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Abstract

Purpose: This research work aims to explore the potential application of Blockchain technology in Lean Six Sigma (LSS) project through a proposed Blockchain-LSS (BLSS) model. The proposed model can tackle real-time problems in information sharing, transparency, and traceability in every stage of the LSS project.

Design/methodology/approach: The scoping review approach is used to develop the integrated model of the Blockchain-LSS approach for operational excellence. The proposed model is validated through expert's input which is collected by a questionnaire survey method.

Findings: The prime function of the proposed BLSS model is the information sharing among the project team and real-time monitoring, transparency, traceability, and immutability in the DMAIC (Define-Measure-Analyze-Improve-Control) phase. The proposed model also consists the information about the role of Blockchain features at each phase of the LSS project. The project team and industry employees can trace the success of the project at every moment, resulting in trust buildup and the elimination of fake data. Moreover, there would be no disputes among various sections/shops of the plant and employees to share the real information.

Practical implications: This paper provides guidelines to practitioners and managers for integrating the LSS approach and Blockchain. The Blockchain helps managers and practitioners in better data traceability and transparency, monitoring of data as well as more sustainable LSS project management.

Originality/value: This is the first research attempt that developed an integrated model of blockchain and LSS approach to maintaining the immutable records of assets in projects and targeted industry 4.0.

Keywords: Lean Six Sigma; Blockchain Technology; Smart contract; DMAIC; Operational Excellence.

1. Introduction

The increasing demands for quality and eco-friendly products, lower operational costs, and higher sustainability have forced organizations to restructure their business strategies (Singh, Rathi, Antony, *et al.*, 2021). Lean Six Sigma (LSS) is a prominent approach used to enhance operational performance through waste reduction and process variation minimization (Singh and Rathi, 2019). It is based on the synergy of DMAIC (Define-Measure-Analyze-Improve-Control) methodology and tools with lean tools (Sony *et al.*, 2020). This approach is adopted fruitfully for continuous improvement in various industrial sectors like oil and gas sector (Nascimento *et al.*, 2019), higher education (Sunder M and Antony, 2018) (Gupta *et al.*, 2020), automotive sector (Rathi and Singh, 2021), and packaging sector (Flor Vallejo *et al.*, 2020), etc. These evidence prove that the LSS approach is capable of providing excellent results, but many organizations are not ready to share the data and information due to fear factor that can create delays and stifle creativity in the execution of the DMAIC methodology (De Mast and Lokkerbol, 2012) (Singh *et al.*, 2019). In most existing industrial systems, the varied cultures, human intervention, inefficient records, diverse regulatory policies, and pilferage of data cause the failure of the LSS approach to attain the expected result (Antony *et al.*, 2020). Moreover, the risk of data forgery and alteration is increased by using paper-based data (Kim *et al.*, 2019). This leads to the failure of sustainable fulfillment of the LSS methodology which results in time wastage, demotivation, and financial loss (Gerger and Firuzan, 2012). This rationale is the impetus for amalgamating blockchain technology in LSS projects through conducting the present research work.

As an emerging technology, Blockchain has drawn much interest in industrial sectors based on peer-to-peer distributed ledger (Goyat, Kumar, Saha, *et al.*, 2020). Blockchain is a digital decentralized and immutable technology that was developed in 2008 by (Satoshi Nakamoto, 2008). The public availability of data and the decentralization aspects of blockchain establish transparency and immutability in records (Goyat *et al.*, 2019) (Bai and Sarkis, 2020). Blockchain works in a distributed manner where each member has equal authority to update the data/information verified digitally and publicly available to all participants of the project (Kim *et al.*, 2020). We want to trigger a new set of research for investigating possible benefits such as transparency, traceability, and immutable ledger of available information and data. Therefore, the present study uses the blockchain in LSS projects to improve traceability and real-time automatic information sharing at each phase of the project. Previous studies generally focus on the execution of each phase of the LSS project without real-time monitoring and traceability of data at every stage (Singh *et al.*, 2022). Also, existing studies primarily address the qualitative benefits of blockchain in the supply chain and ignore its functional implementation in continuous improvement projects (Badzar, 2016) (Upadhyay *et al.*, 2021). Overall, the focus of previous studies related to blockchain either captures the information flow in the supply chain or the industrial Internet of things. Other side, LSS-related existing studies explored the implementation barriers, enablers, and framework without considering blockchain technology (Singh, Rathi and Garza-Reyes, 2021). Due to the huge pressure on manufacturing companies to produce quality products on time and sustain themselves in a competitive environment, organizations can't wait for a longer time for the results of the LSS approach (Chauhan *et al.*, 2021). Here, it becomes essential to speed up the implementation steps of the LSS approach and in this context, the availability of data/information in real-time, accurate, transparent, and easily traceable in a plant facilitated a lot. This vision could be achieved incorporation of Blockchain technology in each phase of the LSS approach. To summarize, this study presents a novel blockchain-LSS model scientifically as compared with existing relevant research. Moreover, this study visualizes the information flow at each phase of the LSS project through the blockchain information management concept.

The present work attempts to answer the following research question through conducting inductive research: How organizations can effectively implement blockchain technology in LSS projects for Operational Excellence (OPEX)? This research is inductive and uses a scoping review methodology to comprehend the synergetic association between LSS and blockchain technology. Initially, the authors collected the information and data through a scoping review followed by an in-depth study and construction of the integrated model of LSS with blockchain technology.

This article is split into a total of nine sections including the introduction part. The remaining sections are as follows: Section 2 represents the application of Blockchain potential of Blockchain OPEX in any organization. Section 3 reveals the literature review on existing LSS frameworks/models followed by Section 4, in which the potential of Blockchain in LSS projects is illustrated. Section 5 reveals the detailed steps of the research methodology adopted to conduct the present study. Section 6 presents the proposed integrated Blockchain-LSS model followed by a detailed discussion of findings as per the set research question in Section 7. Thereafter, the managerial and researcher's implications are presented in Section 8, and in the last Section 9, the conclusion, limitations, and future scope of the research are provided.

