QUALITY MANAGEMENT JOURNAL
2023, VOL. 30, NO. 1, 3–15
https://doi.org/10.1080/10686967.2022.2144783

A systematic review of the integration of Industry 4.0 with quality-related operational excellence methodologies

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ABSTRACT

This study examines the common themes for integrating Industry 4.0 with quality-related operational excellence methodologies to provide a comprehensive overview of "what" and "how" to combine them in an initial integration process. In addition, the gaps in the present literature are aggregated, and a research plan for the future is proposed. The study is based on a systematic review of 37 papers published in academic journals between 2015 and 2021. Unlike previous reviews, this study concentrates on the "what" and "how" level of total quality management, Lean Six Sigma, and business process management as quality-related operational excellence methodologies integrated with Industry 4.0 to provide a practical perspective when executing their integration and implementation. Findings indicate a strong technical and data-driven integration focus across the three themes. Furthermore, modes of action as moderators of success were derived as initial variables to be included in quality-driven Industry 4.0 transitions. Identifying gaps in the present literature and defining a research agenda centered on operational principles opens up opportunities for future study with significant practical value.

ARTICLE HISTORY
Received 13 May 2022
Revised 9 August 2022
Accepted 10 August 2022

KEY WORDS
business process management; Industry 4.0; integration; Lean Six Sigma; systematic literature review; total quality management; transformation

Introduction

While quality management (QM) methodologies share a recognized tradition in operations management, Industry 4.0 is considered the next era (Ghobadian and Gallear 1997; Buer et al. 2021). As a customer-focused approach, QM focuses on improving a company's objective and subjective quality to gain competitive advantages (Aquilani et al. 2017). Industry 4.0, on the other hand, introduces high-tech approaches through several software and hardware advancements (Lu 2017).

Only a few manufacturing organizations currently handle all essential components of QM, and enterprises are still stuck in operational excellence (OpEx) transitions (Bloom et al. 2014; Correani et al. 2020). As a result, rather than managing individual transformations, the challenge is combining them (Belhadi, Touriki, and El Fezazi 2017; Buer et al. 2021). Publications concerning QM and Industry 4.0 integrations have increased dramatically since 2016 (Dias, Carvalho, and Sampaio 2022). Prior studies, however, concentrated on the "why" and "what" levels (Chiarini 2020). In contrast, research on practical integration techniques is limited and begins to explain the practical side of integrating QM with Industry 4.0, which is considered the "how" level (Antony et al. 2021; Sader, Husti, and Daroczi 2021).

To address this gap, this study uses a systematic literature review (SLR) to synthesize the existing body of knowledge as a foundation for this new and operational perspective (Tranfield, Denyer, and Smart 2003). In this manner, the "what" level will be linked to the "how" level. Based on the targeted operational contribution, the research questions are: 1) How can businesses execute an integration of QM with Industry 4.0; and 2) What skills, resources, and processes are necessary to do so. Therefore, this study examines literature published in Web of Science, Scopus, and EBSCOhost from the beginning of this

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research stream in 2015 through 2021. This SLR differs from the previous SLR in that it provides a more operational viewpoint that is closely related to practice. A total of 37 articles are examined after applying the SLR stages and quality-related selection criteria. The findings contribute to a comprehensive understanding of how QM and Industry 4.0 integrations may be executed.

The rest of the article is structured as follows. First, the research strategy employed in this study is described. Then the content of selected publications is summarized, followed by a literature review in which outcomes are discussed and further study areas are suggested. Finally, the conclusions are provided.

Methodology

This research aims to support academics and practitioners with a foundation concerning the practical execution of integrating QM with Industry 4.0. SLRs are a proven approach to synthesize a body of knowledge in a high qualitative and replicable way within and outside the study field (Tranfield, Denyer, and Smart 2003; Buer, Strandhagen, and Chan 2018; Danese, Manfè, and Romano 2018). The SLR approach used in this work is based on Tranfield, Denyer, and Smart (2003) and Thomé, Scavarda, and Scavarda (2016), as summarized in Figure 1.

