International Journal of Lean Six

Integrated Green Lean Six Sigma-Industry 4.0 approach to combat COVID-19: from literature review to framework development

Journal:	*International Journal of Lean Six Sigma*
Manuscript ID	IJLSS-11-2022-0227.R1
Manuscript Type:	Research Paper
Keywords:	Green Lean Six Sigma, Industry 4.0, COVID-19, Lean Six Sigma, framework

Integrated Green Lean Six Sigma-Industry 4.0 approach to combat COVID-19: from literature review to framework development

Abstract

Purpose: The Coronavirus (COVID-19) pandemic has led to a surge in demand for healthcare facilities, medicines, vaccines, and other healthcare items. Integrating Green Lean Six Sigma (GLSS) and Industry 4.0 (I4.0) has the potential to meet the modern demand of healthcare units and also leads to improving the quality of inpatient care with better safety, hygiene, and real-time diagnoses. A systematic review has been conducted to determine the tools/techniques, challenges, application areas, and potential benefits for the adoption of an integrated GLSS-I4.0 approach within healthcare facilities from the perspective of COVID managment. Further, a conceptual framework of integrated GLSS- I4.0 has been proposed for better COVID management.

Methodology: To conduct literature, authors used Preferred reporting items for systematic reviews and meta-analysis (PRISMA) and covers relevant articles from the arrival of COVID-19. Based on the systematic understanding of the different facets of the integrated GLSS- I 4.0 approach and through insights of experts (academicians, and healthcare personnel), a conceptual framework is proposed to combat COVID-19 for better detection, prevention, and cure.

Findings: The systematic review presented here provides different avenues to comprehend the different facets of the integrated GLSS-I4.0 approach in different areas of COVID healthcare management. In this study, the proposed framework reveals that IOT (Internet of Things), Big Data, and Artificial Intelligence (AI) are the major constituents of I4.0 technologies that lead to better COVID management. Moreover, integration of I4.0 with GLSS aids during different stages of the COVID management right from diagnosis, manufacture of items, inpatient and outpatient care of the affected person.

Implications: This study provides a significant knowledge database to the practitioners by understanding different tools and techniques of integrated approach for better COVID management. Moreover, the proposed framework aids to grab day-to-day information from the affected people and ensures reduced hospital stay with better space utilization and the creation of a healthy environment around the patient. This inclusive implementation of the proposed

framework will enhance knowledge-based in medical areas and provides different novel prospects to combat other medical urgencies.

Keywords: Green Lean Six Sigma; Industry 4.0; COVID-19; framework; Lean Six Sigma; Machine learning

1. Introduction

The coronavirus disease (COVID-19) has resulted in unprecedented effects on healthcare providers and their facilities (Chauhan et al., 2021) (Mishra et al., 2021). The direct prospective effect of COVID-19 has already ensued in millions of lives and substantial incremental healthcare costs (Javaid et al., 2020) (Salentijn et al., 2021). Furthermore, in the long run, COVID-19 will result in an increased number of patients related to anxiety and depression (Demir & Turan, 2021). The COVID-19 pandemic is not yet over, so utmost safety, improved diagnosis, monitoring, real-time estimation of cases, and hygienic workplace/healthcare facilities are needed to prevent further outbreaks of this chronic disease (Raja Mohamed et al., 2021) (Singh et al., 2020). Thus, it is imperative to adopt technologies and approaches that provide quick monitoring, appropriate decision-making, analyze problems and provide feasible solutions accruing to the problems related to COVID-19. Integrated Green Lean Six Sigma- Industry 4.0 (GLSS-I4.0) can be the possible answer for the same to mitigating possible outbreaks and their end effects on society (Rathi, Kaswan, Garza-Reyes, et al., 2022). GLSS is the combination of two powerful operational excellence methodologies, i.e. Green Lean and Six Sigma, developed to make operations streamlined, and defects-free, introducing quick monitoring and prompt decision-making along with the flexibility to self-adjustment (Chiarini & Kumar, 2021). It is an approach to sustainable development that makes processes more streamlined through the reduction of wastes, defects, and emissions (Kaswan & Rathi, 2020b). Industry 4.0 (I4.0), on the other hand, is the assimilation of technologies like the Internet of things (IoT), cyber-physical systems (CPS), cloud computing (CC), big data, etc. that provide traceability, visibility, and steadfastness in a system (Surange et al., 2022).

To prevent a further surge of COVID-19, it is essential to provide affordable healthcare facilities (vaccine, diagnosis, and treatment). Integrated GLSS-I 4.0 enhance the level of automation in the healthcare system through the combination of wireless technologies, better data management, and effective workplace sanitization (Kaswan et al., 2022). Integrated GLSS-I4.0 technologies are interconnected and provide better communication exchange among stakeholders to manufacture the vaccine, healthcare equipment, case detection, and determining essential activities with minimum human intervention (Narayanamurthy & Tortorella, 2021a) (Kumar et al., 2020). Integrated GLSS-I4.0 encompasses a different set of technologies coupled with sensors and Artificial Intelligence (AI) that are connected to a master system. This system enables the production line adaptable to quick monitoring, decision-making, tractability, and control to ensure timely and high-quality delivery of medical essentials needed during the COVID pandemic (Hussain et al., 2021). This integrated approach not only ensures timely and safe delivery of medical items but also leads to better management of the healthcare facilities through optimum resource utilization and hygienic work area around the COVID patients. Integrated GLSS-I4.0 uses a smart set of technologies that ensure the timely availability of medical equipment, disposables, and other medical items. Further, this integrated approach induces a smart supply chain of medical essentials in the COVID-19 era for safe and required delivery of items at the required juncture. In the literature few studies related to the application of LSS in healthcare (Bhat et al., 2023) (Noronha et al., 2023) and I4.0 in healthcare have been reported. But no study in the academic literature exists that explores different facets of the integrated approach related to healthcare in the context of COVID-19 has been reported. Further, to date in literature conceptual framework that provides measures to combat the adversity of COVID-19 has been explored. The study tends to answer the research question that what are the different facets of integrated GLSS-I4.0 application areas, challenges, tools, and techniques that are related to COVID-19. The study also answers the questions of how an integrated approach can be executed to provide better detection monitor and cure of the COVID-19-affected person through systematic development of the conceptual framework. Also, to curb the intensity of COVID-19, reduction in the load on existing healthcare facilities, and provide high-quality care to patients, this study enumerated different facets of the integrated GLSS-I4.0 approach and propose a conceptual framework of the integrated GLSS- I4.0 approach.

The rest of the article is organized as follows. The literature search methodology has been presented in the 2nd section of the manuscript. Section 3 depicts literature review of the integrated GLSS-I4.0 approach. Section 4 illustrates descriptive statistics whereas the applications, challenges, and benefits of the integrated approach in the context of COVID management are presented in section 5 th of the article. Section 6 demonstrates enabling technologies of the integrated GLSS- I4.0 approach. The proposed framework has been presented in the 7th section of the manuscript. The final section presents conclusions, limitations, and future research agenda of the work.

2. Literature search methodology

The Preferred reporting items for systematic reviews and meta-analysis (PRISMA) method has been used in this study to filter articles related to the topic of interest. The methodology describes how data from available studies need to be collected and analyzed by establishing explicit and reproducible methods that identify, choose, and critically assess relevant research (Andreo-Martínez et al., 2022) (Kaswan et al., 2022). In this study, the authors used databases of Science Direct, Web of Science, Emerald, and SCOPUS so that all pertinent articles can be included in the study. The study encompasses peer-reviewed articles to ensure the quality of publications. The selection period of the study was 2019-2022. The year 2019 has been selected because this was the inception of the COVID-19 outbreak and many healthcare professionals, doctors, and policymakers started work to curb the outbreak of COVID-19.

Table 2. Keywords with label

Keywords	**Label**
Green Lean Six Sigma	GLSS
Sustainable Lean Six Sigma	SLSS
Sustainable Six Sigma	SSS
Sustainable Lean manufacturing	SLM
Industry 4.0	I4.0
Digital technologies	DT

Table 2 depicts keywords along with their respective labels. A snowball approach has been adopted in this study for search criteria of the keywords to further explore terms related to GLSS, Industry 4.0, and COVID-19. Articles have been explored from the electronic databases by incorporating keywords in the following expressions.

X = [GLSS, SLSS, SLM, SSS]

where, X[1]= GLSS, X[2]= SLSS, X[3]= SLM, X[4]= SSS

XT= X[1]=|| X[2]=|| X[3]=|| X[4]……………………………………………………(1)

where T = total, || = OR

$Y = [I4.0, DT]$

where, $Y[1] = I4.0$, $Y[2] = DT$

$$YT = Y[1] \,||\, Y[2] \quad \text{.......................................} (2)$$

$$ZT = \text{COVID 19} \quad \text{.......................................} (3)$$

$$XT \,\&\, YT \,\&\, ZT \quad \text{.......................................} (4)$$

where & = AND

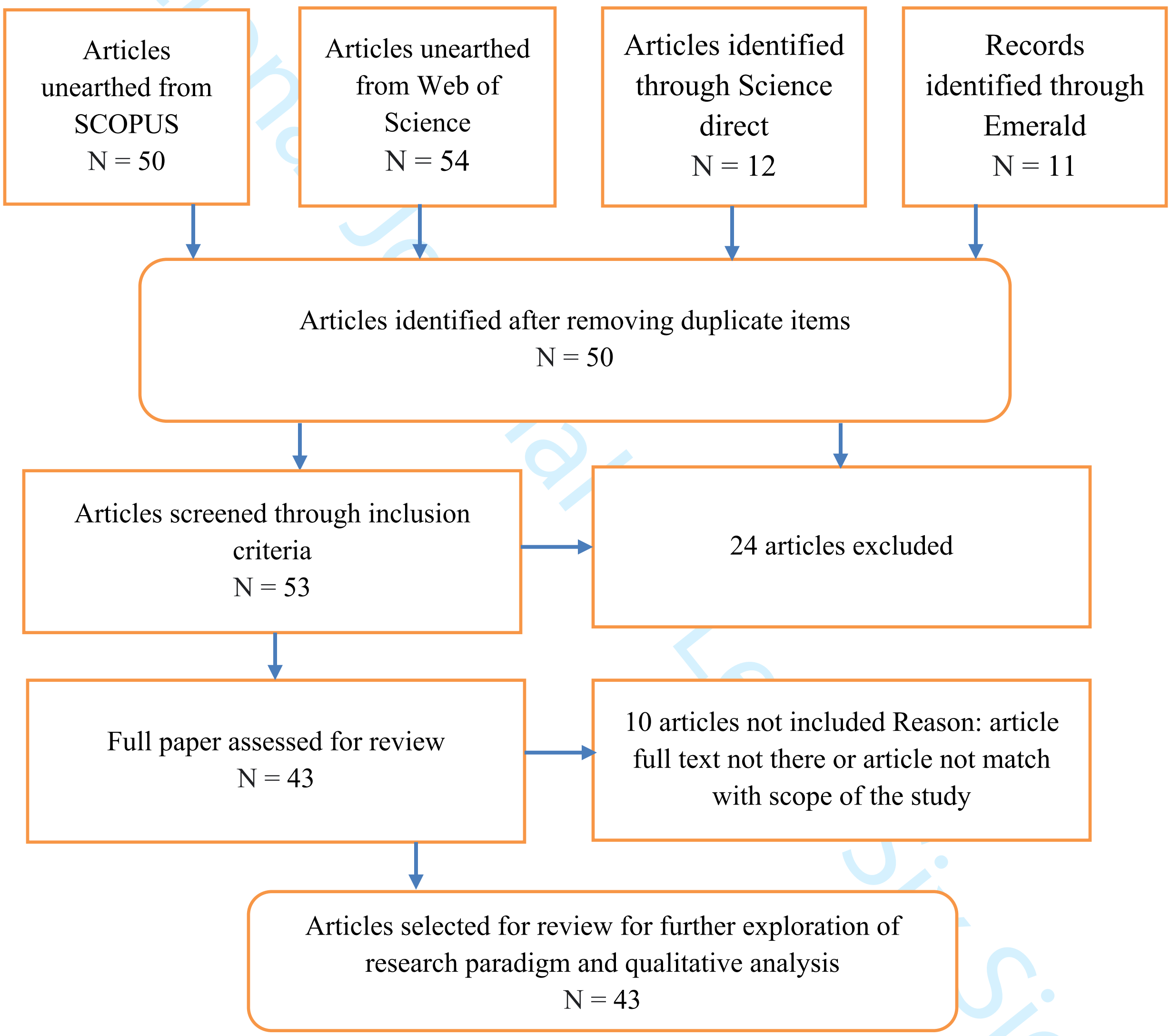

Figure 1: Preferred reporting items for systematic reviews and meta-analysis (PRISMA) flowchart