2. Blockchain for Operational Excellence

Blockchain was discovered as a technology that reinforces Bitcoin in white paper (Nakamoto, 2008), and continuous investigation by researchers strengthens the scope of Blockchain (Chang *et al.*, 2020). Blockchain is one of the transformative technologies and decentralized repository altering in numerous industries globally (Javaid *et al.*, 2021). Blockchain tracks digital ledger transaction that is distributed across the system, rendering it incorruptible (Goyat *et al.*, 2019). Also, Blockchain assists in framing the existing systems more competent, and to run themselves with decentralized and distributed profit margins through Ethereum smart contract (Manski, 2017). Literature reveals various applications of Blockchain for obtaining operational excellence like blockchain-based decentralized cryptocurrency (Yuan and Wang, 2018), Blockchain-based smart contracts (Sheth and Subramanian, 2020), international payment (Ali *et al.*, 2020), etc. Literature stated that 'Blockchain is an emerging technology which can make basics for our social and economic system' (Iansiti and Lakhani, 2017) (Vu *et al.*, 2023). Few studies explored that Blockchain enables support of the dynamics of social sharing and the way people connect around the globe (Pazaitis *et al.*, 2017) (Goyat *et al.*, 2023). Primarily, Blockchain was introduced by (Nakamoto, 2008) for Bitcoin where two parties can communicate transparency without intermediators to make the system decentralized. For example, in banking, a person needs bank authorization to initiate the transaction without intermediate. Other hand, Operational Excellence (OPEX), has become a prime management theme for profit and non-profit industries/organizations (Sony, 2019). A recent study stated that 'OPEX is a management system framed to obtain customer value via technology and innovation development' (Cui *et al.*, 2022). They stated that the goal of OPEX is to continuously enhance the industrial system's efficacy and efficiency. Literature proposed various concepts like 'Audit Sheet', 'Lean Six Sigma', etc. to obtain OPEX for minimizing operational cost and meeting customer demand (Lameijer *et al.*, 2021). Research conducted by Upadhyay *et al.*, (2021) claimed that OPEX can be obtained by adoption of Blockchain Technology in supply chain collaboration. A recent study explored the integration of Blockchain and LSS to improve quality management in different sectors (Ahmad *et al.*, 2022). There is still no study available on the integration of Blockchain and LSS for obtaining OPEX to understand the implementation steps in any organization. In this context, this study put impetus to provide a deep understanding of how Blockchain-based LSS projects can initiate in a particular manufacturing setting for obtaining OPEX.

3. Study of existing LSS frameworks/model

As per the literature, it observed that numerous researchers and practitioners are working on the LSS approach and trying to adapt it to solving real-time problems and achieving success to some extent (Raval and Kant, 2017). Jing *et al.*, 2021, stated that the LSS approach with a Theory of Constraint-based framework was used to improve flow, reduce waste, and increase process capability in manufacturing settings. Such a framework lacks in sharing the data/information at all stages of a project simultaneously. In another research, a based framework was used to minimize the rejection rate in a manufacturing setting, but it failed to provide efficient results during varied cultures and pilferage of data in the industry (Kumar *et al.*, 2021). Moreover, various frameworks related to LSS, Industry 4.0, and Blockchain in the context of OPEX were analyzed to develop the preliminary model of an integrated Blockchain and LSS approach. The reviewed frameworks are summarized in Table 1.

Table 1: Existing framework reviewed to develop an integrated model of Blockchain-LSS

The result of the LSS literature reveals that available frameworks of LSS are conventional and only targeted to minimize waste and enhance process quality statistically. If manufacturing organizations want to use proper skills and resources, then need to take a turn toward the emerging technology of Industry 4.0 (Chiarini and Kumar, 2020). The issues (diverse regulatory policies, varied cultures, human intervention, inefficient records, and pilferage of data) noticed in LSS project execution can be tackled smartly by blockchain technology (Goyat, Kumar, Rai, *et al.*, 2020). Therefore, the present study has taken forward steps to the nexus of blockchain in the LSS project. The next section expresses the potential of Blockchain technology in the LSS project to strengthen and make the more robust project.

4. Potential of Blockchain in Lean Six Sigma Project

Blockchain is a decentralized database in which the information flows digitally among blockchain-participating agents (Crosby *et al.*, 2016). It provides a wonderful impact on the industrial sector to enhance its process, production, and trust-related information (Chen *et al.*, 2022). This technology has been adopted in supply chain management to provide faster, more accurate, and more scalable information among vendors, distribution centers, and plants without any delay (Queiroz *et al.*, 2019a). In an additive manufacturing system, blockchain suggested a secure and fastest path to improving communication protocol based on a cyber-physical system through an autonomous agent (Goyat, Kumar, Saha, *et al.*, 2020). During blockchain adoption in sustainable supply chain management, the researchers have faced some barriers inter-organizational, intra-organizational, external, and technical barriers (Goyat *et al.*, 2019). However, these barriers were focused on at the initial stage of blockchain adoption and got a good result (Goyat *et al.*, 2019). Other practitioners implemented blockchain in a multi-echelon sustainable supply chain and found secure, fastest, and trustable information in between pillars of the supply chain (Manupati *et al.*, 2019). Other practitioners implemented blockchain in a multi-echelon sustainable supply chain and found secure, fastest, and trustable information in between pillars of the supply chain (Manupati *et al.*, 2019). It also provides excellent results in terms of transparency and sustainable development in the supply chain (Bai and Sarkis, 2020); improve solid waste management in small municipalities (França *et al.*, 2020), land titling in India (Thakur *et al.*, 2020), food supply chain (Behnke and Janssen, 2020), agriculture supply chain (Kamble *et al.*, 2020), etc. As per the literature, blockchain technology is having the potential for decentralization; security; immutable; transparency, and open distributed ledger to prove the effectiveness and efficiency of the system (Wang *et al.*, 2020). Another side, most industries preserve their data related to production, material, manpower, machines, etc. manually with human intervention, and inefficient records, cause mishandling of data and delay causing failure of the LSS program (Singh *et al.*, 2019). Such type of failure of LSS project can be overcome by incorporating blockchain technology because of their merits such as transparency, traceability, information sharing, real-time monitoring, etc. Figure 1 exhibits how the information flows between the members in the blockchain model in LSS projects. This model is unique as compared to existing information system designs due to its main features i.e. decentralization of records, security, validation, and smart contract execution (Peters and Panayi, 2016).

