Smart, sustainable and resilient (SSR) healthcare supply chain: A Fuzzy-AHP Approach

Md Kamal Hossain[a] and Dr. Vikas Thakur[b]

[a]*School of Management, National Institute of Technology Rourkela, India 769008, Tel: +91-6294997929, Email: 518sm2001@nitrikl.ac.in*

[b]*School of Management, National Institute of Technology Rourkela, India 769008, Tel: +91-6612462807, Email: thakurv@nitrikl.ac.in*

Abstract

The smart, sustainable and resilient (SSR) healthcare supply chain has been considered as a crucial element in the healthcare industry. However, existing practices and processes are facing many challenges in real world scenarios along with the absence of very few studies in the SSR in healthcare supply chain. The present study aims to analyze the drivers of implementing SSR healthcare supply chain in the Indian context. The method of fuzzy-Analytical Hierarchy Process (AHP) has been implemented to prioritize the identified factors and subsequently ranking them. The study has found process coordination and integration, flexibilities in HCSC and HCSC information system to be some of the most prioritized factors of implementing SSR healthcare supply chain. Policy makers can make the best of the highly prioritized factors and improve on the least prioritized one to suit the organizational need. The implications and conclusion has been highlighted in the present study.

Keywords: Smart, Sustainable and Resilient (SSR); Healthcare Supply Chain (HCSC); Fuzzy-Analytic Hierarchy Process (AHP); Coordination and Integration

1. Introduction

The implementation of the contemporary information and communication solutions has aggravated the problems of inefficient practices urging for the implementation of highly advance and innovative technological solutions (Jayaraman et al., 2019). Thus to counter the shortcomings of the contemporary information and communication technologies, the fourth industrial revolution called as the industry 4.0 can be implemented to achieve innovation for the increased HCSC efficiency (Javaid and Haleem, 2019). The concept of industry 4.0 was first established in Germany in 2011 and since then some countries such as the USA, Japan and China have appropriately applied it in their own plan to revolutionize industries (Gunasekaran and Ngai, 2004; Ding, 2018). Industry 4.0 constitutes of four important components, namely, Internet of Things (IoT), Cyber-physical Systems (CPS), Internet of Services (IoS) and Smart Factory (Hermann et al., 2016). The IoT consists of inter-connected physical objects that are enabled using Radio-frequency Identification (RFID), wireless networks and cloud computing (Trappey et al., 2017). CPS constitute the integration of physical and cyber networks to render more transparent and efficient actions (Zhong et al., 2017). The concept of smart factory involves instituting of robots to automate the processes (Waibel et al., 2017) and cloud computing facilitates recording of all the details being developed across the supply chain through the scanning of bar codes, QR codes and RFID tags (Kache and Seuring, 2017; Alloghani et al., 2018).

Hence, industry 4.0 would facilitate the HCSC to perform various integrated and productive functions to solve various problems multi-dynamic approaches in the HC industry such as: enhanced productivity, quality improvements, improved accuracy and efficiency, managing HCSC data efficiently and an improved information system (Javaid and Haleem, 2019). In carrying out the study very little research works have been carried out providing a window of opportunities to fill the literature and policy gaps in implementing industry 4.0 for designing smart and sustainable HCSC. Hence, the purpose of the current study is to identify and analyze the drivers of implementing the smart, sustainable and resilient (SSR) HCSC. In relation to the pursuance of the study, the following research questions have been developed:

1. What are the crucial drivers of implementing SSR HCSC?
2. How are the selected drivers of implementing SSR HCSC have been analyzed?
3. What are important practical managerial implications of the study?

Based on the above research questions, the following objectives of the study have been derived:

1. To identify the important drivers of implementing SSR HCSC through literature support and experts' opinions.
2. The selected factors have been processed and prioritized by implementing the fuzzy-Analytic Hierarchy Process (AHP).
3. The practical managerial implications have been highlighted to facilitate implementing the prioritized drivers of implementing SSR HCSC.