To select pertinent articles related to the review authors used different keywords and also explored related terms so that no pertinent articles remain left from the review point of view. For instance in literature, different related terms for Green Lean Six Sigma are being used like Sustainable Lean

Six Sigma, Sustainable Lean Manufacturing, Sustainable Six Sigma. So, the authors used all these keywords under inclusion criteria. Further Industry 4.0 is also being used in literature by digital technologies. Moreover, the authors considered only the English language for article selection. This resulted in 127 articles from the said databases. Further, to remove duplicacy of articles from different databases authors used end not software which leads to the removal of 50 articles. The remaining 77 articles' abstracts were analyzed to meet the objectives of the present study and it has been found that 24 articles don't match the objectives of the study and said articles were removed from the study for further consideration. Thereafter, the full-text availability of the articles was considered, that further led to the exclusion of 7 more articles. In the final stage of the review content of the articles was analyzed according to the relevance of the topic, this further led to the exclusion of 3 articles. The final sample encompasses 43 articles, after careful consideration of the articles. The said number of articles was further analyzed in the reporting stage to find potential applications of the GLSS-I4.0 approach in the context of COVID-19, challenges of GLSS-I4.0 approach in healthcare of COVID, enabling technologies of the integrated approach, and finally based on literature and the response of healthcare personnel a systematic framework was developed of integrated GLSS- I4.0 approach to mitigate issues of COVID. The authors also conducted a descriptive analysis of the article country-wise, authors-wise, and year-wise to the scenario of the applications of technologies in the context of COVID-19.

3. Literature review

The literature review section consists of three sub-sections. Subsection one illustrates a brief history of GLSS and I4.0. The second sub-section demonstrates the integration aspects of operational excellence approaches (Lean, Green technology and LSS) with I4.0. The third subsection elucidates review of GLSS and I4.0 technologies within the healthcare sector.

3.1 Background of Green Lean Six Sigma and Industry 4.0

The history of GLSS can be traced back to the Japanese Toyota Production System (TPS), better known as Lean in Western culture (Kaswan & Rathi, 2020a). Lean is a systematic approach that leads to improved organizational performance through the systematic reduction of waste (Buer et al., 2021). However, Lean does not directly address environmental aspects and has minimal focus on reducing variation. Six Sigma focuses on reducing variation and associated defects of the products, providing a robust method to realize a sound product (Belhadi et al., 2021). However, Six Sigma also does not directly address issues related to environmental and social aspects of sustainability. Therefore, there is a need to incorporate green technology (hereafter, Green) with both Lean and Six Sigma to achieve a more holistic improvement approach; that is, Green Lean Six Sigma (GLSS). Green technologies are those sets of measures and methods that lead to lesser environmental degradation through the incorporation of clean technologies (Sony & Naik, 2020). Several studies on Green and integrated Lean Six Sigma (LSS) presented that industries that incorporate LSS merely assimilate Green measures to enhance environmental sustainability (Ruben et al., 2018). Also, it has been found from these studies that Green implemented in conjunction with LSS leads to improved ecological performance. Thus, Green technology integration with LSS leads to a powerful strategy called Green Lean Six Sigma, which makes the industry more sustainable in terms of environmental, social, and economic dimensions (Ershadi et al., 2021; Gholami et al., 2021). GLSS is still in its infancy, and, in the limited case studies which exist, the execution of this approach mainly relies on the popular Six Sigma DMAIC methodology (Gholami et al., 2021; Sagnak & Kazancoglu, 2016).

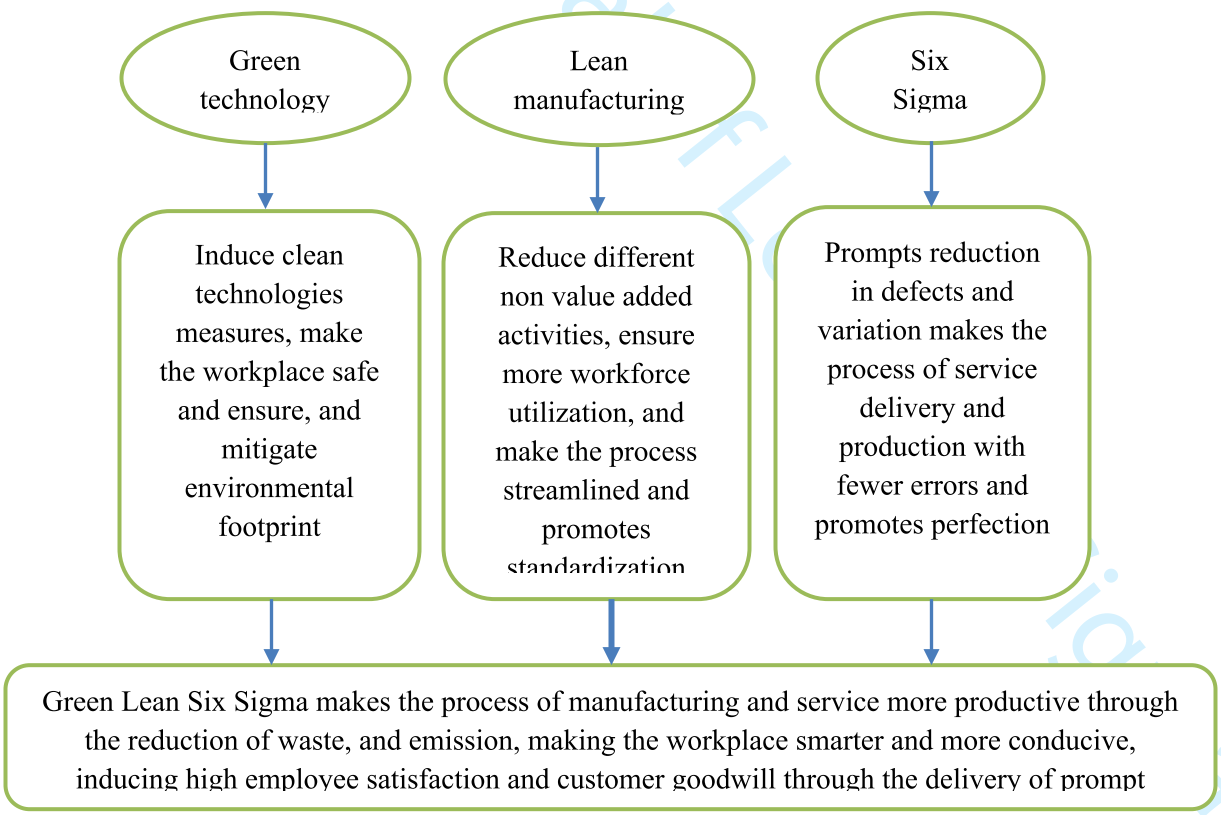

Figure 2: Conceptual model of Green Lean Six Sigma

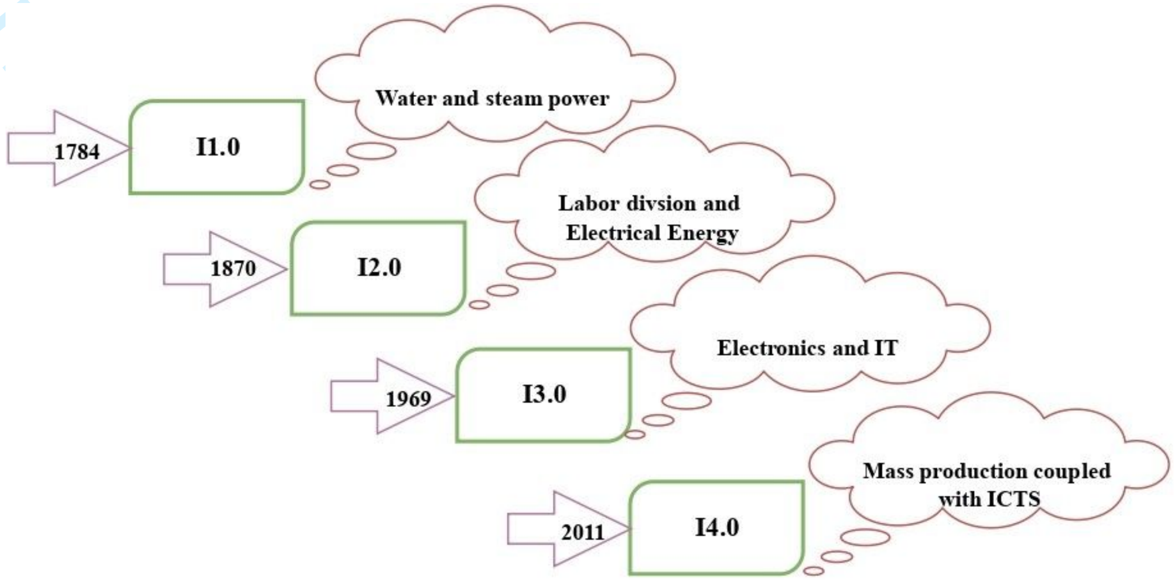

Figure 3: Development in the different revolutions of industry

The fourth industrial revolution is gaining predominance among researchers, policymakers, and manufacturers (Bag et al., 2021). The history of I4.0 can be traced back to the development of different industrial revolutions. In the past centuries different vehicles, weapons, and homes have been designed and fabricated with the help of mankind and animals. Industry 1.0 is characterized by the development of steam-powered engines that changed the way of production of the parts (Maddikunta et al., 2022). This revolution takes place in 1874, and the development time for the first three industrial revolutions was nearly one century, it takes nearly 40 years to reach from the third revolution to 4th revolution. The second industrial revolution was pigeonholed by the development of electrical power, assembly line, and division of labour. This industrial revolution brings the concept of mass production, a work division concept that resulted in the industrial organizations' efficacy. The third industrial revolution (1969) further augmented organizational productivity through the partial automation of electronics and information technology. The concept of I4.0 come to the fore in 2011, which encompasses a wide set of information and communication (ICTs) based technologies to make the production system faster, and highly responsive with less utilization of material and manpower (Bag et al., 2021). This industrial revolution focused on making production systems without humans adding and incorporating an advanced set of robots to control and guide different activities associated with production and control (Gokalp et al., 2017). The main purpose behind the same is to achieve a high level of mass production with improved organizational efficacy by using ICTs technologies (Bag et al., 2021). This new era was termed during the German 2011 Hannover fair as “Industry 4.0” (Nara et al., 2021) (figure 3). I4.0 is built on the development of novel technologies including 3D printing, IoT, cyber-physical systems, and big data (Zheng et al., 2021). The overall impact of this set of technologies provides better industrial operation, real-time adaptation, and control over the process.

