http://doi.org/10.1080/0951192X.2021.1972459.

	Author	Description	CRediT Statement	Signature
1.	Zeynivand, Mehdi	Ph.D. student	Conceptualization, Methodology, Software, Writing original paper, Visualization, Investigation	Zeynivand. M
2.	Ranjbar, Hossein	Researcher		H.Ranjbar
3.	Radmanesh, Seyyed-Alireza	Ph.D. student		
4.	Fatahi Valilai, Omid	Co-Supervisor, Corresponding author	Supervision, Data curation, Methodology, co-writing and revising the paper, Validation	

Figure 3-2. CRediT certificates for research contribution with doi: 10.1080/0951192X.2021.1972459.

3.3. Dynamic mutual manufacturing and transportation routing service selection for cloud manufacturing with multi-period service-demand matching

3.3.1. Summery

To elaborate the realization of mutual transportation and manufacturing operation service management, this research study focused on the dynamic characteristics of service providers in the Cloud. The main idea was the possibility of participation of manufacturing firms and logistics service providers together in Cloud ecosystems aligned with XaaS paradigm. The research study focused on efficient service composition both for including mutual operation and transportation services and their effects on each other in Cloud manufacturing paradigm. The challenges were investigated to be the service composition complexity due to large size and complicated dynamic characteristics for continually received service requests. The study proposed a model for fulfilling the Quality of Service (QoS) requirements for service composition. The study also considered NP-hard characteristics besides the dynamicity of the allocation problem in the Cloud composition problem and contributed for the practical aspects of solving the model time-efficient approach. The results demonstrated the capabilities of the model for service composition with dynamic behavior of manufacturing and logistics service composition for possibility of including arrival of new services and demands into the Cloud.

3.3.2. Bibliography information

S. A. S. Aghili, O. Fatahi Valilai*, A. Haji, und M. Khalilzadeh, "“*Dynamic mutual manufacturing and transportation routing service selection for cloud manufacturing with multi-period service-demand matching”, PeerJ Comput. Sci.,* Bd. 7, S. e461, Apr. 2021, doi: 10.7717/peerj-cs.461 [18].

3.3.3. Author contributions and roles

Please find CRediT author statement for our paper entitled "Dynamic mutual manufacturing and transportation routing service selection for cloud manufacturing with multi-period service-demand matching" Published in **PeerJ Computer Science,** http://doi.org/10.7717/peerj-cs.461.

	Author	Description	CRediT Statement	Signature
1.	Sadeghi Aghili, Seyed Ali	Ph.D. Candidate	Conceptualization, Methodology, Software, Writing original paper, Visualization, Investigation.	
2.	Fatahi Valilai, Omid	Supervisor, Corresponding author	Supervision, Data curation, Methodology, co-writing and revising the paper, Validation	Dr. Omid Fatahi Valilai
3.	Haji, Alireza	Co-Supervisor	Supervision, Validation	
4.	Khalilzadeh, Mohammad	Consulting Advisor	Validation	

Figure 3-3. CRediT certificates for research contribution with doi: 10.7717/peerj-cs.461.

4. Cloud Manufacturing Paradigm & Web 3 paradigm

The third perspective of the research studies would focus on one of the disruptive technologies of recent year known as Web 3 or Blockchain technology. The main motivation behind this theme can be interpreted due to the globalized characteristics of Cloud production and manufacturing networks. While the globalized network of service providers and demanders encompass various individual and firms to collaborate, most of the research studies of former themes considers centralized and inhouse architecture and framework besides operation research models. Moreover, the globalized structure of Cloud networks results in large scale problem size in terms of operations research which would be a great challenge as operations research models of Cloud networks are NP-hard and will face with great problems for proper and optimal policy making in agile and dynamic context. So, the idea of decentralized mechanisms for both frameworks and architectures fulfilling the interactions in Cloud ecosystems and also operations research models for optimal and effective service have been strongly focused on application of decentralized technologies. Over the last four years, this theme of studies has been established with a special focus on Blockchain and Web 3 technologies. The capabilities of these technologies for enabling decentralized network and enabling the seamless interaction among stakeholders can be highly used for fulfilling the former research themes in terms of globalized scale.