Figure 1: Illustration of Blockchain

As per the literature review, blockchain technology displays numerous advantages in its applications, including reliability (Watanabe *et al.*, 2016), transparency (Badzar, 2016), traceability (Goyat *et al.*, 2021), information sharing (Goyat, Kumar, Saha, *et al.*, 2020), and monitoring (Balci and Surucu-Balci, 2021). These advantages would facilitate solving the issues in the LSS project, as shown in Figure 2. The alteration in available data could be controlled through blockchain because each team member would be required a ledger and permission to change in data available to them. Furthermore, the close connection between each stage of DMAIC methodology, results in a higher demand for real-time information sharing and information traceability. Blockchain technology can satisfy these demands to enhance the management of the DMAIC phase. In this study, we build a model to further explain how to realize real-time information sharing and traceability in an LSS project.

Figure 2: Selected merits of blockchain in the LSS project

5. Research Methodology

The present study is conducted through a scoping review methodology which consists of a three-phase review process (Refer to Figure 3). The scoping review approach is identified as a robust approach to exploring the extensive literature review in the field of Industrial and Management (Munn *et al.*, 2018). The scoping review is like a systematic literature review except it provides more prominent outcomes in the case of qualitative and conceptual research (Bragagnolo, et al., 2021). The scoping review provides transparent, comprehensive, and clear information which ensures that the process is directed with the utmost consistency (Garza-Reyes, 2015). As compared to other conventional approaches to literature survey, scoping review exhibits a replicable and scientific approach to collecting existing studies, summarizing the existing evidence with minimal bias (Chakraborty and Chakraborty, 2022) (Chugani *et al.*, 2017). Therefore, we have adopted the same approach in the present study to develop the conceptual theory through the identification of the area where research is needed.

Figure 3: Research methodology adopted in the present study

In the first phase of the adopted research methodology, research questions are set as per the objective of this present study, and the keywords for searching the articles are accordingly. The pertinent research articles have been searched using the keywords 'Lean Six Sigma,' 'Blockchain', Industry 4.0, Operational Excellence, etc. The articles were downloaded from 2002 to 2022 from mainstream search engines such as Elsevier, Emerald, Springer, Taylor & Francis, Scopus, Wiley online library, etc. Only those published articles included in this study contain keywords such as Lean Six Sigma, Blockchain, Operational Excellence, and Industry 4.0 either in the title or abstract. The irrelevant articles, books, conference papers, and papers other than the English language are discarded from the literature. The overall layout of the preliminary integrated model was modeled through the incorporation of the smart contract of Blockchain around the five Define-Measure-Analyze-Improve-Control (DMAIC) steps. Thereafter in the next phase, this preliminary integrated model was revised as per received suggestions from experts globally.

In the second phase, a questionnaire was framed and circulated among a panel of experts to evaluate the reliability of the developed BLSS model. The experts were approached through LinkedIn and/or direct contact with them. During the selection of experts, the following criteria were considered: a) Work as a consultant or academician or manufacturing/service industries; b) Minimum 10 years of experience in industry or academics in LSS/Blockchain/Industry 4.0/OPEX projects. We sent the questionnaire to 40 experts, who agreed to provide their suggestions to validate the developed BLSS model. However, we received the filled responses in the questionnaire from 22 experts only. The geographical details of these experts are shown in Table 2. The suggestions provided by these experts to enhance the robustness of the integrated BLSS model are summarized in Table 3.

Table 2: Geographic details of respondents

Table 3: Experts' suggestions to make a robust integrated BLSS model

A similar validation method (Expert's input) was also adopted in literature to validate the conceptual framework of Green Lean Six Sigma and Industry 4.0 (Kaswan *et al.*, 2023). Overall, the expert's input helps to validate the proposed integrated BLSS model and modify it as per suggestions. Precisely, the experts recommended the amalgamation of the additional features of Blockchain like data provenance, traceability, immutability, finality, etc. with smart contracts at various phases of the LSS project. The practitioners and consultants observed that the developed BLSS model is capable to enhance the transparency in information, and big data handling through smart contracts at each phase of the LSS project in industry.

In the third phase, modification as per the received expert's input has been made and managerial implications are provided with the concluded remarks on the developed BLSS model.

6. Proposed Integrated Blockchain-LSS Model

For manufacturing businesses, it is crucial to uphold quality standards and minimize waste by inefficiencies in the implemented processes. The use of centralized-based systems for data processing and storage results in lengthy transaction execution times and significant operational expenses for businesses. Moreover, industries run by centralized systems lack mutual trust. As a result, a lot of businesses experience waste driven by a lack of trust amongst the involved corporate entities. Blockchain is a decentralized system used for information registration and dissemination that reduces waste by linking entities directly and omitting the need for brokers (Upadhyay *et al.*, 2021). Also, Blockchain provides operational transparency for project teams to validate the resources or information used by the industries, resulting in to increase the value-added services. For example, unnecessary movement of men and material between numerous stations can be overcome through Blockchain, which results in minimizing transportation waste. In this context, Blockchain helps to record the data in an immutable manner as handled and shared among employees. The trusted and registered Oracles can process such records and feed the input to Blockchain about the right data transformed at the right location at the right time to minimize transportation waste. Blockchain has significant potential to restructure the operations and services relevant to auditing and monitoring within manufacturing organizations. Moreover, it reveals a significant role in implementing the LSS approach in manufacturing and/or service sectors for controlling process variations and minimizing waste. Therefore, an integrated model of Blockchain-LSS is proposed in this study which is shown in Figure 4.

Figure 4: Proposed Integrated Blockchain-Lean Six Sigma (BLSS) model

This proposed BLSS model consists of five phases: define, measure, analyze, improve, and control. These five phases were explored by considering the example of manufacturing industries. Initially, the team needs to select the process for beginning the project, and the problem definition is explored according to the process in the existing system. Next, the real-time data and information related to available resources, man, machine, material, etc. are essential to collect for further analysis to extract the root cause of the defined problem. Thereafter, solutions for some common issues i.e. rejection, defect, unnecessary movement, rework, etc. in most of industries have been suggested to the concerned site. In the last stage, the implemented solutions need a close look to be maintained for a longer time. The top management, general manager, and project head can monitor all activity via real-time operation information held at each stage of the project. This operation information exhibits information related to production information, process step information, and available resource information. Production information records the input and output information and available resources information including employee ID, machine name, material bar code, consumable and non-consumable item quantity, lead time, stock availability, and inventory.