3.2 Integration perspective of Green Lean Six Sigma and Industry 4.0

Integration of LSS with Green technology also comes with many difficulties. As stated by Powel et al. (2017) and Ershadi et al.(2021) it tends to focus primarily on economic aspects of sustainability and overlook environmental ones due to a large number of environmental metrics. The inclusion of green metrics also involves many stakeholders such as the customer, organization, government, NGOs, etc. These wide spectra of constituents have different interests and sometimes conflicting ones that lead to difficulty in data gathering and further investigation. Thus, there is a need for big data and further examination of the same is required to make effective judgments on green measures of sustainability. GLSS integration with I4.0 will make the workplace "smarter," enhance decision capability, and ensure improved environmental sustainability of the industry. IoT-based systems can be used to make the workplace more responsive and reduce hazards, as they provide quick information exchange and communication to achieve smart recognition, position, and tracing. GLSS is further augmented by the adoption of artificial intelligence (AI), contributing to reduced workplace accidents and less human intervention in the system (Cheng et al., 2020). The adoption of other I4.0 technologies, such as 3D printing, further supplement GLSS is further augmented by other I4.0 technologies, such as collaborative and autonomous mobile robots (COBOT and AMR), augmented reality (AR), and digital automation with sensors, making systems more responsive, reducing lead time, and supporting adaptation to self-decision making in a complex environment.

There are limited prior studies related to the integration of I4.0 and operational excellence methods, such as Lean, Six Sigma, and LSS. Dalenogare et al., (2018) integrated Lean with I4.0 and found that I4.0 overcomes the limitations of Lean especially when the product differs in terms of variety. They also suggested that I4.0 must be incorporated after Lean is implemented, as Lean creates the process baseline, and then this process baseline can be automated. The same findings have been supported by Wang et al. (2020) who proposed that it is easier for the industry to incorporate I4.0 measures after they have already incorporated Lean measures. Moeuf et al. (2020) found that in SMEs integration of shop floor improvement methods and I4.0 is only the change in software packages that control activities of the production plant. Although the integration of Lean and I4.0 is still in its infancy, initial evidence suggests integration of the two approaches leads to improvement in metrics related to waste, costs, and productivity of the organization. Also, it has been found that I4.0 moderates the effect of Lean practices on the operational efficacy of the industry (Tortorella et al., 2019). Sanders et al. [33] discussed the challenges related to the implementation of Lean and suggested I4.0 technologies can help overcome the same. Therefore, it can be deduced from the limited existing academic literature that Lean practices can be integrated with I4.0 for improved organizational performance.

Similarly, in the literature, few studies related to the possible integration of LSS with I4.0 exists. Jayaram et al. (2016) proposed the possible integration of LSS with I4.0 in the context of the global supply chain. They claimed that LSS and I4.0 complement each other but, contrary to the existing research on Lean and I4.0, suggested that I4.0 implementation must precede LSS execution. However, the study provided limited insights related to how LSS tools can be integrated with I4.0 technologies. Other studies suggested an integrated LSS- I4.0 approach leads to improvement in metrics of cycle time, waste, and quality, but does not identify any impact on environmental metrics (Chiarini & Kumar, 2021). As the last few decades have increased awareness about sustainability, climate change, and human health measures, industries are in continuous pursuit to incorporate green metrics within performance measures (Kaswan, Rathi, Reyes, et al., 2021). The incorporation of green measures in LSS leads to a powerful approach named GLSS. I4.0 technologies enable the organization in terms of swift response, quick changes, better communication/control, and less human intervention (Garza-reyes, 2023). Integration of GLSS with I4.0 supplements the organization's capacity to reduce GHGs emissions and ensures a robust method to incorporate different technologies and facets of I4.0 at different levels of operations (Kaswan et al., 2022). Therefore, it can be deduced from the critical investigation of literature that LSS- I4.0 integration is still in the early stages and, from the best of the authors; knowledge, no study related to integrating aspects of GLSS with I4.0 or proposing an integration framework exists.

3.3 Integrated Green Lean Six Sigma and Industry 4.0 in healthcare

Changes in the patterns of diseases, and intergovernmental policies on climate change have forced the healthcare sector to incorporate new advanced technologies (Kaswan, Rathi, Singh, et al., 2021). Moreover, in developing nations, due to the limited availability of doctors and funds, it is indispensable for the countries to develop breakthrough strategies. GLSS can be a potential solution at this juncture as it provides high-quality inpatient care at reduced costs with less environmental impact (Swarnakar et al., 2021). GLSS leads to high-quality inpatient care at low cost and a faster service level through the systematic reduction of various wastes and variations in existing systems or processes (Singh, and Rathi, 2023). It reduces the length of hospital stays (LOSs) and incorporates time-saving for doctors and other healthcare staff that would otherwise be wasted in non-valued added activities (Iswanto, 2021). Moreover, it improves healthcare service quality through reduction in patient lead time and process cycle time which further leads to improved healthcare sustainability (Swarnakar et al., 2021). GLSS implementation through the mistake-proofing device (poka-yoke) leads to a reduction of the healthcare staff workload like the automatic machine to detect dispense results in the reduction of the workload of the pharmacist that time-saving consequently will lead to better inpatient care of COVID patients (Rathi, Kaswan, Antony, et al., 2022). The application of mistake-proofing devices results in fewer medication errors and that leads to better utilization of hospital resources. Visual management tools in the emergency room can be used to maintain the standard operating procedures during COVID time. Further, the standard operating procedure will lead to lesser medication errors and further adds to improved safety and chances of infection from COVID-affected people. It enables the display of the status of all critical elements of patients that further helps to initiate preventive actions by healthcare staff. GLSS tools like VSM, enable the healthcare unit during the COVID-19 time, where the process has non-value-added activities that can be subsequently removed from the undersigned process, to make the inpatient service time of patients lower in the hospitals. So, it is obvious from the literature that GLSS leads to reduction in different wastes, and leads to improved workplace hygiene and standardization but it is not able to provide methods to provide quick real-time assessment measures that assist in COVID-19 improved diagnosis, monitoring, real-time estimation of cases, and hygienic workplace/ healthcare facility are the need of the hour to prevent further outbreaks of this chronic disease COVID-19 (Singh et al., 2020). So, it is imperative to adopt technologies and approaches that provide quick monitoring, make the appropriate decision, analyze problems and provide feasible solutions accruing to the problem related to COVID-19.

I4.0 technologies can make the system smart assist in quick diagnosis, treatment, recovery, and monitoring, and provides measures of the danger of the pandemic (Chandra et al., 2022). In the course of this pandemic situation, radiographs, scans, and robotics for infection identification were used to form innovative methods for medicinal investigation and will be a benefit for forthcoming performance enhancement (Ahmad et al., 2022). IoT-enabled additive manufacturing can be used to make surgical instruments, masks, ventilator parts, and other allied medical parts with high accuracy and at a pacer rate (Radanliev, and De Roure, 2023). Moreover, this technique needs minimum human intervention as the design of the parts to be manufactured is made on the computer software package and a command is initiated from the system to make the part of the 3-D printing machine (Ahmad et al., 2022). It has been found that surgical masks and N95 masks have detrimental effects on the environment and masks made by 3-D printing technology have been proven to be more recyclable hence contributing to environmental sustainability (Javaid et al., 2020). I4.0' AI can be used to design an autonomous robot that can be used for sanitization and different medical work at healthcare facilities (Popov et al., 2022). Moreover, AI can be used in the clinical trials of drugs and vaccines at research centres to provide realistically the best results. Further, It has been found that big data can be used to grab the data related to the number, spread, deaths, and pattern from numerous sources in the world and enables governments, medical associates, and policymakers to make a quick decisions for precautionary measures to curb the intensity of the COVID -19. (Narayanamurthy & Tortorella, 2021b). Further, Different patches of biosensor that provide different metrics related to temperature, ECG, pulse rate, and blood pressure with a single sensor is in their infancy and will provide a compact device that will replace all devices with a unique device to detect key parameters for early detection of COVID-19. Further, it has been reported that I4.0 technologies can be used for contactless scanning of the chest of COVID patients to detect quantifies the intensity of the COVID virus (Halcomb et al., 2020). This technique provides a real measure of the shapes and size of the organs from which the different associated diseases related to the patient can be diagnosed. So, it can be deduced that integration of both methodologies leads to improved resilience of the healthcare system and provides high-quality patient care and leads to a win-win situation for both at customer end healthcare facility end.

Although the plethora of literature on I4.0 and Lean Six Sigma has sparked scholarly and industrial research on the subject, there is still a dearth of academic summaries on aspects of the integrated

GLSS-I4.0 approach. To date, no review of the different aspects of integrated GLSS-I4.0 in the context of COVID has been reported. Reviews that offer hindsight of nascent areas are imperative as they enable scholars to obtain an overview of the configuration and nomenclature of research extents. This article intends to fill this research gap in the nascent field of integrated GLSS-I4.0 approach for COVID management. Specified the prominence of digital technologies and green technologies, together with the lack of research that combines the extant literature on the industrial applications of digital technologies coupled with green and operational excellence approach, this study offers hindsight of the literature on GLSS and I4.0 towards COVID management and provides a conceptual framework for better detection, cure and management of COVID pandemic.

4. Descriptive statics

The authors also conducted a systematic study of pertinent articles related to GLSS- I4.0 possible interaction areas, since the start of the COVID era (from 2019). Journal, author, year, and country-wise analyses wise also conducted to explore trends and application areas in the researcher community and worldwide. Figure 4 represents the country-wise distribution of the articles related to GLSS-I4.0. The area highlighted in green colour represents that GLSS-I 4.0 has found application in these particular countries and the area that is not highlighted is still not explored. It has been identified that in nations like India, the USA, and Brazil research related to integration aspects of LSS with industry I4.0, Lean with I4.0, and Green technology with I4.0 for healthcare has been conducted comprehensively in the context of healthcare. Besides, the authors also explored the journal-wise distribution of articles of GLSS-Industry 4.0 (table 3). It has been found an integrated approach found a place in top-tier journals like the *Journal of Cleaner Production, the International Journal of Production Research, and the International Journal of Lean Six Sigma*. Moreover, the authors also conducted a systematic analysis to find prominent researchers in the field of integrated operation excellence methods in the context of COVID healthcare. Table 4 presents authors who conducted research in the field of integrated operation excellence methods for COVID healthcare.

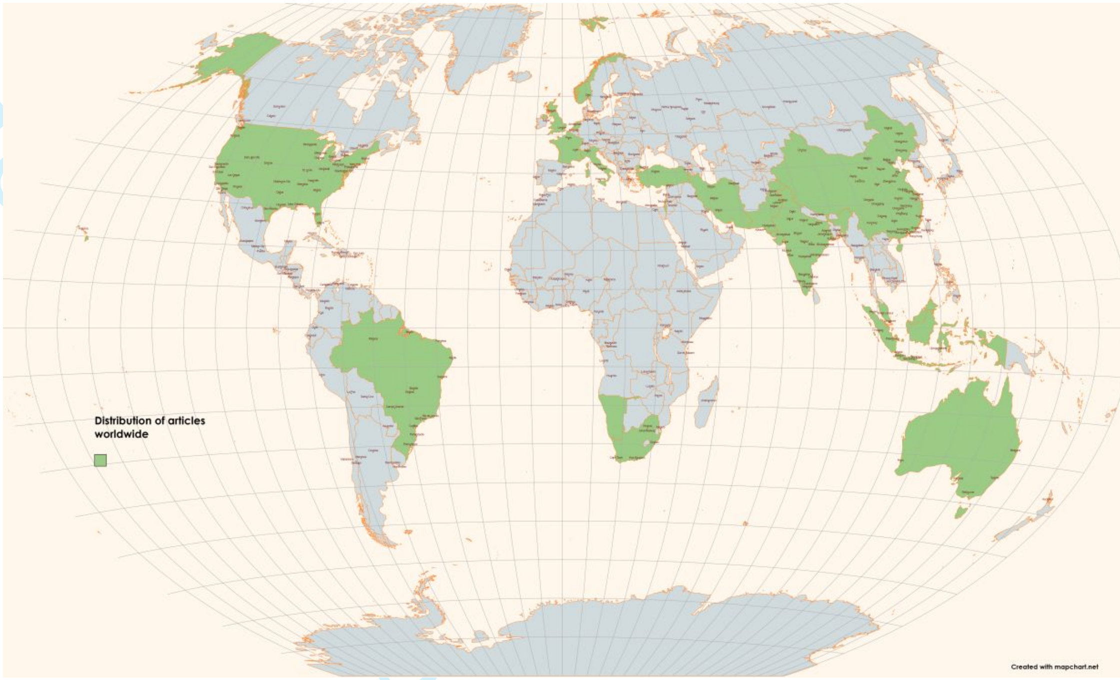

Figure 4: Country-wise distribution of articles

Table 3: Journal-wise distribution of articles

S. No.	Name of the journal	No of articles
1	Jounral of Cleaner Production	3
2	Diabetes and metabolic syndrome clinical research and reviews	3
3	International Journal of Lean Six Sigma	4
4	Production Planning and Control	2
5	Material Today Procedings	1
6	Clean Technologies and Environmental policies	1
7	International Journal of Production Economics	2
8	Sustainabilty	1
9	IEEE Transaction on Engineering and Management	1
10	Environmental Impact Assessment and Review	1
11	International Journal of Sustainable Engineering	1
12	International journal of Production research	3
13	Business strategy and Environment	1
14	Occupational Rehability	1
15	Environmental Science and Pollution Research	1
16	Sustainable Production and Consumption	1
17	International Journal of Operations & Production Management	1
18	World Journal of Enginnering	1
19	International Journal of Quality and Reliability Management	1
20	Rajagiri Management Journal	1
21	International Jounral of Six Sigma and competitive advantage	3
22	*Journal of Primary Care & Community Health*	1