4.1. A novel cloud manufacturing service composition platform enabled by Blockchain technology

4.1.1. Summary

This study established the first application of Blockchain technology among the research in this theme. In this study the inefficiency of service matching models for Cloud production systems were discussed. Considering the requirements of globalized collaboration of stakeholders in this ecosystem, supporting large pools of service providers and Service demanders are inevitable. The study introduced the dynamic behavior of parameters in Cloud networks and challenged the centralized mechanism of service matching problem. A novel platform entitled Blockchain-based service composition model (Block-SC) was based on the Blockchain technology. The proposed model had the capabilities for dividing the original service matching problem into multiple sub-problems each of which contains a small fraction of the service/task pool. The workflow of Blockchain based architecture in terms of Service providers and demanders and introduced solvers was introduced and rewarding mechanisms for encouraging the optimality of solutions in the platform was described. The capabilities of the proposed platform were remarkable for provides an effective mechanism for collaboration of service matching in the service-oriented paradigm and also the optimality of service composition problem.

4.1.2. Bibliography information

E. Aghamohammadzadeh und O. Fatahi Valilai*, "*A novel cloud manufacturing service composition platform enabled by Blockchain technology*", Int. J. Prod. Res., Bd. 58, Nr. 17, S. 5280–5298, Sep. 2020, doi: 10.1080/00207543.2020.1715507 [39].

4.1.3. Author contributions and roles

Please find CRediT author statement for our paper entitled "A Novel Cloud Manufacturing Service Composition Platform Enabled by Blockchain Technology" Published in **International Journal of Production Research,** https://doi.org/10.1080/00207543.2020.1715507.

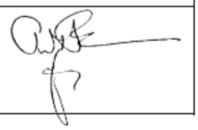
	Author	Description	CRediT Statement	Signature
1.	Aghamohammadzadeh, Ehsan	M.Sc. Graduate	Conceptualization, Methodology, Software, Writing original paper, Visualization, Investigation	
2.	Fatahi Valilai, Omid	M.Sc. Supervisor, Corresponding author	Supervision, Data curation, Methodology, co-writing and revising the paper, Validation	

Figure 4-1. CRediT certificates for research contribution with doi: 10.1080/00207543.2020.1715507.

4.2. Blockchain based Cloud Manufacturing Platforms; A novel idea for service composition in XaaS paradigm

4.2.1. Summery

The capabilities of Blockchain solution for globalized scale of Cloud network was found so promising and the research studies continued for developing and extending the framework of Blockchain technology. The study has elaborated the service-oriented architecture for service composition and allocation to demanders with its dynamic behavior. While criticizing the centralized global optimization models, a distributed deployment of the globalized service matching was proposed. The study mapped the required component in Blockchain platform to the service matching model in terms of service matchings as transactions in the Blockchain and the feasibility of provided solution in terms of consensus mechanism. The concept of Proof of Work (PoW) was also elaborated in terms of the endeavor for proposing the proper service matching. The resulted service matching structure highly increased the response time and improve the overall optimality of supply-demand matching. Although the Blockchain solution was considered as a nonglobal optimization technique, by using the reward mechanisms, the proposed solution was in between 15.14% to 34.8% better for reduction in costs and 20% to 68.4% better solving time. This study encouraged the Blockchain capabilities for enabling effective service processing mechanisms in globalized Cloud manufacturing networks.

4.2.2. Bibliography information

S.-A. Radmanesh, A. Haji, und O. Fatahi Valilai*, "*Blockchain-based cloud manufacturing platforms: A novel idea for service composition in XaaS paradigm*", PeerJ Comput. Sci., Bd. 7, S. e743, Dez. 2021, doi: 10.7717/peerj-cs.743 [42].

4.2.3. Author contributions and roles

Please find CRediT author statement for our paper entitled "Blockchain based Cloud Manufacturing Platforms; A novel idea for service composition in XaaS paradigm" Published in **PeerJ Computer Science, PeerJ Computer Science,** http://dx.doi.org/10.7717/peerj-cs.743.