In existing practice, the issues in real-time communication and information distribution among the project team and industry personnel often result in poor data availability, failure to quality defects, and increased cost. In contrast, with the proposed BLSS model, real-time available resources status and process information are accessible to all team members, project manager and process owner can monitor whether the project step has been conducted according to the requirements outlined in the contract.

Five stages, namely, define, measure, analyze, improve, and control are included in the blockchain network, and everyone has a copy of the ledger, assessing them to gain information regarding any transaction. Within the network, the details about products, processes, and available resources are viewed as entities, and each transaction represents every step to be followed in the LSS project, including production, transportation, and sale/purchase information at sites. The editing of information at any stage of the project cannot be done until all endorsing peers reach a consensus on its authenticity. Each LSS project member can log in with prime information about the project as well as the organization and its progress status on the blockchain network. The project status and process information are stored in the ledger and can be updated via the smart contract once the validity is admitted. The operation functions are defined in a smart contract that can be invoked by the team and industry concerned person. The blockchain network and smart contracts are detailed in the following sections.

6.1 Information flow in blockchain

In the blockchain model, a new transaction in the form of a block is generated by the members for adding to the blockchain. This new transaction comprises the data related to the sales order, material requirement, production quantity, dispatch date, etc., and the block structure is depicted in Figure 5. The transaction is broadcast across the network for verification and validation. The new block is added to the blockchain, once verified by most of the members. The verified block is disseminated to all members for immutability and transparency. Authentication to all members is provided by using a smart contract that has a set of rules and regulations. It eliminates the risk of the interference of third parties' involvement by allowing authenticated members. This model differs from the existing design of the internet in terms of containing original information and being accessible only to authenticated members. In the design of the internet, the non-value-adding information can move with several copies, whereas in blockchain, only verified and secure information can move after auditing as per the set of rules and regulations (Saberi *et al.*, 2019). Once the information is verified, multiple copies of information are created in terms of decentralization to make a trusty chain.

Figure 5: Flow of information in Blockchain

Decentralization is a significant feature of Blockchain that increases the validity of information by verifying it through each applicant who has access to distributed ledgers (Crosby *et al.*, 2016). If a system or project is not decentralized, then it is difficult to make emergency decisions and make healthy coordination among departments. It also leads to a waste of resources and databases can be hacked, compromised, or collapsed at any time (Francisco and Swanson, 2018). Such issues could be overcome through a decentralized system, where the applicants can see the ledgers and transactions to provide transparency and simultaneously confirm secrecy by protecting ledgers behind cryptography (Queiroz *et al.*, 2019b). Meanwhile, a new generation of transactional entities, which establishes confidence, accountability, and transparency, are controlled through the smart contract. A smart contract is a software program that consists of a set of rules and regulations for conveying terms and actions among members. It verifies automatically the contract terms were met and transactions are carried out (Christidis and Devetsikiotis, 2016).

6.2 Algorithm for smart contract

The blockchain can highlight various product/material dimensions like nature, quality, quantity, location, and ownership. The blockchain removes the need for a trustworthy central organization to operate and maintain the system efficiently by providing accurate information to the project teams as well as top management. The reliability and transparency features of the blockchain are designed to make material and information flow more effective at the measure phase, with automated management requirements. This transformation can lead to a wider transition from a sustainable industrial, commodity, and product economy to an information and personalization economy (Pazaitis *et al.*, 2017). The smart contract plays a prominent role in the blockchain. It is a set of rules recorded in the blockchain which ensures the authentication of the members involved within the system. It encourages data sharing among project members with ultimate continuous process improvement objective transparently. After initialization and registration of the information as a block, the smart contract digitally verifies the LSS project members with their description, location, and role in the project (refer to Table 4).

Table 4: Algorithm for blockchain in proposed BLSS model

7. Discussion on findings

This section provides the answer to set research question of "How organizations can effectively implement blockchain technology in LSS projects for OPEX?" In this study, the proposed BLSS model facilitates organizations in analyzing the unique assets to control waste and enhance quality. In the literature, the existing studies focused on the successful adoption of Blockchain in supply chain management only (Vu *et al.*, 2023). Other side, in the context of the LSS project, the role of Blockchain was explored through a review article for quality enhancement only in the manufacturing and healthcare sectors (Ahmad *et al.*, 2022). However, no one article exists in the literature to show the implementation steps of Blockchain in the LSS project as per the author's best knowledge. This research gap is being occupied by the present study through the proposed BLSS model for OPEX in the industrial sector. The proposed BLSS model consists of five implementation stages as DMAIC with Blockchain features to optimize the process/operation/product design. The first phase exhibits the selection of appropriate projects for continuous improvement by adopting Blockchain features such as immutability, data provenance, and finality. The immutability and data provenance provides non-tempered information through cross-functioning (Goyat *et al.*, 2023). The second phase aims to collect the information related to the selected project/process, where data provenance facilitates the data collection with superior efficiency and accuracy. Also, the data provenance provides validated information via all concerned persons through mutual interaction and agreement (Kamble *et al.*, 2020). The third phase consists of the root cause analysis to identify the most responsible factors for poor performance, where the product/information can be easily tracked through traceability. Further consensus features assist in making a fair and quick decision regarding the proposed solutions to tackle the identified issues in the LSS project.

To implement Blockchain technology effectively in LSS projects within the manufacturing and service industry, organizations must focus on four key activities to optimize OPEX. Initially, organizations must identify the necessity of Blockchain for enhanced product tracking and information authenticity (Casino *et al.*, 2020). Next, a thorough understanding of the technology is essential, followed by the development of relevant solutions (Kamble *et al.*, 2020). Subsequently, the adoption decision should be made after carefully considering both driving and inhibiting factors (Wang *et al.*, 2019). Additionally, it is essential to conduct a pilot study before implementing the full BLSS model in the running system (van Hoek, 2019). Presently, the extensive literature fails to exhibit the intuitions about post-implementation effects, probably due to the dearth of successful initiation of Blockchain in LSS projects.