23	International Journal of Productivity and Performance Management	1
24	Technology forecasting and Social Change	1
25	Journal of Nursing Scholarship	1
26	Computers in Biology and Medicine	1
27	TQM journal	1
28	Health and Technology	1
29	Materials	1

Table 4: Prominent authors in the concerned area of research

S. No.	**Authors' Name**	**No of articles**
1	A. Chauhan, S. K. Jakhar, and C. Chauhan	1
2	M. Javaid, A. Haleem, R. Vaishya, S. Bahl, R. Suman, and A. Vaish	1
3	E. Demir and H. Turan	1
4	R. P. Singh, M. Javaid, A. Haleem, and R. Suman	1
5	R. Rathi, M. S. Kaswan, J. A. Garza-Reyes, J. Antony, and J. Cross	1
6	A. Chiarini and M. Kumar	1
7	V. G. Surange, S. U. Bokade, A. K. Singh, and S. N. Teli	1
8	M. S. Kaswan and R. Rathi	1
9	G. Narayanamurthy and G. Tortorella	1
10	M. S. Kumar, D. R. D. Raut, D. V. S. Narwane, and D. B. E. Narkhede	1
11	A. Hussain, M. U. Farooq, M. S. Habib, T. Masood, and C. I. Pruncu	1
12	M. S. Kaswan, R. Rathi, J. A. G. Reyes, and J. Antony	1
13	M. S. Kaswan and R. Rathi	1
14	R. Sreedharan V, G. Sandhya, and R. Raju	1
15	M. Sony and S. Naik	1
16	A. Belhadi, S. S. Kamble, A. Gunasekaran, K. Zkik, D. K. M, and F. E. Touriki	1
17	S. V. Buer, M. Semini, J. O. Strandhagen, and F. Sgarbossa	1
18	H. Gholami, N. Jamil, M. Z. Mat Saman, D. Streimikiene, S. Sharif, and N. Zakuan	1
19	M. J. Ershadi, O. Qhanadi Taghizadeh, and S. M. Hadji Molana	1
20	A. S. K. Cheng, P. H. F. Ng, Z. P. T. Sin, S. H. S. Lai, and S. W. Law	1
21	S. Bag, S. Gupta, and S. Kumar	1
22	Nara, E. O. B., da Costa, M. B., Baierle, I. C., Schaefer, J. L., Benitez, G. B., do Santos, L. M. A. L., & Benitez, L. B	1
23	T. Zheng, M. Ardolino, A. Bacchetti, and M. Perona,	1
24	A. Moeuf, S. Lamouri, R. Pellerin, S. Tamayo-Giraldo, E. Tobon-Valencia, and R. Eburdy	1
25	G. L. Tortorella, R. Giglio, and D. H. van Dun	1
26	V. Swarnakar, A. R. Singh, and A. K. Tiwari	1
27	M. S. Kaswan, R. Rathi, M. Singh, J. A. Garza-Reyes, and J. Antony	1
28	G. F. Frederico	1

29	Hundal, G. S., Thiyagarajan, S., Alduraibi, M., Laux, C. M., Furterer, S. L., Cudney, E. A., & Antony, J.	1
30	Sarfraz, A., Sarfraz, Z., Sarfraz, M., Abdul Razzack, A., Bano, S., Singh Makkar, S., Thevuthasan, S., Paul, T., Khawar Sana, M., Azeem, N. and Felix, M	1
31	C. Acioli, A. Scavarda, and A. Reis	1
32	A. Kuiper, R. H. Lee, V. J. J. van Ham, and R. J. M. M. Does	1
33	A. Yilmaz, M. Dora, B. Hezarkhani, and M. Kumar	1
34	Halcomb, E., McInnes, S., Williams, A., Ashley, C., James, S., Fernandez, R., Stephen, C. and Calma, K.	1
35	W. E. Frazier	1
36	Ahmad, M., Sadiq, S., Alluhaidan, A.S., Umer, M., Ullah, S. and Nappi, M.	1
37	W. Salentijn, J. Antony, and J. Douglas,	1
38	Y. Praharsi, M. A. Jami'in, G. Suhardjito, and H. M. Wee	1
39	M. N. Mishra, A. Mohan, and A. Sarkar	1
40	K. B. N. Raja Mohamed, P. R. M, S. P. S, J. R. A, and R. Anderson,	1
41	M. Chandra, K. Kumar, P. Thakur, S. Chattopadhyaya, F. Alam, and S. Kumar	1
42	M. M. Ahsan and Z. Siddique	1
43	V. V. Popov, E. V. Kudryavtseva, N. Kumar Katiyar, A. Shishkin, S. I. Stepanov, and S. Goel	
44	A. H. Iswanto	1

To the best of the knowledge of authors in the literature, no study reviews different facets of the integrated GLSS-I4.0 approach within the context of healthcare and provides a conceptual framework of the same for improved healthcare performance. Thus, the aforementioned gaps in the literature, better service to humanity in this time of the pandemic, and social responsibility towards mother earth provide direction and impetus for this research work.

5. Application areas, challenges, and perceived benefits of integrated GLSS-Industry 4.0

Integrated GLSS- I4.0 approach provides a concrete solution to the different facets of problems during the COVID-19 crisis. Integrated GLSS-I4.0 can be used in the different areas related to healthcare facilities to curb COVID-19. This approach can be used in the managing waiting room for the treatment of patients together with the cleanliness of the workplace and different wards through the systematic application of GLSS tools and autonomous robots. The COVID-19 pandemic brings huge pressure on the existing healthcare facilities through increased hospital intake and scarcity of essential medicare items (Frederico, 2021). This approach facilitates reduce in the length of the hospital stay of the patients and hence manages the work follow that consequently leads to the increased capacity utilization of the available healthcare facilities. Further, an integrated approach can be used to manage the supply chain of healthcare essentials through faster production of items thus meeting high demands of the essentials at a crucial time within different regions of the world (Praharsi et al., 2021). The safety and cleanliness of the operating rooms as well as patients and healthcare facilities can be improved through the systematic application of AI tools and autonomous rooms. Although integrated GLSS-I4.0 brings a slew of benefits for patient care as well as healthcare facilities but its implementation is also not deprived of challenges. Firstly, being a new approach to healthcare, due to cultural differences within the facilities organizational personnel may feel reluctant to the adoption of the same. But the same can be removed by providing confidence to the management that same if implemented in the long run it will bring a win-win situation both upstream and downstream of the supply chain. Secondly, the adoption of this integrated approach a lot of investment in the procurement of new technologies, training, and infrastructural changes within the healthcare facilities. This can be mitigated by making collaboration with financial institutions and educational institutions to make credit access easier for healthcare facilities. Third, as an integrated approach highly realizes the data set to decide the complex environment, quality and sanctity of the data will also be a challenge to healthcare authorities. The same can be solved through the systematic application of big data, IoT, and artificial intelligence over the supply of healthcare. It has been identified that the application of integrated GLSS-I4.0 in healthcare in the context of COVID-19 brings a lot of challenges but provides a slew of opportunities to solve the different issues related to the safety and services of COVID-19 patients. Figure 5 illustrates integrated GLSS-I4.0 tools/techniques, application areas, perceived benefits, and challenges within healthcare in the context of COVID-19. An integrated GLSS-I4.0 approach can be used for better planning of different facets and measures related to COVID-19 (Hundal et al., 2020).

Better information management within the entire supply chain consequently leads to improved profitability dynamics for upstream and downstream partners of the supply chain (Acioli et al., 2021). Better estimation of large datasets helps to investigate the different trends of the pandemic in different times and regions. Monitoring and real-time estimation of patient statistics in different areas of the globe can be monitored through big data and other statistical tools of the integrated approach. Exploration of new medical-related IoT devices that provides a quick assessment of the primary statics that helps doctors to reach a logical conclusion about the patients. COVID has resulted in the disruption in demand, supply, and capacity of the healthcare system throughout the world. In the healthcare system capacity is estimated in terms of available funds, beds, and manpower. It has been identified that bed capacity shows a vital role in handling the COVID-19 demand for hospital processes (Halcomb et al., 2020). Besides, augmented demand for inadequate healthcare resources led to the issue of arrival rate variability downstream of the healthcare supply chain (Halcomb et al., 2020). This integrated GLSS-I 4.0 approach can be implemented to reduce the length of hospital stay. Further, through the use of different tools like 7S, poka-yoke, COBOT, and other integrated technologies workplaces can be made more sanitized and also limited space can be better utilized. Further, through the use of GLSS tools like EVSM scheduling of the inpatients' care and health worker management can also be done. Moreover, it also has been reported the use of advanced digital technologies further leads to better work experience and ambience with minimized direct contact with the affected people. 3D printing technologies of integrated GLSS- I4.0 approach lead to faster production of medical items (medicines, vaccines, and other allied surgical instruments that can meet the growing demand for medical essentials in the pandemic times. The integrated GLSS-I4.0 approach directly helps to improve the process of healthcare delivery to patients like emergency facilities, clinical amenities, and inpatient or outpatient care (Hundal et al., 2020). COBOT are used to make the workplace clean with the required degree of accuracy and faster rate that also leads to lesser infection to the health care workers. The use of different IoT-based devices for the detection of different health parameters also leads to better inpatient care for the patients as service providers or doctors can also check the real-time status of the patients which leads to better healthcare management of the COVID-affected people.(Kuiper et al., 2022) (Yilmaz et al., 2022).

