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Enhancing Quality Control in Medical Devices Supply Chain Using Artificial Intelligence and Machine Learning

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Abstract

Due to its significance, it plays in the management of public health, the healthcare industry is among the most important sectors. The rapid spread of several diseases, most notably the COVID-19 pandemic, has put this sector of the economy in the spotlight. The healthcare supply chain (HSC) has had its weaknesses exposed by the pandemic. The healthcare supply chain is undergoing a period of revolutionary change due to new inventions such as the advent of various cutting-edge technologies such as Industry 4.0 and artificial intelligence. Within the context of a growing economy, this research aims to identify the most critical success factors for using AI in HRM. Using an approximation of SWARA, the HSC ranks CSFs of AI adoption. According to the findings, technological (TEC) factors have the greatest impact on the adoption of AI in HCI within the setting of developing nations. The following dimensions pertain to human beings, groups, and institutions: INT, HUM, and ORG.

Keywords: Medical Devices; Supply chain; Artificial intelligence; Machine learning.

1. Introduction

The fourth industrial revolution, or Industry 4.0, is the theoretical foundation for AI research, which aims to leverage sophisticated algorithms and processing capabilities to derive useful insights from pertinent data [1,2]. In the era of the Internet of Things (IoT), manufacturing will be more open, efficient, high-quality, and easy to administer.Smart factories built on the Industry 4.0 framework will achieve this goal by combining physical and cyber technologies. Most significantly, the intelligence of factory automation systems can be enhanced by the use of sensors and artificial intelligence [3,4]. Recent developments in sensor technology, particularly in the context of Industry 4.0, have been a boon to the growth and success of numerous companies, as well as to the economy ofindividuals and countries. Businesses in the supply chain and industrial industries need access to cutting-edge sensor technology that is both inexpensive and efficient so they can gather data and put it to good use.

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Among the most common types of sensors used nowadays are instruments that measure location, flow, temperature, flow rate, pressure, and force. The agricultural, healthcare, manufacturing, and transportation sectors are just a few of the many others that rely on them regularly. Increasing output through mechanization is a primary goal of Industry 4.0, as stated in references [5, 6].

In the realm of healthcare, artificial intelligence (AI) technologies have made tremendous progress in recent times, which has sparked a vigorous debate about the possibility that AI doctors would one day replace human physicians [7,8]. Within the next few decades, it is highly improbable that computers will take the role of human medical professionals. Artificial intelligence (AI), on the other hand, may help doctors make far better treatment decisions.

The "supply chain" in healthcare refers to the intricate network of interrelated processes and components that ensure patients have access to their drugs and other healthcare supplies. Due to the unique nature of the healthcare industry and the need to be ready for extreme events such as the emergence of a pandemic or biological or chemical warfare, the management of healthcare supply chains differs from that of commercial supply networks [9]. Patient safety, interrelated health outcomes, and the participation of numerous partners are complicating elements in the healthcare supply chain (HSC). High service standards, operational hazards, and critical supply chain flows make it difficult and complex to reproduce conventional procedures in different situations. In addition, there is concern that a breach in the supply chain of the healthcare business might cause a false shortage of drugs and medical equipment, encourage the global trade of fake pharmaceuticals, and endanger the security of connected medical devices. If we want to optimize patient care, minimize inventory wastage, reduce error likelihood, and improve stakeholder coordination—all through HSC—we must overcome the unique hurdles that HSC faces, which is why we must increase our knowledge of the field.

Although the benefits of AI-integrated HSCs have been discussed in the literature, there has been inadequate attention to the factors that facilitate AI adoption in HSCs. Increases in demand, and prices, changing consumer expectations, increased competition, and new interdependencies are all good things happening in the HSC industry right now [10]. This study offers valuable information that can streamline HSC management's AI implementation. This study shares these insights because AI technology can greatly improve HSC problems and because it is necessary to ensure that HSC operations continue in the event of a pandemic or other catastrophic event.

Highlights

- The major goal of this effort is to determine what aspects of AI implementation are most important for HSC to succeed.
- As a result of the findings, it appears that TEC elements are the most influential factors that influence AI adoption.
- Several other aspects play a significant impact in the adoption of AI, including INT, HUM, and IT.
- Given the recent breakout of several diseases, the significance of this study in the healthcare sector cannot be overstated.

A brief overview of AI in QA: Some of the more complex tasks that used to need human intelligence are now within AI's capabilities, such as:

Machine learning (ML) is an AI subfield that enables computers to autonomously learn from their data sets with little to no human oversight. The AI can be trained by QA teams during testing sessions. Over time, the AI will become accustomed to the QA teams' testing habits, allowing it to provide more organization-specific recommendations.