The present study proceeds firstly, by identifying the various drivers of implementing SSR HCSC through literature review and experts' support. The experts were consulted to finalize the drivers. The experts consulted include: HCSC experts, procurement officers, medical doctors and hospital managers. The rest of the paper has been carried out by the following ways: Section 2 covers the literature review, Section 3 discusses the solution methodology, Section 4 highlights the application of the methodology, and Section 5 covers results and discussions. Finally, Section 6 highlighted the practical managerial implications and conclusion of the study has been developed in Section 7.

2. Literature Review

In the HCSC, mass customization, shorter lead time and other issues cannot be solved with the existing practices and require incorporating SSR techniques. The technologies of industry 4.0 enables safety, conforming standards and increased information management (Javaid and Haleem, 2019). Implementing industry 4.0 would revolutionize the entire HCSC through the integration of the physical and the virtual realm involving people as well as things (Kagermann, 2015). The big data and advanced analytics perform a crucial role in implementing SSR in the HCSC (Waller and Faucett, 2013).

Some of the research studies of implementing industry 4.0 in HCSC have been conducted to highlight the technical basis and implications in the HC industry (Waibel et al., 2017). The implementation of smart technologies in the manufacturing sector have given birth to the evolution of industry 4.0 helps to decentralize business process (Wiengarten and Longoni, 2015). In order to realize the application of industry 4.0 in the HCSC, process integration is required to achieve expected performances that demands coordination of various stakeholders across the entire supply chain (Gunasekaran and Ngai 2004). Besides, HCSC flexibilities enabled through stakeholder's collaboration is required to enhance the performance and responsiveness of the supply chain for an effective HC services.

Table 1: The drivers of implementing SSR in the HCSC

Sl. No.	Drivers	References
1.	Coordinating and integrating of processes in the HCSC (HCSC1)	Kowalski (2009); Kagermann (2015); Waibel et al. (2017)
2.	Maintaining HCSC flexibilities (HCSC2)	McKone-Sweet et al. (2005); Wiengarten and Longoni (2015)
3.	HCSC information system (HCSC3)	Datta (2017); Waibel et al. (2017)
4.	HCSC agility and resilience (HCSC4)	Altay et al. (2018); Singh (2019)
5.	Implementing IoT in HCSC (HCSC5)	Gunasekaran and Ngai (2004); Jayaraman et al. (2019)
6.	Use of RFID tags (HCSC6)	Kache and Seuring (2017); Hossain and Thakur (2020)
7.	Promoting e-Health services (HCSC7)	Rahmani et al. (2018); Rotich (2018)
8.	Lean HCSC practices (HCSC8)	Hossain and Thakur (2020); Singh (2019)
9.	Adequate HCSC knowledge (HCSC9)	McKone-Sweet et al. (2005); Kasthuri (2018); Lasi et al. (2014)
10.	Managing HCSC quality standards (HCSC10)	Hossain and Thakur (2020); Zhong et al. (2017)
11.	Equitable HC accessibilities (HCSC11)	Kasthuri (2018); Singh (2019)
12.	Infrastructural development supporting cyber-physical systems and smart factories(HCSC12)	Hermann et al. (2016); Zhong et al. (2017)
13.	Investment in HCSC R&D (HCSC13)	Hossain and Thakur (2020); Alloghani et al. (2018)

delivery (Datta 2017). The presence of HCSC viability that is agility and resilience is a critical to implement SSR that enhances required operational performances (Altay et al., 2018). To enhance the HCSC performances, implementing SSR would be considered as a value driven strategy to revolutionize the entire supply chain processes (Kache and Seuring, 2017).

2.1. Literature on solution methodology perspective

The methodology of fuzzy-AHP has been implemented in the study to prioritize the selected drivers of implementing SSR in HCSC. In order to prioritize the drivers, experts were consulted for pair-wise comparison of the drivers. Fuzzy-AHP is an improvement of the simple AHP. Due to the presence of the inconclusiveness and the biasedness of human judgements in the AHP method, the concept of fuzzy has been integrated to form the methodology of fuzzy-AHP (Hossain and Thakur, 2020). The various studies have been conducted implementing the methodology of fuzzy-AHP. Thakur and Ramesh (2017) have implemented the fuzzy-AHP to sort out complex problems.