8. Implications of study

To sustain in the current competitive environment, industrial organizations need to adopt such an emerging approach that provides reliable, faster, and accurate results with transparency and reliability. The present study provides comprehensive knowledge to adopt the BLSS approach through integration measures and conceptual framework. The integration of LSS and blockchain provides logical awareness about the effective utilization of the resources and material that leads to enhanced transparency and traceability of information (Wang *et al.*, 2020). The incorporation of Blockchain technology in the LSS project bridges OPEX theories and Industry 4.0 associated theories such as social-technical interface theory and will influence complex project management/utilization, records management, data handling, and storage. Every data will be transferred, approved, and recorded in a traceable, trusted, and secured manner. Moreover, Smart Contracts will assist and minimize the unnecessary movement of team members as data would be shared automatically among the different sections in the manufacturing industries. Furthermore, data retrieval and analysis will be much faster and more flexible in each phase of the LSS project which will result in more efficient, transparent, and rapid execution of LSS projects in manufacturing industries. The integrated BLSS model facilitates greener deployment of LSS projects through less waste and energy use with more possibility of sustained results and hence less chance of failure. The suggested model will also have positive social implications through the development of a dynamic digital community locally, nationally, and internationally to handle resource-intensive complex LSS projects in a better and more ethical way. This will also promote a paradigm shift in OPEX education suggesting a more innovative approach in the digital era.

In the context of theoretical implication, the present study aims to improve OPEX in the manufacturing environment through the application of the LSS approach with the amalgamation of Blockchain technology. Few studies in the literature propose an integrated model of Blockchain and LSS approach for quality control only in manufacturing and healthcare industries (Ahmad *et al.*, 2022). The existing studies overlooked how the LSS approach with the integration of Blockchain can affect OPEX in manufacturing.

As we know LSS approach is applicable for in-house only and provides significant results within the organizations. However, the proposed BLSS model can connect two or more organizations worldwide by sharing real-time information/data related to sales, purchases, inventory, orders received, orders dispatched, etc. The proposed model also builds a good connection with external partners in the supply chain if it is available in the LSS project practically.

The present research also provides significant scope for researchers by suggesting the new model of LSS which is based on blockchain technology for continuous improvement. Besides, they can implement the BLSS approach with the help of the proposed conceptual framework for solving complex industrial problems in their research work. The proposed framework focuses on improving specific project metrics, defined as a project goal that describes the measures of success. The practitioners can train the project teams through systematic knowledge of the proposed framework with appropriate tools and their linkage. The improvements are being systematically subjected to deployment to quantify key BLSS performance metrics. The workers and supervisors are also being trained on LSS and blockchain, which supported them to participate in BLSS deployment efforts with interest.

9. Conclusion, limitations, and future research direction

In this study, the primary current information on integration among Blockchain and LSS approach are reviewed thoroughly from the existing literature. Thereafter, common features of Blockchain are explored which assist in LSS projects to enhance OPEX in any organization. Further, an integrated model of Blockchain and LSS approach is developed and improved through expert input from academia as well as industry background. Finally, fine-tuning in proposed BLSS model is being done by incorporating expert's suggestions. The final proposed BLSS model is capable to fill the gap between the Blockchain and LSS approach in the manufacturing domain by sharing real-time information with transparency and traceability in each stage of the project. The information may include the team member's name, product detail, process steps, available resources like machine, tool, material, etc. in quantity, operation time, and lead time which are stored in a shared ledger and the LSS project team with industrial persons have permission to access this information at any time. Moreover, the real-time monitoring and control of information in the DMAIC phase can be edited by any project team members and industrial persons, but confirmation is required at each member's end. Once the ledger is verified, no further modification can be done, resulting in better control over the project information and success rate. The proposed BLSS model can increase real-time communications among the section head and enhance the competence of the LSS project.

Despite numerous aids, the present work has its limitations. The integrated BLSS model has been developed and validated through a literature review, and suggestions received from experts belonging to academia and industry background. There is a need to check the efficacy of the proposed model by implementing it in organizations through case studies. Also, future research can be focused on more empirical research towards the investigation of which barriers and success factors have having crucial role in the implementation of the proposed model in various industrial sizes (small, medium, or large industries) under varying economies. This would facilitate the industries for better utilization of their resources while implementing the proposed BLSS model. Moreover, the researchers can mold the steps proposed BLSS framework similarly in the case of other industrial sectors in future research direction.

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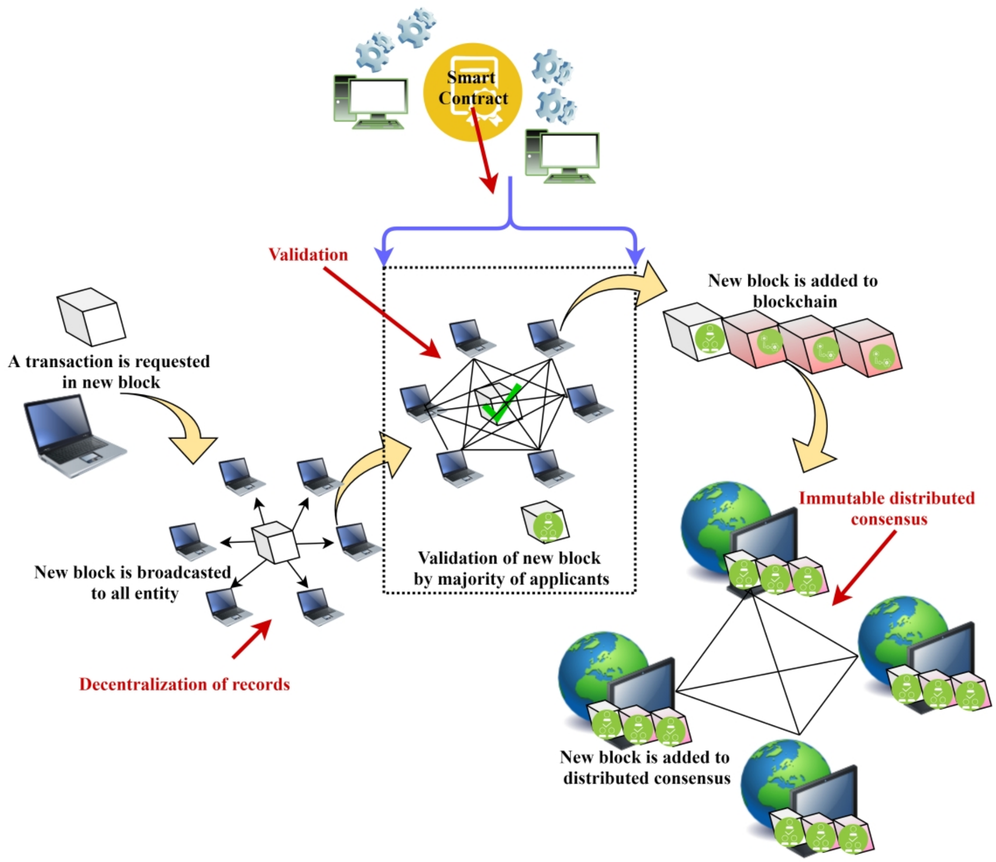