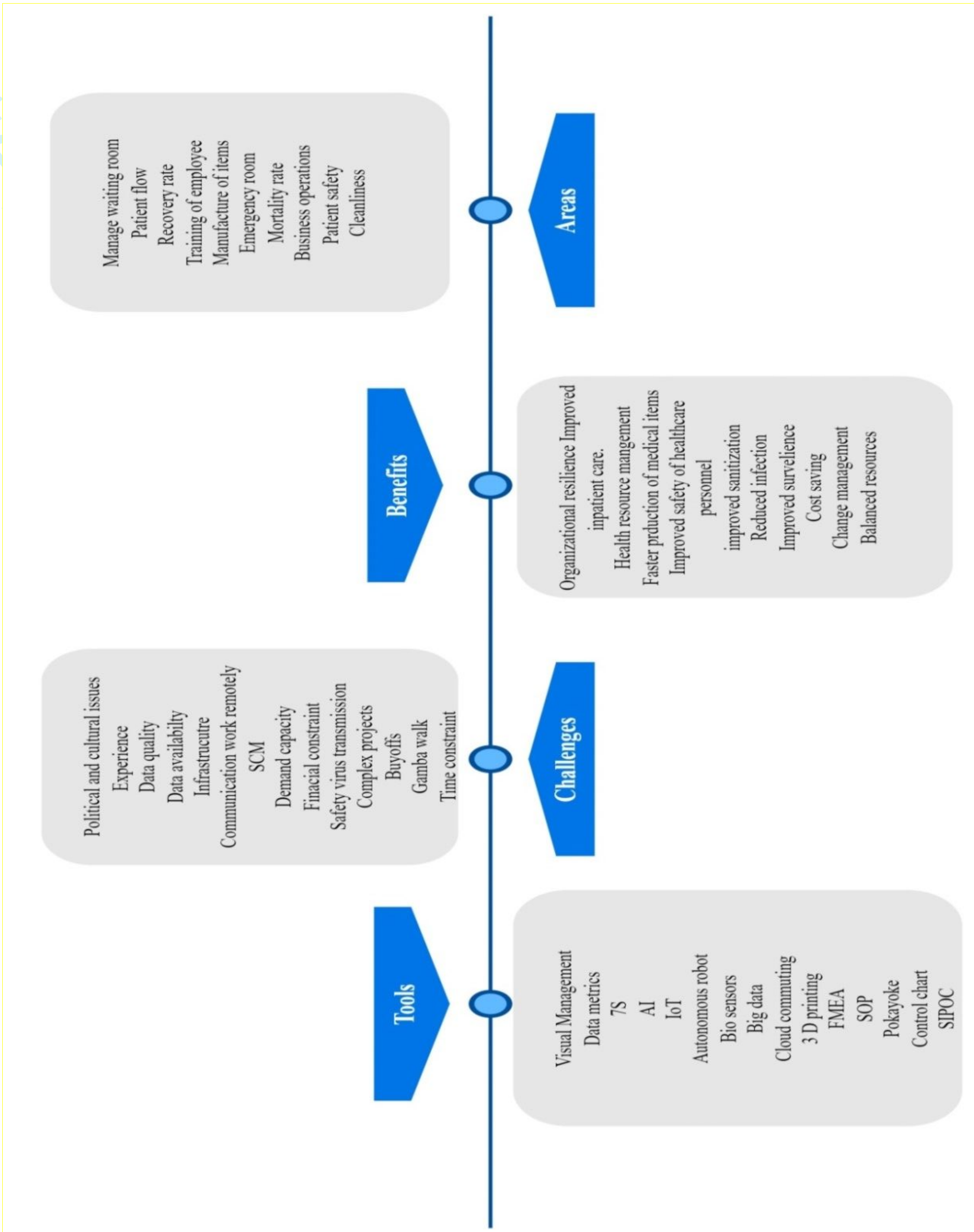

Figure 5: Integrated GLSS-Industry 4.0 tool/techniques, application areas, perceived benefits, and challenges

6. Enabling technologies and tools of Green Lean Six Sigma and Industry 4.0 in the context of COVID-19

In the context of healthcare, GLSS application leads to high-quality inpatient care at low cost and a faster service level through the systematic reduction of various Green Lean wastes and variations in existing systems or processes. GLSS implementation in healthcare services reduces the length of hospital stays (LOSs), provides real-time information sharing in the healthcare supply chain, and incorporate time-saving for doctors and other healthcare staff that would otherwise be wasted in non-valued added activities (Iswanto, 2021) Moreover, it improves the service quality of healthcare entities by decreasing patient lead time and process cycle time while also improving sustainability by reducing cost, resources, and waste (Swarnakar et al., 2021). Changes in the patterns of diseases have increased healthcare expenses, and intergovernmental policies on climate change have forced the healthcare sector to incorporate new advanced technologies (Kaswan, Rathi, Singh, et al., 2021). Moreover, in developing nations, due to the limited availability of doctors and funds, it is indispensable for the countries to develop breakthrough strategies. GLSS can be a potential solution at this juncture as it provides high-quality inpatient care at reduced costs with less environmental impact (Swarnakar et al., 2021). Further, utmost safety, improved diagnosis, monitoring, real-time estimation of cases, and hygienic workplace/ healthcare facility are the need of the hour to prevent further outbreaks of this chronic disease COVID-19 (Singh et al., 2020). So, it is imperative to adopt technologies and approaches that provide quick monitoring, make the appropriate decision, analyze problems and provide feasible solutions accruing to the problem related to COVID-19. I4.0 technologies can make the system smart assist in quick diagnosis, treatment, recovery, and monitoring, and provides measures of the danger of the pandemic (Chandra et al., 2022). Integration of both methodologies leads to improved resilience of the healthcare system and provides high-quality patient care and leads to a win-win situation for both at customer end healthcare facility end. The roles of different technologies and tools of this integrated approach have been presented in table 5.

Table 5: Technologies and tools of integrated GLSS-I 4.0 approach to mitigate COVID-19

Technologies/tools	Definition	Benefits during COVID era
Additive manufacturing	The process to manufacture products by depositing layer by layer so that human intervention and defects can be minimized. It is one of the most emerging filed in the manufacturing domain. By using this technology small and precise can be manufactured within a few periods and with high accuracy than traditional methods of manufacturing (Frazier, 2014).	Additive manufacturing techniques can be used to make surgical instruments, masks, ventilator parts, and other allied medical parts with high accuracy and at a pacer rate(Singh et al., 2020). Moreover, this technique needs minimum human intervention as the design of the parts to be manufactured is made on the computer software package and a command is initiated from the system to make the part of the 3-D printing machine (Ahmad et al., 2022). Surgical masks and N95 masks have detrimental effects on the environment and masks made by the 3-D printing technology have been proven to be more recyclable hence contributing to the environmental sustainability
Artificial intelligence	Artificial intelligence (AI) enables machine tools to perform tasks that are typically possible only through human intelligence. It enables to adjudge risk of infection and screening of people. It enables the computer system to construct models based on the analysis of large data systems, developed construct models then proceed, recognize, explain and predict the available pattern based on the developed construct system.	Artificial intelligence is a technology of I4.0 that is a critical nonmedical interference for overcoming the current global health crisis, developing future pandemic preparation, and retrieval of resilience (El-Sherif et al., 2022). AI is the powerful technique of I4.0 system that helps to adjudge the COVID spread pattern and helps to further spread the same. There exist a lot of rumours and misconceptions newly related to COVID on different platforms with the help of AI, the same can be removed to provide realistic information to the people. AI can be used to design an autonomous robot that can be used for sanitization and different medical work at healthcare facilities (Popov et al., 2022). Moreover, AI can be used in the clinical trials of drugs and vaccines at research centres to provide realistically the best results.
IoT	IoT is the network to connect things with the internet through sensing equipment for exchanging information to achieve better recognition, tracing, and other analyses.	IoT brings different realistic measures to fight against COVID-19 (Sarfraz et al., 2022). For example, drones can be used for surveillance of people during the lockdown. This technology can be used to find the origin of COVID in particular and its outbreak. The compliance and surveillance of patients can be maintained through this technology without coming in direct contact with affected people.
Big data analytics	Provides a way to decipher large data sets that cannot be handled by traditional database technologies. Analytics is withdrawn from the intelligence of business and support system of decision that facilitates the organization to make evidence-based decisions. Big data enables to encapsulation of a large amount of data set of COVID patients and enables the system to make quick	Big data prompts us to investigate the impacts of COVID and its spread in different regions of the world (Ahsan & Siddique, 2022). The COVID-19 chasers can grab the data related to the number, spread, deaths, and pattern from numerous sources in the world and enablers the governments, medical associates, and policymakers to make a quick decision for precautionary measures to curb the intensity of the COVID -19

	decisions based on the facts derived from the analysis of the real-time data set.	
Poka-yoke	As COVID-19 is a highly infectious disease, its cure examination needs devices that prevent direct interaction of the healthcare staff with patients. Pokayoke devices are mistake-proofing devices that lead to minimization of the error at different stages of the COVID patient recovery.	GLSS implementation through the mistake-proofing device (poka-yoke) leads to a reduction of the healthcare staff workload like the automatic machine to detect dispense results in the reduction of the workload of the pharmacist that time-saving consequently will lead to better inpatient care of COVID patients. The application of mistake-proofing devices results in medication errors and that leads to better utilization of hospital resources.
Bio-Sensor	Biological sensors are used to convert any biological signal into an electrical one and provide useful information. In Medicare, this technology is a new one, as in the COVID era there is a high demand for devices that easily detect different metrics related to human health at a faster rate. For this, biosensors can be useful to construct different devices related to the diagnosis of human health parameters that further add doctors to make different logical decisions related to the health of the human being.	Biological sensors facilitate to manufacture of devices that are easy to fit, sensitive, and provide precise medical information related to the patients. A glucose meter equipped with a biosensor can be used to detect the level of glucose in real-time. Different patches of biosensor that provide different metrics related to temperature, ECG, pulse rate, and blood pressure with a single sensor is in their infancy and will provide a compact device that will replace all devices with a unique device to detect key parameters for early detection of COVID-19.
Data metrics	Data metrics of the integrated GLSS-Industry 4.0 approach enable the healthcare organizations to capture data from a different process that can be further utilized to make the process of healthcare delivery more efficient	Integrated GLSS-I 4.0 is data intensive approach it enables the system to capture data sets from different venues, can encapsulate data related to the hand hygiene process, and provides further actions for improvement. By analyzing different actions for inefficiencies and providing the solution for improvement integrated GLSS-I 4.0 make the process of hand hygiene in compliance with regulatory norms set by different medicare agencies to protect against COVID-19.
Value stream mapping	Value stream mapping is used to capture all key flow (of patient service, information, equipment) in the healthcare delivery process in hospitals and encapsulate important metrics of the process.	Value stream mapping is convenient for mapping the present state of the processes; recognizing inefficacy in the process and aiding healthcare units to map both the current and future better-quality states. It enables the healthcare unit during the COVID-19 time, where the process has non-value-added activities that can be subsequently removed from the undersigned process, to make the inpatient service time of patients lower in the hospitals.
Visual management tools	Visual management tools encompass a variety of display in the different zones of the hospital that depicts different metrics related to COVID person, present a standardized method to adopt, and helps	Visual management tools in the emergency room can be used to maintain the standard operating procedures during COVID time. The standard operating procedure will lead to lesser medication errors and further adds to improved safety and

	to communicate performance measures in the healthcare facility	chances of infection from COVID-affected people. It enables the display of the status of all critical elements of patients that further helps to initiate preventive actions by healthcare staff. It enables to and fro feedback among health staff that further eliminates the need for further personal contact with supporting staff and thus eliminates the danger of infection from COVID-19.
Cloud computing	Cloud computing is to provide on-demand availability of the hosted service without direct active management by the user. It enables the computer system resource sharing over the cloud or internet which makes faster delivery of information and technology sharing that leads to lesser cost and improved system efficacy.	Covid-19 has brought social isolation due to an increased period of lockdowns throughout the world. In this era, people maintained their social life through the service providers of amazon web, google cloud, etc. The request for special packages for healthcare delivery units increased tremendously during the lockdown period.
Robot mechanism	The autonomous robot can be used to work independently in different environments. It can work for a prolonged duration and can adjudge the surrounding ambience and collect different data.	COVID-19 brings a lot of uncertainties to human society. It is highly infectious so it is advised to prevent direct human contact with affected people. The autonomous robot can be used in such situations for different routine work within healthcare facilities or outside. It can be used for patrolling work in contaminated zones. Moreover, it assists medical staff to perform their assignments without any intervention.
3D scanning	The 3D technique is used to convert a physical model into a computer-aided design. This technique is useful in medical science for scanning the human body and its different organs with exact information. Precise 3D models are compared with different 3D scanning models obtained from different people to get exact information on the functioning of different organs their shape, and size to detect different abnormalities.	This is a powerful technique for contactless scanning of the chest of COVID patients to detect quantifies the intensity of the COVID virus. This technique provides a real measure of the shapes and size of the organs from which the different associated diseases related to the patient can be diagnosed.