3. The Solution methodology

The present study has considered the implementation of fuzzy-AHP to prioritize the drivers of implementing SSR in HCSC. The method of fuzzy-AHP is an improvement of AHP as given by Prof. T. L. Saaty in 1990. The step wise process of calculation using fuzzy-AHP is as follows:

Step 1: Identify the critical drivers of implementing SSR HCSC.

The factors have been identified and finalized through the consultation with experts and support from the existing relevant literatures.

Step 2: Recording experts' inputs on the pairwise-comparison of the drivers of implementing SSR HCSC.

The experts were advised to rate the drivers on the basis of a five-point linguistic scale (shown in Table 2) and subsequently their inputs have been recorded.

Table 2: Fuzzy linguistic variables for pairwise comparison of the factors of SSR in the HCSC

Linguistic Variables	**TFN**	**Inverse TFN**
Equally preferred ($\tilde{1}/\tilde{1}^{-1}$)	(1, 1, 3)	(1/3, 1, 1)
Weakly preferred ($\tilde{3}/\tilde{3}^{-1}$)	(1, 3, 5)	(1/5, 1/3, 1)
Strongly preferred ($\tilde{5}/\tilde{5}^{-1}$)	(3, 5, 7)	(1/7, 1/5, 1/3)
Very strongly preferred ($\tilde{7}/\tilde{7}^{-1}$)	(5, 7, 9)	(1/9, 1/7, 1/5)

Extremely preferred ($\tilde{9}/\tilde{9}^{-1}$)	(7, 9, 9)	(1/9, 1/9, 1/7)

The pair-wise comparison of the drivers can be developed in the form as given in Eqn. (1)

$$\tilde{Z} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \ldots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{n1} & 1/\tilde{a}_{n2} & \ldots & 1 \end{bmatrix} \quad (1)$$

Where $\tilde{X}$ is the individual bran-storming session.

Step 3: The linguistic variables were converted into Triangular Fuzzy Numbers (TFN).

After recording inputs from experts, the linguistic variables were converted into TFNs using the Eqn. (2).

$$\tilde{a}^{k}{}_{12} = \frac{\sum_{k=1}^{k} \tilde{a}^{k}{}_{ij}}{3} \quad (2)$$

Step 4: Calculating the fuzzy geometric mean using the Eqn. (3).

$$\tilde{f}_m = \tilde{a}_{m1} \otimes \tilde{a}_{m2} \otimes \ldots \otimes \tilde{a}_{mn}\,)^{1/n} \quad (3)$$

Where, $\tilde{f}_m$ is fuzzy geometric mean and $\tilde{a}_{mn}$ pair-wise comparison value.

Step 5: Calculation of the fuzzy weight using the Eqn. (4).

$$\tilde{v}_m = \tilde{f}_m \otimes (\tilde{v}_1 \oplus \tilde{v}_2 \oplus \ldots \oplus \tilde{v}_n)^{-1} \quad (4)$$

Step 6: Defuzzifying the TFNs into crisp values by the center of area (COA) method using Eqn. (5)

$$\text{Center of Area } \tilde{v}_m = \frac{(lv_m, mv_m, uv_m)}{3} \quad (5)$$

Step 7: Normalizing the crisp values using the Eqn. (6) to identify the relative weight of the drivers of implementing industry 4.0 in HCSC.

$$N_m = \frac{v_m}{\sum_{m=1}^{n} v_m} \quad (6)$$

4. Application of the solution methodology

In the present study, data have been collected from experts having relevant experiences and were analyzed using the fuzzy-AHP method. Initially, the drivers of SSR in HCSC have been compared pairwise by the experts and a fuzzy geometric mean matrix have been developed as shown in Table 3.

Table 3: Fuzzy geometric mean value of the drivers of SSR in the HCSC

2.50	3.86	5.51
1.42	1.94	3.21
0.82	1.10	2.16
0.78	1.09	1.89
0.86	1.25	2.02
0.64	0.99	1.64
0.53	0.80	1.32
0.46	0.73	1.10
0.59	0.93	1.40
0.34	0.54	0.82
0.24	0.37	0.56
0.67	1.31	1.59
0.33	0.64	0.84

After the fuzzy geometric values were calculated, defuzziffied weights of the drivers have been calculated. Since, the sum of the defuzziffied weights have been found to be greater than 1, normalized weights have been calculated. Finally, the ranks have been developed for the drivers from the normalized weights (shown in Table 4).