2. Literature Review

2.1. Scenario of healthcare supply chain (HSC) network

Healthcare Supply Chain (HSC) is an innovative supply chain that aims to streamline supply processes and efficiently distribute medical goods and services to patients and providers [11]. Manufacturers, healthcare facilities, providers, insurers, government bodies, and individuals undergoing treatment are all considered stakeholders in this process. Because of the upstream and downstream interactions involved in this supply chain, as well as the fact that each actor is looking out for their interests, HSCs are complicated and disjointed [12]. Vaccines, medical equipment, and other healthcare supplies have all been the subject of supply chain models proposed in HSC studies [13].

The factors that might help or hinder efforts to enhance HSC performance have likewise been the subject of scant research. Among the factors that have been found to impede HSC performance include insufficient funding, inadequate infrastructure, a lack of public understanding, and unclear government policy. There has been a lot of recent demand for HSCs to become as lean as feasible to cut costs, meet changing client expectations, increase efficiency, and improve healthcare. Changes in the political and economic climate, changes in manufacturing practices, and other disruptions make these objectives more difficult to attain. A worldwide scarcity of medical supplies was caused by the recent COVID-19 outbreak, which widely exposed HSC. Then, experts in the field began to stress the importance of HSC for foreseeing, preparing for, and responding to interruptions in the value chain at various points.

2.2. Artificial intelligence (AI) in the healthcare supply chain (HSC)

The implementation of artificial intelligence has the potential to significantly impact numerous industrial applications, including supply chain management [14]. Artificial intelligence has revolutionized supply chain management in many ways. Forecasting demand, locating facilities, selecting suppliers, replenishing inventory, managing risks, ensuring a sustainable supply chain and many more are all part of this [15].

The limited insights provided by most AI studies in the supply chain may not apply to other circumstances because they do not consider specific industrial settings. Furthermore, the present literature leaves the potential for new research directions concerning the underexplored topic of AI implementation in HSCs.

A recent analysis predicts that the global market for artificial intelligence will grow at a CAGR of 57% from 2017 to 2025.

The healthcare supply chain is only one of several fields that have seen an upsurge in scholarly writings about AI's possible applications [16]. Managing chronic diseases and drug development are only two examples of the many therapeutic and scientific applications of artificial intelligence in healthcare. When combined with AI, HSC can eliminate inefficiencies in product distribution, tracking, inventory sharing, and resource pooling.

Product authenticity, counterfeit product tracking, and medical device authentication can all be aided by this. The enormous potential of AI in healthcare data administration, producer eligibility verification, and price fixing has also been the subject of research. Discussed potential uses of AI-powered healthcare in HSCs in a recent study.

3. Methodology

3.1. The role of artificial intelligence in quality management

Enhancing Precision Through Recent Developments in Medical Equipment To be successful in the medical devices industry, you need to have a high level of accuracy that leaves no room for error. The industry of medical device manufacturing is transforming as a result of artificial intelligence's ability to successfully analyze and derive insights from vast datasets. Quality Management Systems (QMS) that are powered by artificial intelligence ensure that the highest quality standards are adhered to throughout the entire process, which includes design, prototyping, production, and post-market surveillance respectively.

3.2. Rough Step-wise weighted assessment ratio analysis (R-SWARA)

To lessen the amount of subjectivity and ambiguity that is present in complicated decision-making issues, the R-SWARA approach was developed and is mostly utilized to establish the relative weights of the qualities through the utilization of rough values. Researchers and practitioners alike have shown a growing interest in R-SWARA as of late. Hybrid frameworks that incorporate MCDM (multiple criteria decision-making) and rough set numbers are also being used by an increasing number of studies to address research issues.

For instance, considering the existence of uncertainty, one innovative MCDM solution in the logistics business is the use of rough SWARA.

3.3. Enhanced precision and dependability

With the help of conception automation and the use of complex algorithms, artificial intelligence eliminates the possibility of human error in the quality control process. The precision and dependability of quality control jobs are both improved by the use of artificial intelligence through this method. It is possible for artificial intelligence (AI) systems to effectively discover and investigate defects, which ultimately leads to quality results that are reliable and consistent.

Figure 1 shows the results of the proposed research methodology that was used in this investigation to prioritize AI CSFs. With an emphasis on India, it used rough SWARA (R-SWARA) to evaluate the significance of the healthcare supply chain in developing nations.