A clear definition of objectives based on the research questions was established in the first phase. This study compiles the state-of-the-art literature that integrates QM with Industry 4.0 on the level of constituent elements. In addition, as a unique contribution, this SLR clarifies the body of knowledge on how integrations may be carried out by distinguishing integration patterns and modes of action.

The scope is defined in contrast to the previous SLR, which took a higher-level approach to this issue. This work demonstrates a desire to uncover a deeper layer of operational integration patterns (Dias, Carvalho, and Sampaio 2022). Previous research on QM-derived metrics and best practices for quality inspection, assurance, control, and more comprehensive methodologies such as total quality management (TQM), which together with Lean Six Sigma (LSS) is considered one of the prevalent themes of this research stream, serves as an initial subset of constituting elements for the operational perspective of this research (Sader, Husti, and Daroczi 2021; Singh and Arora 2022). Because the definition of Industry 4.0 varies depending on the scope, for this research, Industry 4.0 is defined as an integrated, adaptive, optimized, service-oriented, interoperable manufacturing process that is linked to algorithms, big data, and advanced technologies (Lu 2017). Cloud computing, cyber-physical systems (CPS), robots, additive manufacturing, augmented reality, industrial internet of things, and artificial intelligence are all constituent aspects of Industry 4.0, as established by an ABC categorization of citations in scholarly publications (Pacchini et al. 2019).

The scope was then transferred to inclusion and exclusion criteria in accordance with past research. The previously mentioned components of QM and Industry 4.0 were used as the first searching criteria. Four hundred twenty-two papers published in academic journals between January 2015 and July 2021 were discovered during the literature search. This time limit is reasonable, since papers meeting the inclusion and exclusion criteria have not previously been published in the academic databases EBSCOhost, Scopus, and Web of Science. The inclusion and exclusion criteria were used to guide the full-text review screening procedure, which was then cross-evaluated using a text-mining classification algorithm. As a result, a total of 37 articles were considered for full-text review.

Data collection, analysis, and synthesis were completed in the fourth stage. Classic variables such as important study themes, technique, geography, industry, and specialized variables such as integration type influenced data collection throughout the full-text review. NVivo was used for coding, and a second researcher double-checked the results. Based on the coding, the articles were clustered according to their origin, such as TQM. The findings were compared within the defined clusters based on the coding to meet the study aims.

Literature review

General considerations about publications, authors, and journals

The core themes of the literature in integrating QM with Industry 4.0 are presented in this subsection. Publications have risen sharply since 2016. We expect the upward trend to continue as interest in this future-proof topic grows (Antony et al. 2021). Figure 2 shows how the upward trend will be broken owing to the termination of article selection in July 2021.

Contributions from India, Germany, the United Kingdom, Brazil, and Italy, which account for 53 percent of published articles, are driving the upward trend. Articles published in the United States reached a high