Table 4: Normalized weight of the drivers of SSR in the HCSC and their rankings

Drivers	**Normalized weights**	**Rank**
Coordinating and integrating of processes in the HCSC (HCSC1)	0.236	1
Maintaining HCSC flexibilities (HCSC2)	0.132	2
HCSC information system (HCSC3)	0.084	3
HCSC agility and resilience (HCSC4)	0.076	5
Implementing IoT in HCSC (HCSC5)	0.083	4
The widespread use of RFID tags (HCSC6)	0.066	7
Promoting e-Health services (HCSC7)	0.054	9
Lean HCSC practices (HCSC8)	0.046	10

Adequate HCSC knowledge (HCSC9)	0.059	8
Managing HCSC quality standards (HCSC10)	0.034	12
Equitable HC accessibilities (HCSC11)	0.023	13
Infrastructural development supporting cyber-physical systems and smart factories (HCSC12)	0.071	6
Investment in HCSC R&D (HCSC13)	0.036	11

5. Results and Discussions

The analysis of the study using the fuzzy-AHP has found that ‘Coordinating and integrating of processes in the HCSC’ is the most prioritized drivers of implementing SSR to achieve the desired HC performances and responsiveness (Datta 2017). The drivers of “maintaining HCSC flexibilities” and “HCSC information system” have attained the second and third rank in the prioritization respectively. Consecutively, “implementing IoT in HCSC”, “HCSC agility, resilience”, “infrastructural development supporting cyber-physical systems and smart factories”, and “the use of RFID tags” have been ranked fourth, fifth, sixth, and seventh respectively. IoT and cyber-physical systems in HCSC is needed to transform the physical processes into virtualized services (Hermann et al. (2016); Zhong et al. (2017). In order to improve the operational performances of the HCSC, viability in the form of agility and resilience is necessary (Singh, 2019). The drivers, namely, “adequate HCSC knowledge”, “promoting e-Health services”, “lean HCSC practices”, “investment in HCSC R&D, “managing HCSC quality standards”, and “equitable HC accessibilities” have attained eight, ninth, tenth, eleventh, twelfth, and thirteenth respectively. Limited HCSC knowledge has been an impediment factors and capitalization should be made to enhance the skill set up of the workers (McKone-Sweet et al. (2005). The lean HCSC practices are required to reduce wastage of the limited HC resources and enhance the quality of services at the same time so that much attention can be paid toward providing medical accessibilities to as much population as possible (Kasthuri, 2018; Hossain and Thakur, 2020). The HCSC research and development requires considerable amount investment to enhance the efficiency of delivering HC services (Rahmani et al., 2018; Rotich, 2018) and mainstreaming the e-health services into the realm of the physical HC delivery would alleviate the existing burdening on the HC industry (Gunasekaran and Ngai, 2004; Jayaraman et al., 2019).

6. Implications of the Study

The present research bears important insights for the selected drivers of implementing SSR in HCSC. The results of the study have been discussed with the experts and the following implications are developed:

(1) The highly prioritized drivers should be patronized and implemented on priority basis whereas, the less prioritized drivers should be controlled and enhanced to raise their performance levels.
(2) HC managers should exert much emphasis on coordination and integration of HCSC processes to enhances performance of HC delivery.
(3) Managers should consider the drivers of IoT, cyber-physical systems, internet of services and smart factory applications into HCSC to drive the implementation of SSR concepts.
(4) Much of the emphasis should be paid towards mainstreaming the e-health services into the physical real of HC delivery.

7. Conclusion of the Study

The implementation of the concept of SSR in the HCSC can be considered as a paradigm shift in the HC industry. The implementation of the highly prioritized factors of the present study, namely, process coordination and integration, HCSC flexibilities, CPS, IoT, and RFID can initiate the functioning of a highly cohesive and a responsive HCSC. The implementation of these drivers can lead to an enhanced transparency in the supply chain processes. Executing SSR at the organizational level in the HC industry would facilitate process improvements and subsequently, enhances the performance through the enabling technologies. The promotion of digitalization and automation through implementation of SSR in HCSC would result in problem solving by technical and analytical capabilities to enhance the efficiency at the level of supply chain processes.