7. Proposed framework of integrated GLSS-I 4.0

The COVID-19 pandemic has affected every aspect of human life including the healthcare supply chain. Early detection, monitoring, clean surrounding, and inpatient care of COVID patient is required to curb the intensity of the damage of this pandemic. Integrated GLSS-I4.0 is a novel approach that helps in early detection, proper surveillance, maintaining hygiene within healthcare facilities, and aids in better inpatient care. Besides, the application, potential areas, tools, and challenges to the execution of this integrated approach within healthcare, the study also proposes a conceptual framework for this integrated approach to COVID-19.

Framework development

An integrated GLSS-I4.0 conceptual framework has been proposed by the authors to combat COVID-19 for better detection, prevention, and cure. The Integrated GLSS-I4.0 framework evolved here is dependent on three design dimensions. The first design dimension comprised the activity of assessment of different parameters related to COVID, and the appropriateness of the GLSS-I4.0 conceptual framework. There is a need for personnel protective types of equipment even digital technologies are being used to assess different parameters related to COVID. It has been found that devices like X-Ray, Oxo meters, Glucose meters, blood pressure measurement devices, and pulse meter devices have been widely used for better detection of different parameters related to COVID patients. This set of equipment can provide a large set of data related to different diagnostic parameters of COVID-19. So, based on the literature these can be put into the discernment layer for the assessing of different sets related to COVID. Further, integrated application of big data with cloud computing coupled with cyber security must be included to have authentic information flow and data for research and analysis related to prevention, cure, and different drugs and vaccination analysis. The lessons learned from here is that integrated application of digital technologies will make access and easier transfer of large datasets that can further be utilized for assisting the healthcare personnel to adjudge the level of COVID spread in different regions of the world, and the level of potential damage and helps to develop the plan for the healthcare policymakers in other parts of the world to curb and mitigate the potential danger of COVID in their region. So, the lesson learned here is that application of an integrated set of I4.0 technologies can be used.

Further, the authors reviewed different frameworks related to GLSS and I4.0 and integrated operational excellence with I4.0 (table 6). It has been found that there are ample opportunities to integrate operational excellence approaches like GLSS with I4.0 in service sectors. It is also has been found that I4.0 can be integrated with the popular DMAIC methodology of Six Sigma improvement in the process and different metrics. Based on the note of DMAIC, different technologies and tools of GLSS have been incorporated at different stages to provide better prevention and cure during the application layer of the framework. This secured the incorporation of the most current and specific conceptual knowledge into the developed GLSS-I4.0 framework. The second design dimension incorporated using the substantial theoretical and industrial level of the authors and academic researchers to help the development of the proposed framework (table 7). Garza-Reyes et al., (2016) recommend that the experience of practitioners performs a crucial role while developing conceptual frameworks which are needed to be implemented in the industry.

Table 6: Frameworks reviewed to formulate the application layer of the preliminary framework of GLSS-Industry 4.0

Source	**Contribution**	**Limitations**	**Lesson learned from the development of the existing framework**
Pongboonchai-empl et al., 2023	The study contributes towards the field of knowledge by providing a conceptual I.40 enabled DMAIC framework. The study illustrates how different LSS tools can be benefitted from I4.0 technologies	The study doesn't provide a sector or industry-specific project	How different tools of LSS and techniques of I4.0 can be integrated to realize a sustainability-focused LSS project.
Chiarini and Kumar, (2020)	Investigated possible integration of LSS tools and Industry 4.0 technologies based on grounded theory.	Limited to the integration of LSS with Industry 4.0 and did not address how a formal framework can be developed and executed.	Integration of LSS tools and enabling technologies of I4.0, provides a systematic way to improve the process or project under consideration
Hundal et al., 2020	The main contribution of this study lies in the identification of the principles of LSS, within organizational resilience that upkeep a healthcare entity's ability to lessen the effect of COVID-19.	The study is not providing a direct framework to improve the organization's effectiveness to deal with COVID. The findings of the study were based on the semi-structured interview so cannot be generalized for a large spectrum of the disease	This study gives insights to be learned in terms of How VSM, FMEA and other LSS tools can be used to build organizational resilience in the potential areas of patient safety and performance improvement. The lessons related to resource balancing, tasks ordering and organized problem-solving methods are the prospective benefits recognized in healthcare operations for COVID-19 response.

Kaswan and Rathi, 2020	Formulated an introductory GLSS framework based on literature review.	The study provides a generalized framework, but it did not provide ways to utilize it in the service sector, especially in the healthcare domain	How GLSS project can be used to improve the performance of an industrial organization by the systematic application of DMAIC and associated GLSS tools.
Kaswan et al., 2023	Proposed an integrated GLSS-Industry 4.0 framework for a manufacturing entity along with success and failure factors for the integrated approach	The study is confined to the manufacturing entity	How an integrated framework can be realized through project identification and sustaining of the best solutions using cohesive application GLSS-I4.0 tools and techniques.
Ahmad et al., 2022	Provided deep learning-based framework to diagnose COVID-19	The study only provided method for detection but not provides for protection and cure	How different techniques of I4.0 especially AI and DNN can be used to extract significant features and discriminate X-Ray images to provide information related to COVID detection.
Hussain et al., 2021	The study investigated the potential of I4.0 technologies in sustaining business operations and solving COVID-19 challenges for long-term sustainability through a systematic investigation of literature and a conceptual framework based on insights from the literature.	Study findings are based on the literature and did not address how I4.0 technologies can provide measures for the prevention and cure of diseases.	The study provides useful insights in terms of the integrated applications of the I4.0-technologies for mitigating challenges to COVID.
Tufail et al., 2021	The main contribution of the study lies in the integration of LSS tools with DMAIC to resolve operational complications in hospitals.	The study is related to the potential application of LSS tools for healthcare operations and did not encompass the possible effect of the tools related to pandemic	Insights related to the management of healthcare facilities for time-saving and managing useful resources with better healthcare are gathered from this study.
Rathi et al., (2022)	The proposed model to improve environmental and economic sustainability using a DMAIC-based framework	The study only encompasses GLSS tools and can include industries 4.0 technologies to improve environmental	Guidelines for the use of different tools during the realization of the GLSS project for improvement in organizational sustainability.

		and economic sustainability	

Table 7: Panel of respondents from academia

S. No.	Profile	Average work experience	Number of people	Average Age
1	Professors	25	15	54
2	LSS Green belt	20	13	46
3	LSS black belt	18	11	45

Lastly, the third design dimension incorporated the consideration of appropriate inputs from the different healthcare facilities throughout the globe. Thus, the authors discussed with a team of, 40 prominent healthcare personnel from different continents. The expert panel (healthcare personnel) comprised medical officers, doctors, and healthcare staff (table 8). Each expert that was included in the panel had more than twenty years of experience to deal with healthcare operations. The experts dispensed valuable feedback and criticism to improve the applicability and maturity of the GLSS-I4.0 framework. Consolidated inputs from the academic personnel and healthcare personnel are given in Table 9 and the corresponding modification has been incorporated within the final developed framework.

Table 8: Panel of respondents from healthcare facilities to validate the developed framework

S. No.	Profile	Average work experience	Number of people	Average Age
1	Doctors	25	18	51
2	Chief executive of the medical center	26	9	52
3	Laboratory and other support staff	21	6	34
4	Medical Association officer	28	7	33

The proposed framework is exhibited in Figure 4. The said framework is divided into three segments.

1. Discernment layer

In the first segment which is the discernment layer, here data related to COVID patient detection, their severity, and different parameters of healthcare monitoring are adjudged using automated devices like X-Ray, Oxo meter, Glucose meter, blood pressure measurement device, pulse meter device. Adopting an automatic prediction method will aid in preparing officials to respond correctly and speedily. The application of AI firstly prevents direct contact of patients with healthcare staff, thus helping to prevent the spread of further infection. Such techniques can also improve automatically through experience, and data science in their pursuit to better monitor and respond intensively in context of the information sharing about the spread of diseases, detection of risky areas, their follow-up and potential effects in the health sector. As responded by academic personnel and healthcare experts it is imperative to include more protective equipment for the healthcare staff to adjudge different parameters of the COVID patients even though the non-contact type of devices are being used to check different parameters related to COVID. It is imperative to wear protective glass, a personnel prevention kit, and the incorporation of better hygiene and sanitization is needed to prevent infection in the COVID prevention task force.

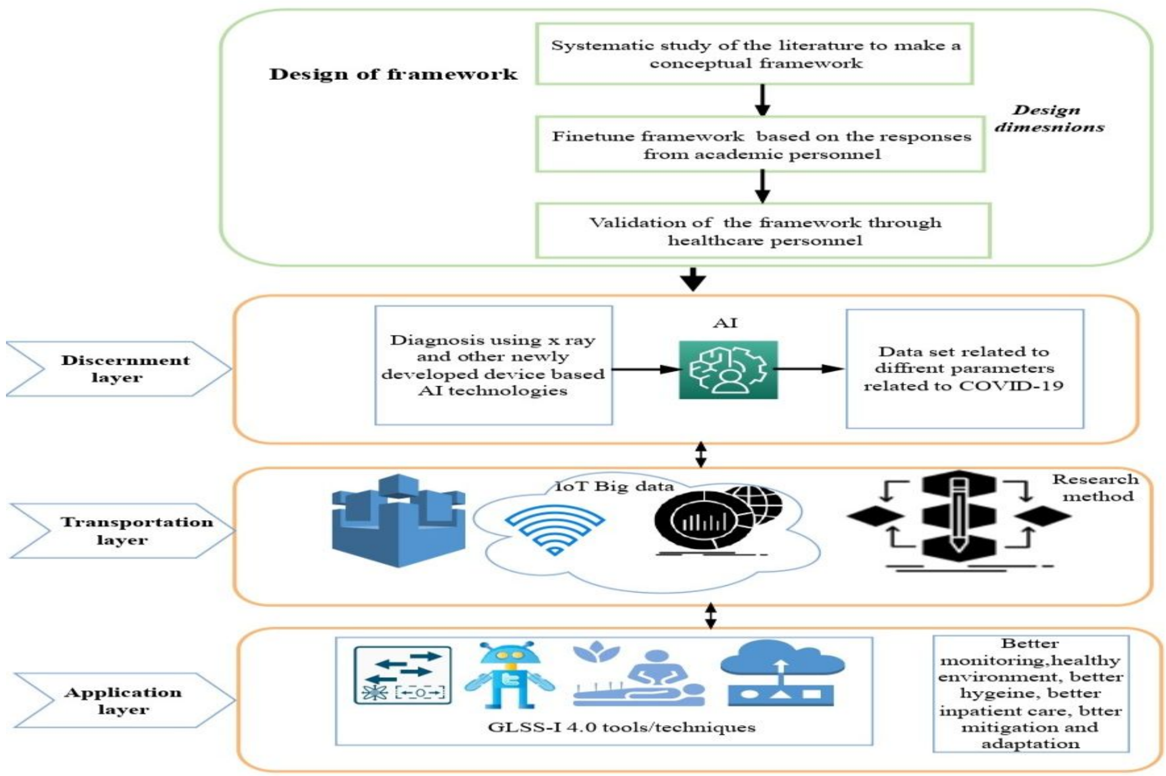

Figure 6: Proposed framework of Integrated GLSS-I4.0

2. Transportation layer

This data related to different health metrics is then uploaded to the cloud for further analysis and research tasks. It has facilitated tracking the virus in populations, even down to the neighbourhood level. It has also been used in tactical planning and decision-making procedures to anticipate and prepare for future pandemics. This procedure assists the healthcare personnel to adjudge the level of COVID spread in different regions of the world, and the level of potential damage and helps to develop the plan for the healthcare policymakers in other parts of the world to curb and mitigate the potential danger of COVID in their region. This layer assists to store the data and provides real-time information related to patients infected with COVID with the help of I4.0 techniques like data science, big data, cloud computing, etc. Such information could be easily analyzed for taking further steps to tackle the COVID spread in a particular region.