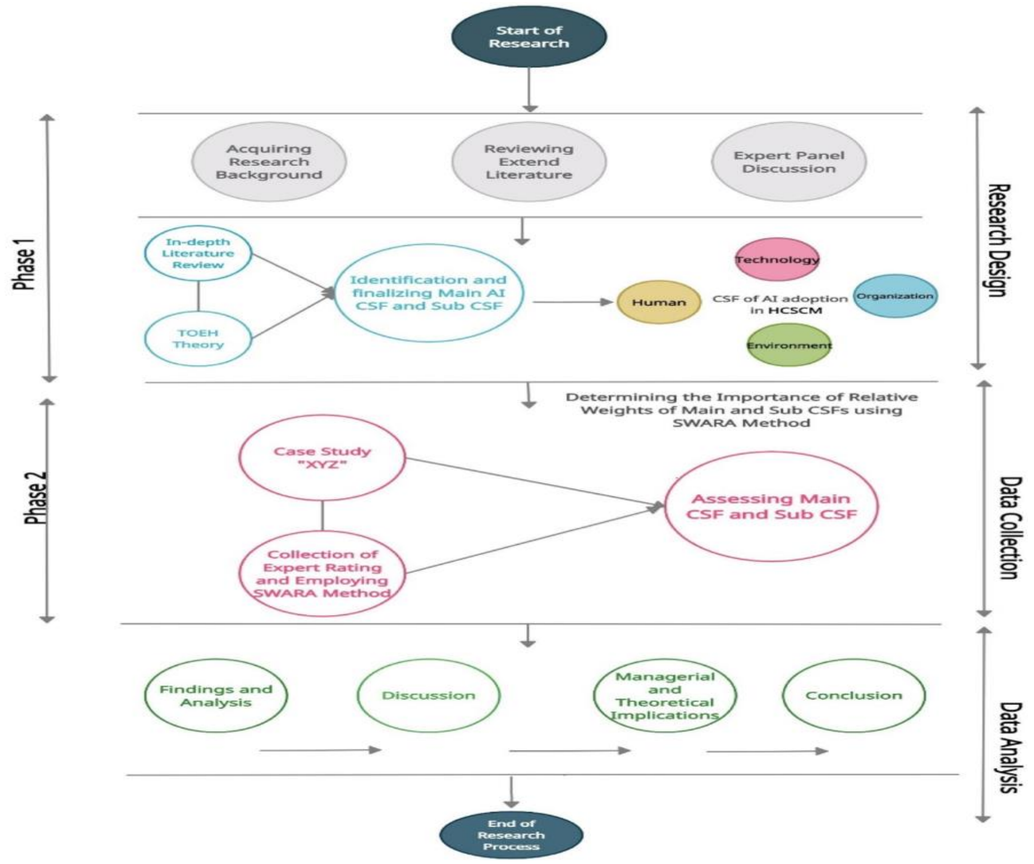

Figure 1: Research Framework

Artificial intelligence (AI) and its usability would provide a substantial contribution to the development of HSC that is both effective and resilient, as was addressed in the section on the literature review. With the use of R-SWARA, decision-makers would be able to make more informed choices if they had a thorough understanding of the important elements. To accomplish this, we will evaluate the acknowledged CSFs for HSC AI implementation and compare and contrast their significance. This study aims to use the TOE and HOT frameworks to identify and classify the key success factors (CSFs) of AI adoption.

3.4. Optimizing the supply chain

Systems used in the manufacturing of medical equipment could benefit from the integration of artificial intelligence (AI) to increase their efficiency and effectiveness. With the help of AI models, it is possible to analyze internal processes and identify inefficiencies, along with bottlenecks and risks in the supply chain.

The identification of these areas for improvement might be of assistance to manufacturers in the process of reorganizing their supply networks to improve their resilience. For modeling and anticipating disruption and risk, machine learning is an extremely useful tool. Companies in the medical device industry that have amassed enough data on their supply chain can create a digital replica of the network. These businesses can achieve their goals by utilizing AI.

To evaluate its resistance to various disturbances and give manufacturers insights on necessary improvements, this virtual representation may mimic a variety of disturbances. With the help of this data, predictive artificial intelligence models may be improved, which will allow manufacturers to proactively anticipate and address supply bottlenecks as well as any other potential interruptions. Increasing their safety stocks or taking other precautions could be one way for businesses to lessen the impact of the situation.

Accelerated Research and Development: The development of medical devices is being sped up thanks to the assistance of artificial intelligence, which is facilitating research and development. Obtaining regulatory approval for a Class 2 medical device can cost between $2 million and $5 million, and that's before you even consider R&D costs. By highlighting problem areas and allowing for the quick creation of prototypes, artificial intelligence can help optimize operations. The present market might be analyzed by models driven by artificial intelligence to identify unfulfilled patient wants. This data can be used by manufacturers to create new products that are better than existing ones in areas where they are lacking. As a consequence, they might take advantage of a market that has not yet been exploited, which would ensure improved sales performance and improve the outcomes for patients.