References

Alloghani, M., Al-Jumeily, D., Hussain, A., Aljaaf, A. J., Mustafina, J., and Petrov, E. (2018), "Healthcare services innovations based on the state of the art technology trend industry 4.0", *In 2018 11th International Conference on Developments in eSystems Engineering (DeSE)* (pp. 64-70). IEEE.

Datta, P. (2017), "Supply network resilience: a systematic literature review and future research", *The International Journal of Logistics Management.*

Ding, B. (2018). Pharma industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains. Process Safety and Environmental Protection, 119, 115-130.

Gunasekaran, A., and Ngai, E. W. (2004), "Information systems in supply chain integration and management", *European journal of operational research,* 159(2), 269-295.

Haleem, A., and Javaid, M. (2019), "Additive manufacturing applications in industry 4.0: a review", *Journal of Industrial Integration and Management,* 4(04), 1930001.

Hermann, M., Pentek, T., and Otto, B. (2016), "Design principles for industrie 4.0 scenarios", *In 2016 49th Hawaii international conference on system sciences (HICSS)* (pp. 3928-3937). IEEE.

Hossain, M. K., and Thakur, V. (2020), "Benchmarking health-care supply chain by implementing Industry 4.0: a fuzzy-AHP-DEMATEL approach", *Benchmarking: An International Journal.*

Jayaraman, R., Salah, K., and King, N. (2019), "Improving opportunities in healthcare supply chain processes via the internet of things and blockchain technology", *International Journal of Healthcare Information Systems and Informatics (IJHISI),* 14(2), 49-65.

Kache, F., and Seuring, S. (2017), "Challenges and opportunities of digital information at the intersection of Big Data Analytics and supply chain management", *International Journal of Operations & Production Management.*

Kagermann, H. (2015), "Change through digitization -Value creation in the age of Industry 4.0", *In Management of permanent change* (pp. 23-45). Springer Gabler, Wiesbaden.

Kasthuri, A. (2018), "Challenges to healthcare in India-The Five A's", *Indian journal of community medicine: official publication of Indian Association of Preventive & Social Medicine,* 43(3), 141.

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., and Hoffmann, M. (2014), "Industry 4.0. Business & information systems engineering", 6(4), 239-242.

McKone-Sweet, K. E., Hamilton, P., and Willis, S. B. (2005), "The ailing healthcare supply chain: a prescription for change", *Journal of Supply Chain Management,* 41(1), 4-17.

Rahmani, A.M., Gia, T.N., Negash, B., Anzanpour, A., Azimi, I., Jiang, M. and Liljeberg, P. (2018), "Exploiting smart e-Health gateways at the edge of healthcare Internet-of-Things: a fog computing approach", *Future Generation Computer Systems*, Vol. 78, pp. 641-658.

Singh, P. (2019), "Lean in healthcare organization: an opportunity for environmental sustainability", *Benchmarking: An International Journal*, Vol. 26 No. 1, pp. 205-220.

Trappey, A. J., Trappey, C. V., Govindarajan, U. H., Chuang, A. C., and Sun, J. J. (2017), "A review of essential standards and patent landscapes for the Internet of Things: A key enabler for Industry 4.0", *Advanced Engineering Informatics,* 33, 208-229.

Waibel, M. W., Steenkamp, L. P., Moloko, N., and Oosthuizen, G. A. (2017), "Investigating the effects of smart production systems on sustainability elements", *Procedia Manufacturing*, 8, 731-737.

Waller, M. A., and Fawcett, S. E. (2013), "Data science, predictive analytics, and big data: a revolution that will transform supply chain design and management".

Wiengarten, F., and Longoni, A. (2015), "A nuanced view on supply chain integration: a coordinative and collaborative approach to operational and sustainability performance improvement. Supply Chain Management: An International Journal".

Zhong, R. Y., Xu, X., Klotz, E., and Newman, S. T. (2017), "Intelligent manufacturing in the context of industry 4.0: a review", *Engineering*, 3(5), 616-630.