Table 9: Input from experts and healthcare personnel to develop the GLSS-I4.0 framework

Framework step/layer	Experts' input from academia	Healthcare personnel inputs	Modifications made in the framework
Discernment layer	Incorporation of more sophisticated technologies of AI and self-protection types of equipment is demanded at the discernment layer to protect healthcare staff from COVID-affected person	There is a need for personnel protective types of equipment even digital technologies are being used to assess different parameters related to COVID	The use of 3D protective glass, PPE kits, and an advanced set of protective types of equipment are incorporated for better protection of healthcare staff.
Transpoertation layer	It is imperative to have authentic data on COVID. Chances of pilferage and bugs demand more sophisticated measures towards cyber security to prevent any distorted information	Integrated application of big data with cloud computing coupled with cyber security must be included to have authentic information flow and data for research and analysis related to prevention, cure, and different drugs and vaccination analysis	Cyber security integrated with big data measures is provided to provide authentic and real-time information on COVID characteristics and related information
Application layer	Real-time monitoring devices and self-observation devices are needed for the track record of medicine is demanded better inpatient care	Better automatic hygiene and cleaning system is needed to create a positive atmosphere around the affected person. It is also viable to provide continuous motivation and psychological add to the patients for better recovery and fight against COVID	Integrated application of COBOT and GLSS tools inserted to make the healthcare facility time to time cleanliness, with self-dispense of medicine, and sanitiser. Incorporation of online sessions with affected people from motivational speakers and psychologists is included for better and fast cure of the affected people.

Synchronized application of I4.0 and GLSS technologies like cloud computing, big data, and data metrics, leads to the development of a comprehensive database related to COVID patients, that further assists in different plans to curb, mitigate, and improve the different facets of the healthcare supply chain. Big data prompts us to investigate the impacts of COVID and its spread in different regions of the world. The COVID-19 chasers can grab the data related to the number, spread, deaths, and pattern from numerous sources in the world and enablers the governments, medical associates, and policymakers to make a quick decision for precautionary measures to curb the intensity of the COVID -19. Based on the feedback from academia and healthcare personnel; it is imperative to induce cyber security measures to maintain the sanctity of the data for correct information that is being used for further research and development on drugs and vaccination.

3. Application layer

Finally, the last segment of the framework is the application of the technologies and tools of the integrated approach to the affected person for better care. As COVID is a highly infectious disease, so, it is always imperative to maintain and healthy and clean environment around the patient for better care and reduce the chances of further infection. The application of an autonomous robot can be used in such situations for different routine work like patrolling work in contaminated zones, delivery of medicines to patients etc. Moreover, the application of Visual management tools in the emergency room can be used to maintain the standard operating procedures during COVID time. The standard operating procedure will lead to lesser medication errors and further add to improved safety and chances of infection from COVID-affected people. It enables the display of the status of all critical elements of patients that further helps to initiate preventive actions by healthcare staff. It enables to and fro feedback among health staff that further eliminates the need for further personal contact with supporting staff and thus eliminates the danger of infection from COVID-19. Further, compliance with rules and regulations in contaminant zone surveillance of patients can be maintained through IoT-based mechanisms like drones without coming in direct contact with affected people can be assured. So, the application of different tools and techniques of the integrated approach leads to better detection, cure, and control of this highly infectious disease. Based on experts' inputs integrated applications of COBOT and GLSS tools are inserted to provide cleanliness to the healthcare facility from time to time, with self-dispense of medicine, and sanitiser. Incorporation of online sessions with affected people from motivational speakers and psychologists is included for better and fast cure of the affected people.

Implications

The present research work provides manifold implications for researchers and practitioners. The potential researchers can comprehend different know-how related to the integrated approach like, how to integrate individual Green Lean Six Sigma and Industry 4.0 approaches under the umbrella of the unified Green Lean Six Sigma-Industry approach. Secondly, the study provides a complete knowledge base to the researchers by understanding different tools and techniques of an integrated approach for better COVID management starting from early detection to cure. Further study also provides know-how on different techniques of integrated approach for better space management in healthcare entities, manufacturing of medical essentials using additive manufacturing and capture of different metrics related to detection and pattern recognition of COVID-19. The study also provides implications for healthcare managers by providing useful insights better planning related to capacity management during the pandemic times, the use of different tools and techniques to reduce the length of hospital stay for patients, and improved hygiene in hospitals using COBOTs.

8. Conclusion, limitations, and future research agenda

The Integrated GLSS-I4.0 approach leads to the development of smart solutions for manufacturing industries and other allied areas. This integrated approach encompasses different facets of tools and techniques that make the system of service delivery and production of items faster, with lesser errors. It prompts minimum human interruption, a healthy work environment, and assists in complex decision-making based on the analysis of realistic information analysis. This set of technologies and tools provides better management of healthcare facilities, provides risk-free isolation of the COVID patient, boosts the production of vaccines, and assists in monitoring and surveillance of the affected people. This approach tends to develop a clean work ambience and provides automatic solutions for the sanitization of healthcare facilities. The proposed framework of the Integrated GLSS-I4.0 approach facilitated healthcare practitioners to adopt the aspects of integration for better capacity management of the facility, improved monitoring, and better patient care within their facilities. This approach further facilitates healthcare facilities to extend their current capacity by proper workspace utilization, increasing value-added time for healthcare staff, and reducing the length of hospital stay for the patients. Integrated GLSS-I4.0 facilitates remote operations using a smart set of technologies that facilitates the COVID outbreak. The Integrated GLSS-I4.0 approach leads to the better management of crowds, transportation facilities, industrial operations, and the healthcare supply chain. Application of the integrated approach leads to a virtual clinic minimum with minimal human intervention through the complete record of patient history, monitoring through advanced digital measures, and delivery of medicines. This leads to a reduction in the patient rush at healthcare facilities and clinics that allows the hospital to tap the full potential of available capacities.

Despite meaningful contributions, the study is not deprived of limitations. The main limitation of the study is that it provides a conceptual framework that can be further pragmatically validated. Further, as research is continuously growing with a set of green and digital technologies to address challenges related to healthcare, so few articles related to healthcare may be leftover in the study. The integrated GLSS-I4.0 approach is capable to store and retrieve sensitive data from the healthcare system that can be used for the analysis of other pandemics like COVID. The incorporation of tools and techniques of the integrated approach leads to better detection and treatment of the COVID patient. So, the same set of technologies can be adopted in the coming times to care for other pandemics. Moreover, future healthcare systems need to be made smart for sustaining demand patterns, reduction in LOS, and ensure faster production of essential medical items. Researchers, in the future, can develop a systematic framework for the integrated GLSS-I4.0 approach to improve the environmental and social sustainability of healthcare facilities. Moreover, analysis and modelling of the different barriers related to the adoption of GLSS-I4.0 can also be explored by potential researchers in the future.

References

Acioli, C., Scavarda, A., & Reis, A. (2021). Applying Industry 4.0 technologies in the COVID–19 sustainable chains. *International Journal of Productivity and Performance Management*, *70*(5), 988–1016. https://doi.org/10.1108/IJPPM-03-2020-0137

Ahmad, M., Sadiq, S., Eshmawi, A. A., Alluhaidan, A. S., Umer, M., Ullah, S., & Nappi, M. (2022). Industry 4.0 technologies and their applications in fighting COVID-19 pandemic using deep learning techniques. *Computers in Biology and Medicine*, *145*(March), 105418. https://doi.org/10.1016/j.compbiomed.2022.105418

Ahsan, M. M., & Siddique, Z. (2022). *Industry 4.0 in Health care: A systematic review*. http://arxiv.org/abs/2201.06999

Andreo-Martínez, P., Ortiz-Martínez, V. M., Salar-García, M. J., Veiga-del-Baño, J. M., Chica, A., & Quesada-Medina, J. (2022). Waste animal fats as feedstock for biodiesel production using non-catalytic supercritical alcohol transesterification: A perspective by the PRISMA methodology. *Energy for Sustainable Development*, *69*, 150–163. https://doi.org/10.1016/j.esd.2022.06.004

Bag, S., Gupta, S., & Kumar, S. (2021). Industry 4.0 adoption and 10R advance manufacturing capabilities for sustainable development. *International Journal of Production Economics*, *231*(June 2020), 107844. https://doi.org/10.1016/j.ijpe.2020.107844

Belhadi, A., Kamble, S. S., Gunasekaran, A., Zkik, K., M, D. K., & Touriki, F. E. (2021). A Big Data Analytics-driven Lean Six Sigma framework for enhanced green performance: a case study of chemical company. *Production Planning and Control*, *0*(0), 1–24. https://doi.org/10.1080/09537287.2021.1964868

Buer, S. V., Semini, M., Strandhagen, J. O., & Sgarbossa, F. (2021). The complementary effect of lean manufacturing and digitalisation on operational performance. *International Journal of Production Research*, *59*(7), 1976–1992. https://doi.org/10.1080/00207543.2020.1790684

Chandra, M., Kumar, K., Thakur, P., Chattopadhyaya, S., Alam, F., & Kumar, S. (2022). Digital technologies, healthcare and Covid-19: insights from developing and emerging nations. *Health and Technology*, *12*(2), 547–568. https://doi.org/10.1007/s12553-022-00650-1

Chauhan, A., Jakhar, S. K., & Chauhan, C. (2021). The interplay of circular economy with industry 4.0 enabled smart city drivers of healthcare waste disposal. *Journal of Cleaner Production*, *279*, 123854. https://doi.org/10.1016/j.jclepro.2020.123854

Cheng, A. S. K., Ng, P. H. F., Sin, Z. P. T., Lai, S. H. S., & Law, S. W. (2020). Smart Work Injury Management (SWIM) System: Artificial Intelligence in Work Disability Management. *Journal of Occupational Rehabilitation*, *30*(3), 354–361. https://doi.org/10.1007/s10926-020-09886-y

Chiarini, A., & Kumar, M. (2021). Lean Six Sigma and Industry 4.0 integration for Operational Excellence: evidence from Italian manufacturing companies. *Production Planning and Control*, *32*(13), 1084–1101. https://doi.org/10.1080/09537287.2020.1784485

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, *204*(December 2017), 383–394. https://doi.org/10.1016/j.ijpe.2018.08.019

Demir, E., & Turan, H. (2021). An integrated spherical fuzzy AHP multi-criteria method for Covid-19 crisis management in regarding lean six sigma. *International Journal of Lean Six Sigma*, *12*(4), 859–885. https://doi.org/10.1108/IJLSS-11-2020-0183

El-Sherif, D. M., Abouzid, M., Elzarif, M. T., Ahmed, A. A., Albakri, A., & Alshehri, M. M. (2022). Telehealth and Artificial Intelligence Insights into Healthcare during the COVID-19 Pandemic. *Healthcare (Switzerland)*, *10*(2), 1–15. https://doi.org/10.3390/healthcare10020385

Ershadi, M. J., Qhanadi Taghizadeh, O., & Hadji Molana, S. M. (2021). Selection and performance estimation of Green Lean Six Sigma Projects: a hybrid approach of technology readiness level, data envelopment analysis, and ANFIS. *Environmental Science and Pollution Research*, *2009*. https://doi.org/10.1007/s11356-021-12595-5

Frazier, W. E. (2014). Metal additive manufacturing: A review. *Journal of Materials Engineering and Performance*, *23*(6), 1917–1928. https://doi.org/10.1007/s11665-014-0958-z

Frederico, G. F. (2021). Towards a Supply Chain 4.0 on the post-COVID-19 pandemic: a conceptual and strategic discussion for more resilient supply chains. *Rajagiri Management Journal*, *15*(2), 94–104. https://doi.org/10.1108/ramj-08-2020-0047