	Author	Description	CRediT Statement	Signature
1.	Radmanesh, Seyyed-Alireza	Ph.D. Candidate	Conceptualization, Methodology, Software, Writing original paper, Visualization, Investigation.	
2.	Haji, Alireza	Supervisor	Supervision, Validation	
3.	Fatahi Valilai, Omid	Co-Supervisor, Corresponding author	Supervision, Data curation, Methodology, co-writing and revising the paper, Validation	

Figure 4-2. CRediT certificates for research contribution with doi: 10.7717/peerj-cs.743.

4.3. Blockchain-Based Architecture for a Sustainable Supply Chain in Cloud Architecture

4.3.1. Summery

This study continued the application of Blockchain based solutions in Cloud network of service providers by elaborating the service matching. The study considered the wide range service types like transportation service network suggested by former studies [58] [59]. The study also targeted the sustainability perspective in terms of carbon-di-oxide (CO2) emissions control. The proposed platform elaborated the Blockchain's capabilities such as consensus mechanism in form of Proof of Stake (PoS); smart contracts; and solvers roles for best possible service matching scenarios and encryption mechanism for data access security. The reward function encouraged the solvers for service matchings which fulfilled the sustainability perspective with priority. The study encouraged the role of matching services in the ecosystem as a new form of obtainable service besides service providers and demanders. This study has considered the globalized characteristics of transportation services and the challenges for optimal matching. Components of this Blockchain based model like the smart contract mechanisms for managing the financial interaction of service demanders and providers and the related claim management structure and the Decentralized Application (DApps) for enabling the flexibility of service network have been discussed. This study encouraged the idea of developing a new role in service-oriented Clouds for service organization and matching which resembles the tokenization model in shared economy perspectives.

4.3.2. Bibliography information

S.-A. Radmanesh, A. Haji, und O. Fatahi Valilai*, "“*Blockchain-Based Architecture for a Sustainable Supply Chain in Cloud Architecture*", Sustainability, Bd. 15, Nr. 11, Art. Nr. 11, Jan. 2023, doi: 10.3390/su15119072 [43].

4.3.3. Author contributions and roles

This is the CRediT author statement for our paper entitled "Blockchain-Based Architecture for a Sustainable Supply Chain in Cloud Architecture" Published in **Sustainability** 2023, 15, 9072. https://doi.org/10.3390/su15119072.

	Author	Description	CRediT Statement	Signature
1.	Radmanesh, Seyyed-Alireza	Ph.D. Candidate	Conceptualization, Methodology, Software, Writing original paper, Data curation, Visualization, Investigation.	
2.	Haji, Alireza	Ph.D. Co-Advisor	co-writing and revising the paper, Validation	
3.	Fatahi Valilai, Omid	Ph.D. Advisor, Corresponding author	Conceptualization, Supervision, Formal analysis, Data curation, Methodology, co-writing and revising the paper, Validation, Resources, Project administration	

Figure 4-3. CRediT certificates for research contribution with doi: 10.3390/su15119072.

5. Conclusions

The paradigm of Cloud production and manufacturing systems can be considered as one of the most dominant enablers of Industry 4.0 paradigm. The emphasize of this paradigm for realization of service-oriented production and manufacturing systems has established new perspectives for manufacturing business models toward globalized and distributed orientations. Using other emerging technologies in Industry 4.0 like Digital Twins (DT), Internet of Things (IoT) and Data Analytics (DA) has empowered more this paradigm in terms of global interactions of processes, data and knowledge in the Cloud ecosystems.

The analysis of the research studies in first perspective "XaaS paradigm realization in production and manufacturing business models" demonstrates the different aspects of improving the production and manufacturing systems for service-oriented paradigm adoption. The studies are aligned with the motivations in Industry 4.0 in terms of benefiting from digital transformation technologies. The most important aspects in this theme can be interpreted as the fulfilment of challenges which were affecting the process and data integration and interoperability for globally distributed production and manufacturing service providers. The studies in this area shall be continued with a special focus for enabling the integration of knowledge models among the service providers. The proposal of service providers for facilitation of interoperable frameworks would of other interesting further research topics in this theme. This research theme requires to be continued with a focus on knowledge interoperability in autonomous form for future research plans.