Figure 1

1354x1181mm (72 x 72 DPI)

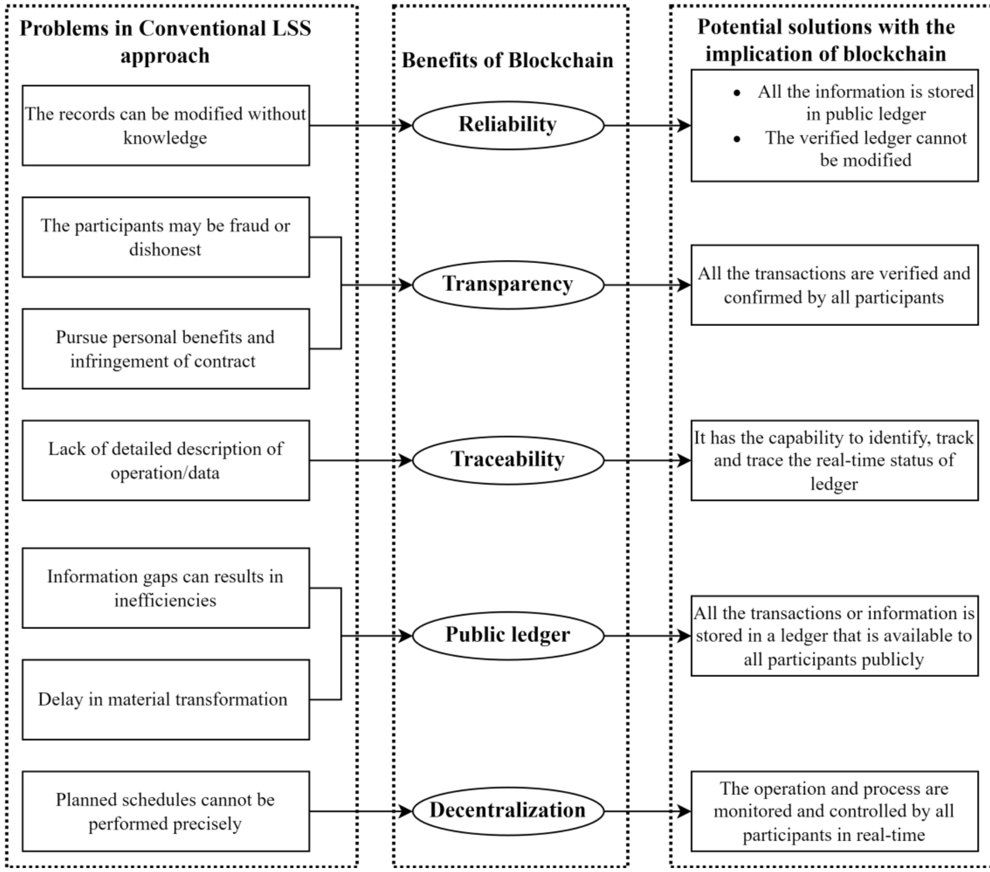

Figure 2

1105x956mm (72 x 72 DPI)