Garza-reyes, J. A. (2023). *Industrial revolution and environmental sustainability : an analytical interpretation of research constituents*. https://doi.org/10.1108/IJLSS-02-2023-0030

Garza-Reyes, J. A., Al-Balushi, M., Antony, J., & Kumar, V. (2016). A Lean Six Sigma framework for the reduction of ship loading commercial time in the iron ore pelletising industry. *Production Planning and Control*, *27*(13), 1092–1111. https://doi.org/10.1080/09537287.2016.1185188

Gholami, H., Jamil, N., Mat Saman, M. Z., Streimikiene, D., Sharif, S., & Zakuan, N. (2021). The application of Green Lean Six Sigma. *Business Strategy and the Environment*, *30*(4), 1913–1931. https://doi.org/10.1002/bse.2724

Gokalp, M. O., Kayabay, K., Akyol, M. A., Eren, P. E., & Kocyigit, A. (2017). Big data for Industry 4.0: A conceptual framework. *Proceedings - 2016 International Conference on Computational Science and Computational Intelligence, CSCI 2016*, 431–434. https://doi.org/10.1109/CSCI.2016.0088

Halcomb, E., McInnes, S., Williams, A., Ashley, C., James, S., Fernandez, R., Stephen, C., & Calma, K. (2020). The Experiences of Primary Healthcare Nurses During the COVID-19 Pandemic in Australia. *Journal of Nursing Scholarship*, *52*(5), 553–563. https://doi.org/10.1111/jnu.12589

Hundal, G. S., Thiyagarajan, S., Alduraibi, M., Laux, C. M., Furterer, S. L., Cudney, E. A., & Antony, J. (2020). Lean Six Sigma as an organizational resilience mechanism in health care during the era of COVID-19. *International Journal of Lean Six Sigma*, *12*(4), 762–783. https://doi.org/10.1108/IJLSS-11-2020-0204

Hussain, A., Farooq, M. U., Habib, M. S., Masood, T., & Pruncu, C. I. (2021). Covid-19 challenges: Can industry 4.0 technologies help with business continuity? *Sustainability (Switzerland)*, *13*(21), 1–25. https://doi.org/10.3390/su132111971

Iswanto, A. H. (2021). Impact of lean six sigma at pharmacy unit on hospital profitability before and during Covid-19 pandemic. *International Journal of Lean Six Sigma*, *12*(4), 718–743. https://doi.org/10.1108/IJLSS-10-2020-0182

Javaid, M., Haleem, A., Vaishya, R., Bahl, S., Suman, R., & Vaish, A. (2020). Industry 4.0 technologies and their applications in fighting COVID-19 pandemic. *Diabetes and Metabolic Syndrome: Clinical Research and Reviews*, *14*(4), 419–422. https://doi.org/10.1016/j.dsx.2020.04.032

jayaram, Aradhya, V. N. M., Amity University, IEEE-USA, Institute of Electrical and Electronics Engineers. Uttar Pradesh Section, & Institute of Electrical and Electronics Engineers. (2016). *Proceedings of the 2016 2nd International Conference on Contemporary Computing and Informatics (IC3I) : 14-17 December 2016, Noida, India*. 89–94.

Kaswan, M. S., Cross, J., Garza-reyes, J. A., & Antony, J. (2022). *Integrating Green Lean Six Sigma and industry 4 . 0 : a conceptual framework*. https://doi.org/10.1108/JMTM-03-2022-0115

Kaswan, M. S., & Rathi, R. (2020a). Green Lean Six Sigma for sustainable development: Integration and framework. *Environmental Impact Assessment Review*, *83*(March), 106396. https://doi.org/10.1016/j.eiar.2020.106396

Kaswan, M. S., & Rathi, R. (2020b). Investigating the enablers associated with implementation of Green Lean Six Sigma in manufacturing sector using Best Worst Method. *Clean Technologies and Environmental Policy*, *22*(4), 865–876. https://doi.org/10.1007/s10098-020-01827-w

Kaswan, M. S., Rathi, R., Reyes, J. A. G., & Antony, J. (2021). Exploration and Investigation of Green Lean Six Sigma Adoption Barriers for Manufacturing Sustainability. *IEEE Transactions on Engineering Management*, 1–15. https://doi.org/10.1109/TEM.2021.3108171

Kaswan, M. S., Rathi, R., Singh, M., Garza-Reyes, J. A., & Antony, J. (2021). Exploration and prioritization of just in time enablers for sustainable health care: an integrated GRA-Fuzzy TOPSIS application. *World Journal of Engineering*, *November 2020*. https://doi.org/10.1108/WJE-09-2020-0414

Kuiper, A., Lee, R. H., van Ham, V. J. J., & Does, R. J. M. M. (2022). A reconsideration of Lean Six Sigma in healthcare after the COVID-19 crisis. *International Journal of Lean Six Sigma*, *13*(1), 101–117. https://doi.org/10.1108/IJLSS-01-2021-0013

Kumar, M. S., Raut, D. R. D., Narwane, D. V. S., & Narkhede, D. B. E. (2020). Applications of industry 4.0 to overcome the COVID-19 operational challenges. *Diabetes and Metabolic Syndrome: Clinical Research and Reviews*, *14*(5), 1283–1289. https://doi.org/10.1016/j.dsx.2020.07.010

Maddikunta, P. K. R., Pham, Q. V., B, P., Deepa, N., Dev, K., Gadekallu, T. R., Ruby, R., & Liyanage, M. (2022). Industry 5.0: A survey on enabling technologies and potential applications. *Journal of Industrial Information Integration*, *26*(July).

https://doi.org/10.1016/j.jii.2021.100257

Mishra, M. N., Mohan, A., & Sarkar, A. (2021). Role of Lean Six Sigma in the Indian MSMEs during COVID-19. *International Journal of Lean Six Sigma*, *12*(4), 697–717. https://doi.org/10.1108/IJLSS-10-2020-0176

Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E., & Eburdy, R. (2020). Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. *International Journal of Production Research*, *58*(5), 1384–1400. https://doi.org/10.1080/00207543.2019.1636323

Nara, E. O. B., da Costa, M. B., Baierle, I. C., Schaefer, J. L., Benitez, G. B., do Santos, L. M. A. L., & Benitez, L. B. (2021). Expected impact of industry 4.0 technologies on sustainable development: A study in the context of Brazil's plastic industry. *Sustainable Production and Consumption*, *25*, 102–122. https://doi.org/10.1016/j.spc.2020.07.018

Narayanamurthy, G., & Tortorella, G. (2021a). Impact of COVID-19 outbreak on employee performance – Moderating role of industry 4.0 base technologies. *International Journal of Production Economics*, *234*(October 2020), 108075. https://doi.org/10.1016/j.ijpe.2021.108075

Narayanamurthy, G., & Tortorella, G. (2021b). Impact of COVID-19 outbreak on employee performance – Moderating role of industry 4.0 base technologies. *International Journal of Production Economics*, *234*(February), 108075. https://doi.org/10.1016/j.ijpe.2021.108075

Popov, V. V., Kudryavtseva, E. V., Kumar Katiyar, N., Shishkin, A., Stepanov, S. I., & Goel, S. (2022). Industry 4.0 and Digitalisation in Healthcare. *Materials*, *15*(6), 2140. https://doi.org/10.3390/ma15062140

Powell, D., Lundeby, S., Chabada, L., & Dreyer, H. (2017). Lean Six Sigma and environmental sustainability: the case of a Norwegian dairy producer. *International Journal of Lean Six Sigma*, *8*(1), 53–64. https://doi.org/10.1108/IJLSS-06-2015-0024

Praharsi, Y., Jami'in, M. A., Suhardjito, G., & Wee, H. M. (2021). The application of Lean Six Sigma and supply chain resilience in maritime industry during the era of COVID-19. *International Journal of Lean Six Sigma*, *12*(4), 800–834. https://doi.org/10.1108/IJLSS-11-2020-0196

Raja Mohamed, K. B. N., M, P. R., S, S. P., A, J. R., & Anderson, R. (2021). Six sigma in health-care service: a case study on COVID 19 patients' satisfaction. *International Journal of Lean Six Sigma*, *12*(4), 744–761. https://doi.org/10.1108/IJLSS-11-2020-0189

Rathi, R., Kaswan, M. S., Antony, J., Cross, J., Garza-Reyes, J. A., & Furterer, S. L. (2022). Success factors for the adoption of green lean six sigma in healthcare facility: an ISM-MICMAC study. In *International Journal of Lean Six Sigma*. https://doi.org/10.1108/IJLSS-02-2022-0042

Rathi, R., Kaswan, M. S., Garza-Reyes, J. A., Antony, J., & Cross, J. (2022). Green Lean Six Sigma for improving manufacturing sustainability: Framework development and validation.

Journal of Cleaner Production, *345*(August 2021), 131130. https://doi.org/10.1016/j.jclepro.2022.131130

Ruben, R. Ben, Vinodh, S., & Asokan, P. (2018). Lean Six Sigma with environmental focus: review and framework. *International Journal of Advanced Manufacturing Technology*, *94*(9–12), 4023–4037. https://doi.org/10.1007/s00170-017-1148-6

Sagnak, M., & Kazancoglu, Y. (2016). Integration of green lean approach with six sigma: an application for flue gas emissions. *Journal of Cleaner Production*, *127*, 112–118. https://doi.org/10.1016/j.jclepro.2016.04.016

Salentijn, W., Antony, J., & Douglas, J. (2021). Six Sigma to distinguish patterns in COVID-19 approaches. *TQM Journal*, *33*(8), 1633–1646. https://doi.org/10.1108/TQM-11-2020-0271

Sarfraz, A., Sarfraz, Z., Sarfraz, M., Abdul Razzack, A., Bano, S., Singh Makkar, S., Thevuthasan, S., Paul, T., Khawar Sana, M., Azeem, N., Felix, M., & Cherrez-Ojeda, I. (2022). Industry 4.0 Technologies for the Manufacturing and Distribution of COVID-19 Vaccines. *Journal of Primary Care and Community Health*, *13*. https://doi.org/10.1177/21501319211068638

Singh, R. P., Javaid, M., Haleem, A., & Suman, R. (2020). Internet of things (IoT) applications to fight against COVID-19 pandemic. *Diabetes and Metabolic Syndrome: Clinical Research and Reviews*, *14*(4), 521–524. https://doi.org/10.1016/j.dsx.2020.04.041

Sony, M., & Naik, S. (2020). Green Lean Six Sigma implementation framework: a case of reducing graphite and dust pollution. *International Journal of Sustainable Engineering*, *13*(3), 184–193. https://doi.org/10.1080/19397038.2019.1695015

Surange, V. G., Bokade, S. U., Singh, A. K., & Teli, S. N. (2022). Prioritization of roadblocks to adoption of industry 4.0 technologies in manufacturing industries using VIKOR. *Materials Today: Proceedings*, *50*, 2194–2200. https://doi.org/10.1016/j.matpr.2021.09.448

Swarnakar, V., Singh, A. R., & Tiwari, A. K. (2021). Evaluating the effect of critical failure factors associated with sustainable Lean Six Sigma framework implementation in healthcare organization. *International Journal of Quality and Reliability Management*, *38*(5), 1149–1177. https://doi.org/10.1108/IJQRM-07-2020-0243

Tortorella, G. L., Giglio, R., & van Dun, D. H. (2019). Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement. *International Journal of Operations and Production Management*, *39*, 860–886. https://doi.org/10.1108/IJOPM-01-2019-0005

Yilmaz, A., Dora, M., Hezarkhani, B., & Kumar, M. (2022). Lean and industry 4.0: Mapping determinants and barriers from a social, environmental, and operational perspective. *Technological Forecasting and Social Change*, *175*(February 2021), 121320. https://doi.org/10.1016/j.techfore.2021.121320

Zheng, T., Ardolino, M., Bacchetti, A., & Perona, M. (2021). The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. *International Journal* *of Production Research*, *59*(6), 1922–1954. https://doi.org/10.1080/00207543.2020.1824085