Data management: A new study by Towards Data Science found that insufficient data quality assessments cause over 40% of projects to fail. To do AI-powered quality assurance testing, large datasets are required, and cleaning and conserving data can be a difficult task. Inadequately clean data hinders AI's capacity to distinguish between real mistakes and may unintentionally give testers misleading positive results during its training phase.

4. Results and discussions

Using existing literature resources and multiple rounds of interviews with industry specialists, twenty-two critical success factors (CSFs) of AI adoption in the HSC sector were discovered, and they formed the basis of the analysis in this research.

When it comes to developing nations' adoption of AI in high-stakes computing, the study found that the principal technological component of the CSF (TEC) was the most weighted and influential aspect. The expert ratings and the formulae in Table 1 were used to determine the AI adoption in HSC monarch of all the main and sub-dimension CSFs.

Table 1: Results of the CSFs for AI adoption in HSC ranked

Main CSF	Local weight	Sub-CSF	Local weight	Global weight	Global ranking
TEC	0.465	TEC1	0.410	0.191	1
		TEC2	0.097	0.045	9
		TEC3	0.277	0.129	2
		TEC4	0.049	0.023	13
		TEC5	0.170	0.079	5
ORG	0.084	ORG1	0.263	0.022	14
		ORG2	0.332	0.028	12
		ORG3	0.179	0.015	16
		ORG4	0.064	0.005	20
		ORG5	0.035	0.003	21
		ORG6	0.115	0.010	18
		ORG7	0.017	0.001	22
INT	0.293	INT1	0.286	0.084	4
		INT2	0.050	0.015	17
		INT3	0.099	0.029	11
		INT4	0.397	0.116	3
		INT5	0.176	0.052	7
HUM	0.165	HUM1	0.179	0.029	10
		HUM2	0.405	0.067	6
		HUM3	0.047	0.008	19
		HUM4	0.282	0.046	8
		HUM5	0.094	0.016	15

Based on the results of this rough-SWARA study, the technological component (TEC) is the most important CSF category in terms of crucial dimensions. Technical CSFs' relative relevance weight changes with each run owing to the 0.1 increments.Therefore, it is necessary to make adjustments to the CSFs of the other primary dimensions at the same time. For the four primary CSF dimensions that use sensitivity analysis, Table 2 also includes their respective relevance weights.

Table 2: Sensitivity analysis of main CSF's dimension

CSFs	**Normalized**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**	**Scenario 8**	**Scenario 9**
TEC	0.465	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900
ORG	0.084	0.141	0.125	0.110	0.094	0.079	0.063	0.048	0.032	0.017
INT	0.293	0.490	0.436	0.382	0.328	0.274	0.220	0.166	0.112	0.058
HUM	0.165	0.276	0.246	0.215	0.185	0.154	0.124	0.093	0.063	0.033

Table 3: Represent the changes in ranking using sensitivity analysis

Sub-CSF	**Normalized Ranking**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**	**Scenario 8**	**Scenario 9**
TEC1	1	9	4	2	1	1	1	1	1	1
TEC2	9	18	16	12	9	7	6	4	4	4
TEC3	2	11	7	5	3	2	2	2	2	2
TEC4	13	21	19	17	14	13	10	8	6	5
TEC5	5	15	11	8	6	4	3	3	3	3
ORG1	14	10	12	13	13	14	14	14	14	14
ORG2	12	8	10	11	12	12	13	13	13	13
ORG3	16	13	14	15	16	16	16	16	16	16
ORG4	20	19	20	20	20	20	20	20	20	20
ORG5	21	20	21	21	21	21	21	21	21	21
ORG6	18	16	17	18	18	18	18	18	18	18
ORG7	22	22	22	22	22	22	22	22	22	22
INT1	4	2	2	3	4	5	5	6	7	7
INT2	17	14	15	16	17	17	17	17	17	17
INT3	11	7	9	10	11	11	12	12	12	12

Sub-CSF	Normalized Ranking	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
INT4	3	1	1	1	2	3	4	5	5	6
INT5	7	4	5	6	7	8	8	9	9	9
HUM1	10	6	8	9	10	10	11	11	11	11
HUM2	6	3	3	4	5	6	7	7	8	8
HUM3	19	17	18	19	19	19	19	19	19	19
HUM4	8	5	6	7	8	9	9	10	10	10
HUM5	15	12	13	14	15	15	15	15	15	15