The analysis of the research studies in second perspective "Service oriented manufacturing & Supply chain networks with transportation integrated models." demonstrates the aspects of transportation and logistics service evolvement in Cloud production and manufacturing systems. The studies emphasized the important of service-oriented transportation for XaaS production systems. While the first theme of research studies was more focusing on shopfloor aspects of material processing Cloud ecosystems, the second theme has concentrated on the efficient models of transportation in global manufacturing. The studies have tried to open new paradigms of Industry 4.0 technologies like drone technologies and social media data analytics. This theme of research studies is an essential key factor for successful Cloud based production systems which benefit from distributed services over the globe and keep their performance criteria in terms of transportation costs and challenges. The studies in this area shall be continued with a special focus for enabling more efficient transportation service composition models and alignment with sustainability perspectives of transportation paradigm. It is worth mentioning that as stated earlier, the overlap of the research studies in the second theme with other themes is inevitable as for practical aspects operations research models were also developed. However, the focus of these research studies was mostly toward the service-oriented frameworks for transportation aligned with second theme focus. This research theme requires to be more elaborated to encompass whole supply chain process integration in the form of as a service structure. Especially focus for share economy of transportation services and focus on sustainability perspectives will highlight the future studies in this theme.

Moreover, mathematical models for service-oriented production and manufacturing system operation management and planning. While in two former themes, the elaboration of architectural framework for realization of Cloud manufacturing and transportation systems were focused, in this theme the operational aspects of service definition, allocation scheduling and matching was investigated. It can be emphasized on the importance of service planning in Cloud ecosystems. While one part of the research studies was concentrating on private Clouds and tried to offer competitive advances for better operation management in comparison with conventional production and manufacturing systems, the second part has proposed the concept of public Cloud networks. The possibility of matching the services and demands and the design of effective strategies for service providers and demanders would be fundamental of public Cloud service-oriented production and manufacturing networks. The studies in this theme shall be continued with a perspective of sustainable Cloud supply networks and effective mathematical models which can provide near to optimum solutions with agility and encompass the tradeoff of stakeholders' preferences through model components.

The analysis of the studies in third perspective "Cloud Manufacturing Paradigm & Web 3 paradigm." shows the promising future research studies for Blockchain application in Cloud production and manufacturing networks. Most of the challenges expressed in former perspectives have been approached and effective solutions have been provided. The challenges regarding the globalized and large-scale model of interactions in Cloud ecosystems can be efficiently treated by Blockchain based models. The main challenge would be the mapping of the Cloud production and manufacturing networks to Blockchain architectures. The consensus mechanisms and reward function definition which help the effective processing of distributed interactions in the Cloud networks are of the most important issues in this research theme. The research theme proposes the establishment of complementary and supportive services in Cloud ecosystems in form of tokenized services which facilitate the organization and management of services and highly increase the performance of Cloud networks. The research studies have accomplished the early steps for improving the effectiveness of the third theme and are continued with the perspective of share economy and tokenization models in service-oriented networks. The studies emphasize the potential and capabilities of Web 3 for establishment of new business models in this network. These services can be imagined through a token model structure which supports the more efficient service and demand matching. The role of smart contracts for increasing the autonomous level of Cloud manufacturing and supply network would be one of the important future research directions.

The convergence of the themes in this research concentrates on more realization of service-oriented production and supply networks. The globalized interaction frameworks which operate with autonomous structures that resemble the preferences of their stakeholders in this ecosystem. From the point view of sustainability pillars, high research potential can be refereed. The potential of service-oriented network manufacturing for Small and Medium Enterprises (SMEs) has been found to be great, which can be a unique opportunity for globalized production networks.

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7. Index list

8. Publication list

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