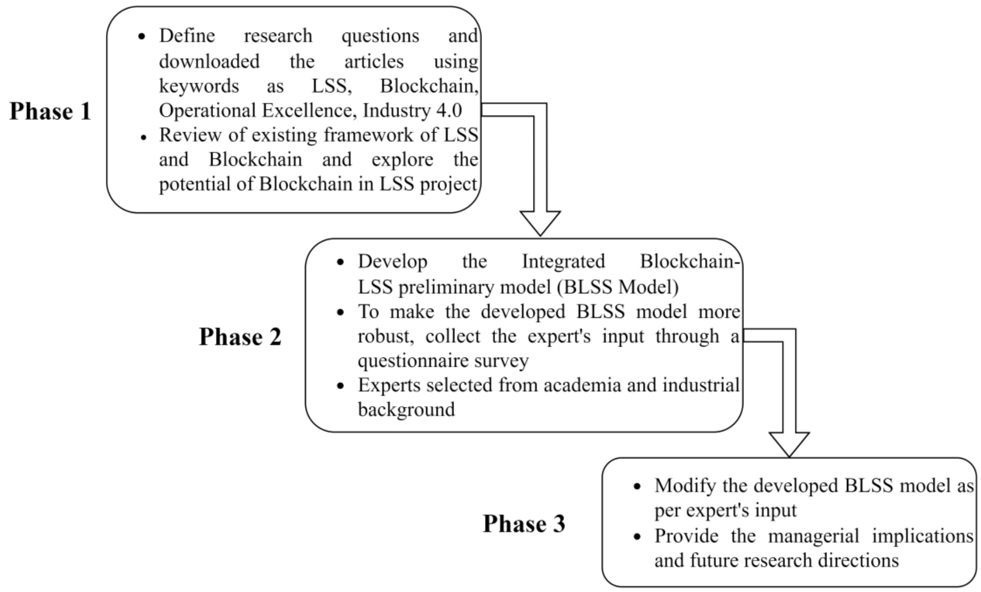

Figure 3

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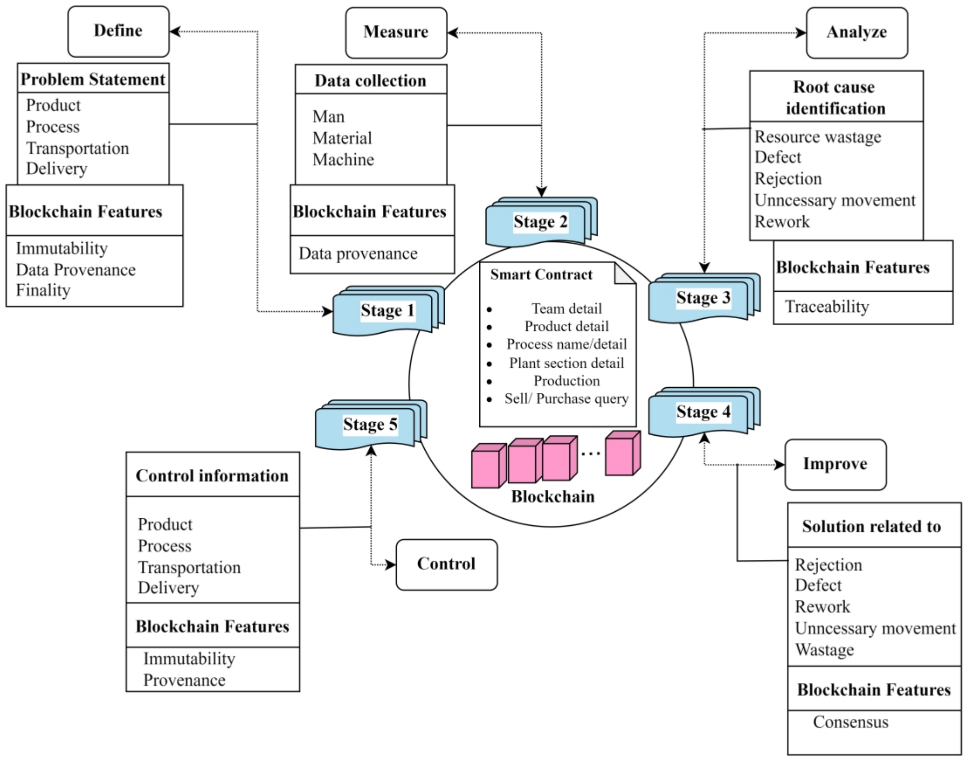

Figure 4

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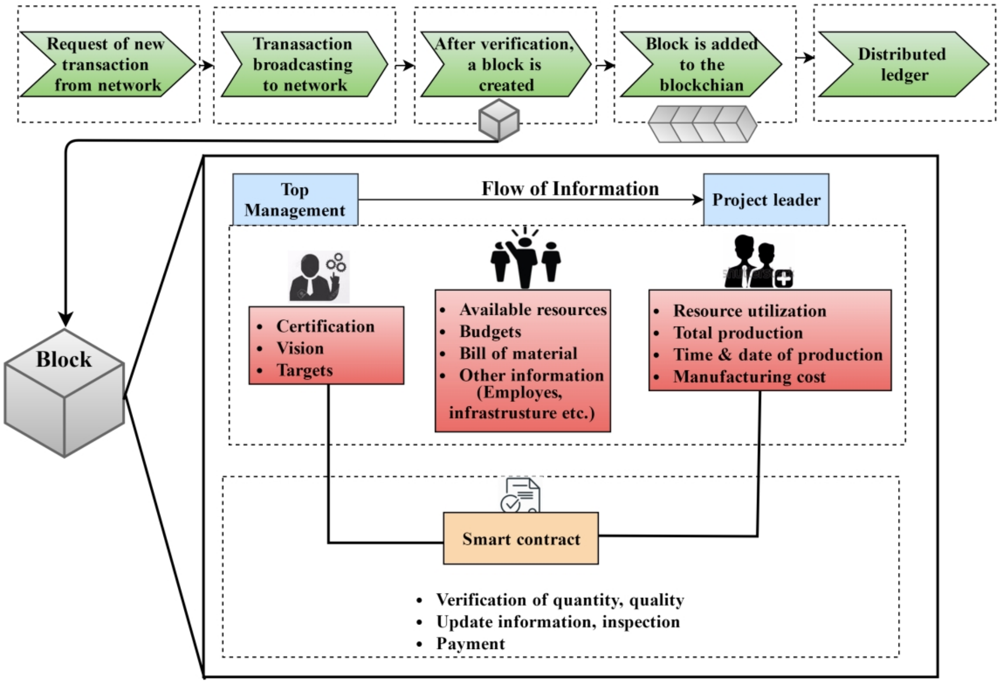

Figure 5

1095x749mm (72 x 72 DPI)

Table 1: Existing framework reviewed to develop integrated model of Blockchain-LSS

Author/ Year	Framework	Addressing problem (pros)	Journal	Shortcoming in the existing framework (cons)
(Kaswan *et al.*, 2023)	Integrated framework of GLSS-Industry 4.0	To mitigate the Emissions control by making processes automated, rationalized and more reactive	*Journal of Manufactruing Technology*	The framework was developed based on conceptual methodology and lacks in traceability and transparency in data storage.
(Jing *et al.*, 2021)	LSS with Theory of Constraint based framework	Improved flow, reduced waste, and increased process capability	*Journal of Quality*	The framework was not exploring the data/information at all stage of project simultaneously.
(Kumar *et al.*, 2021)	DMAIC framework	Rejection rate reduced	*International Journal of Quality and Reliability Management*	The framework fails to provide efficient result during varied culture and pilferage to data.
(Nascimento *et al.*, 2019)	Three-dimensional LSS framework	Reducing waste and material recycling	*International Journal of Lean Six Sigma*	This framework was failed to work during varied culture and more human intervention involved.
(Trehan *et al.*, 2019)	DMAIC framework	Reduce failure of a product	*International Journal of Six Sigma and Competitive Advantage.*	This framework is not linked the data with all stage of project.
(Moya *et al.*, 2019)	LSS framework	Enhancement incapability index of a plant.	*International Journal of Lean Six Sigma.*	This framework is lacking to express the strategy when inefficient record are there in project.
(Sunder M *et al.*, 2019)	LSS framework	Consumer banking	*International Journal of Quality and Reliability Management*	In the adopted framework, the concept of effective resource utilization is missing.
(Prashar, 2018)	LSS framework	Cycle time reduction	*Quality Engineering*	Sustainability, cleaner production aspects are missing from the proposed framework