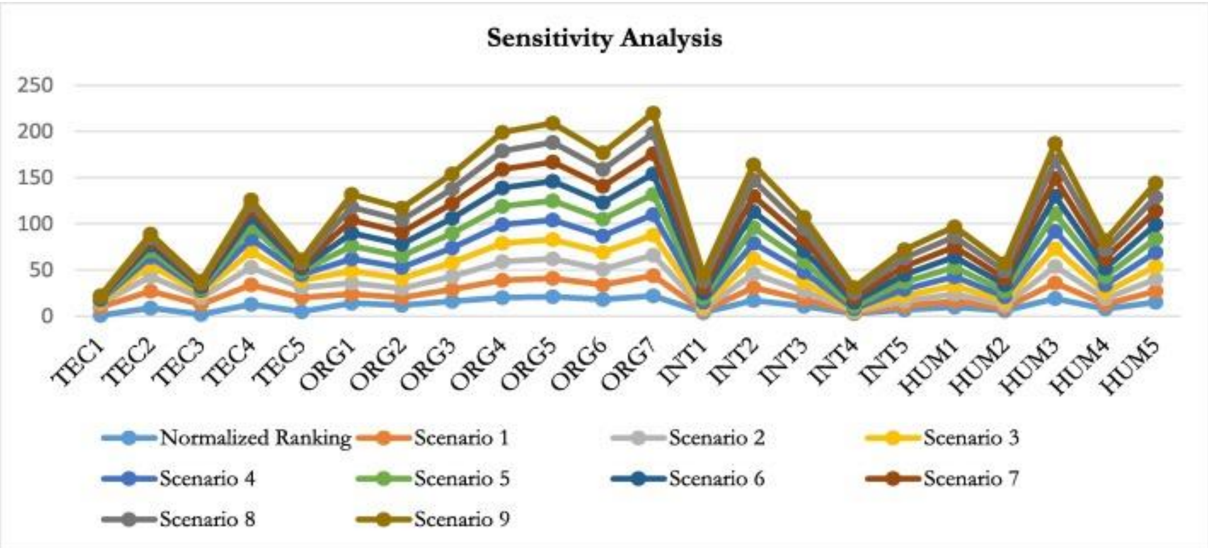

Figure 2: Variation in CSF's

The rankings and relative importance of the sub-dimension CSFs change when the incremental weights are added to the main dimensions in Table 3. From run 4 to run 9, the sensitivity analysis is dominated by (TEC1) when the weight of the technological factor (TEC) is adjusted. Likewise, (TEC3) and (TEC5) maintain their positions as third and second, respectively, when the weight is adjusted from run 5 to run 9. From run 1 through run 9, various weight modifications are illustrated in Fig. 2, and the last place is contained in (ORG7). So, it's commonly believed that stakeholders should emphasize technology CSFs when making decisions about short-term plans to integrate AI into the healthcare supply chain. Since the study's results are robust enough to withstand expert evaluation, they can be utilized for decision-making purposes.

5. Conclusion

Using CSF from the TOE and HOT frameworks, the study assesses the prevalence of AI deployment in HSC in developing nations. Traditional supply chain models are reportedly failing developing-world businesses. On top of that, companies in these nations are more eager and ready to put money into healthcare and take advantage of technology advancements, especially in supply chain management. Our work is timely because it can help alleviate the supply chain disruptions caused by the COVID-19 pandemic by integrating new technologies with existing HSCs. Practitioners can enhance their competitive advantage and reduce negative outcomes caused by supply chain and market failures by doing this. As a result of our research, we should be able to better comprehend AI technology and resolve related challenges that are preventing its widespread use in HSCs. Here, we integrate the TOE and HOT models to provide a theoretical foundation for HSC AI that accounts for the driving forces behind this emerging field. In addition, R-SWARA was used to assess the importance of coefficients considering the expertise, data, and personal experiences of the experts. Our research indicates that the most important sub-dimensions of the TOEH framework for facilitating AI implementation in HSC are technological feasibility, sustained data quality and integrity, and competitive pressure. The study's CSF visualization can help healthcare practitioners, academics, researchers, consultants, and lawmakers comprehend how to implement AI in HSC, resulting in enhanced accessibility, safety, quality, and cost-effectiveness. Still, the research isn't without its limitations. This study may have skewed or ambiguous conclusions because it relies on academic and professional opinions in logistics, supply chain management, and IT. As an additional caveat, the study relies on a small sample of specialists; to further validate the conclusions, future research may examine crucial success determinants with statistical tools such as structural equation modeling. To further investigate the interplay between these crucial success criteria, future research can employ causal-effect methods like DEMATEL.

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