(Sreedharan V and Sunder M, 2018)	SDMMAIC framework	Reducing internal failure of a product	*Production Planning and Control*	This framework is missing sustainability aspects.
(Yadav *et al.*, 2018)	Barrier framework	Improve the LSS project success rate	*Production Planning and Control*	Just barriers and their solutions tackled in this framework. The data sharing option with all stage of LSS project is missing.
(Sunder M and Antony, 2018)	LSS framework	Improvement Quality excellence	*International Journal of Quality and Reliability Management*	This framework is limited when data is accurate and no diverse regularity policy is there in the system.
(Yadav and Desai, 2017)	LSS Enabler framework	Improve organizational performance	*TQM Journal*	This framework integrates the enablers of LSS using ISM by managerial aspects but fails to link operational facets within it.
(Raval and Kant, 2017)	LSS framework	Literature review	*International Journal of Lean Six Sigma*	The study only summarized the available LSS framework.
(Cherrafi *et al.*, 2017)	Green LSS framework	Improve sustainability performance	*Interantional Journal of Production Research*	This framework was lacking to results in case of inefficient records, unavailability of data at each stage of project.
(Timans *et al.*, 2016)	LSS framework	Enhance organizational performance	*Total Quality Management and Business Excellence*	The study only focus on LSS framework and fails to integrate any sustainability approach.
(Tsironis and Psychogios, 2016)	Multi-factor framework	Improve overall performance	*Business Process Management Journal.*	This framework fails to provide a clear roadmap to LSS execution.
(Garza-Reyes *et al.*, 2016)	LSS framework	Reduction of ship loading commercial time in iron ore	*Production Planning & Control*	This framework was lacking to adopt emerging tools related to Blockchain.

(Garza-Reyes, 2015)	Lean-green Six Sigma framework	Improve organizational performance	*Journal of Cleaner Production*	This framework fails to represents of readiness measure role in LSS execution.
(Hilton and Sohal, 2012)	LSS framework	Continuous improvement	*International Journal of Quality and Reliability Management*	The framework was not exploring any way to represent the data at all stage of project.

Table 2: Geographic details of respondents

Expert	Designation	Country	Years of experience in LSS/Blockchain/OPEX/Industry 4.0
Expert 1	Professor	Australia	20
Expert 2	Senior Lecturer	South Africa	10
Expert 3	General Manager	Oman	18
Expert 4	Consultant	Italy	13
Expert 5	Senior Lean Engineer	India	16
Expert 6	Blockchain Architect	United Kingdom	10
Expert 7	Industrial Engineer	Germany	10
Expert 8	Continuous Improvement Manager	Ireland	16
Expert 9	Deputy General Manager	Italy	25
Expert 10	Senior Engineer	United Kingdom	18
Expert 11	Manager	Germany	21
Expert 12	Professor	India	30
Expert 13	Professor	New Zealand	25
Expert 14	Quality Assurance Engineer	Japan	15
Expert 15	Production Manager	USA	28
Expert 16	Operation Manager	South Africa	24
Expert 17	Plant Director	India	31
Expert 18	Professor	Portugal	22
Expert 19	Manager	China	26
Expert 20	Chief Executive Engineer	Switzerland	23
Expert 21	Consultant	India	14
Expert 22	Professor	United Kingdom	26

Table 3: Experts suggestions to make robust integrated BLSS model

Stages in Integrated BLSS model	Experts Input	Modification made in the model
Stage 1: Define	The developed model logically integrates Blockchain Technology and Lean Six Sigma. Due to its distributed, decentralized ledger Blockchain enables a transparent and highly secure approach for ensuring product quality, and this integrates well with the Lean Six Sigma continuous improvement methodology. It is suggested from experts that define phase should include following blockchain features: immutability, data provenance, finality.	The preliminary BLSS model only consisting the key metrics related to project selection. Further we have included the suggested Blockchain features by the experts in project selection phase. The suggested blockchain features as immutability, data provenance, finality can assist to investigate the requirements of project in the define phase through exploring the trusted data captured of an industry.
Stage 2: Measure	Experts suggested that Measure phase involves more statistical and numerical studies than the define phase. Therefore, in this phase, data provenance feature of Blockchain may relate to data collections.	The preliminary integrated BLSS model was incorporated only smart contract to collect the data. But the suggested feature of Blockchain like data provenance is facilitated in analysing alteration the demand over time in this phase.
Stage 3: Analyze	In this phase, experts guided that to systematically analyze the data, traceability features of blockchain can be used. Moreover, root causes of poor organizational performance need to be estimated through brainstorming session.	We have incorporated the traceability feature of Blockchain with basic features of LSS in the analyze phase of model.
Stage 4: Improve	As per experts' suggestions, data provenance and immutability are prime factors to evaluate the process performance in LSS projects.	The preliminary model did not include such features and later on the expert suggestions, we have incorporated them in improve phase of model.
Stage 5: Control	No changes suggested	No actions taken

Table 4: Algorithm for blockchain in proposed BLSS model

Algorithm 1: Smart contract design

Registration rule for smart contract

Parameters:

Block_Chain: Blockchain

1. Begin: *Check whether the provided system ID exists in blockchain system or not*

*2. **if** (S_ID exist (S_id, Block_Chain)=**true) then***

*\\ **if** the provided system ID exists in blockchain system than return exist*

3. return exist()

4. else

***5. Apply** for registration process (Registration_ S_ID) (S_id, Block_Chain) // Apply the provided system ID with blockchain*

6. end else

7. end if

8. end begin

Authentication rule for smart contract

9. *if* (the provided system ID exists in the blockchain or not)

*(S_ID exist (S_id, Block_Chain)=**true) then***

***10.** Check the authentication detail in the blockchain*

11. if** (all parameters are validated =true) **then

***12.** Authenticated done successfully*

13. else

***14. Return error ()** \\ if authentication is not validated*

15. end else

16. end if

17. end if