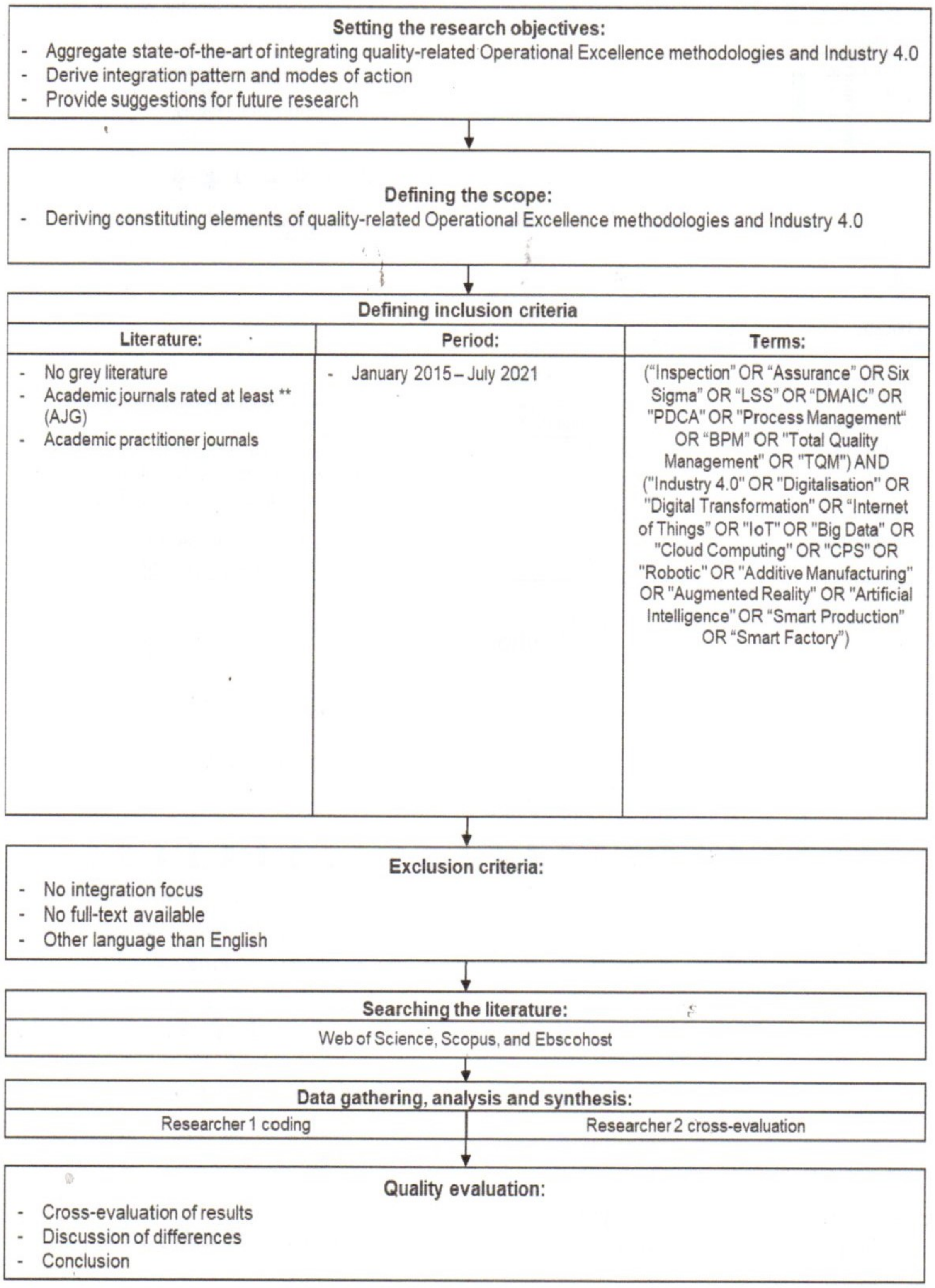

Figure 1. SLR process (Tranfield, Denyer, and Smart 2003; Thomé, Scavarda, and Scavarda 2016).

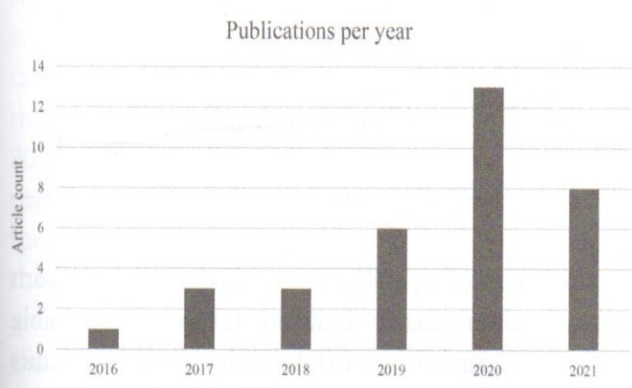

Figure 2. Publications per year.

in 2020, explaining fifth place among contributing nations. Figure 3 lists the publications per country.

The literature on this subject is scattered. Only two authors published more than one paper. The two most prolific writers and their current research emphasis are shown in Table 1.

This SLR detected publications from 22 journals, with five journals accounting for half of all publications. *TQM Journal* and *Business Process Management Journal* account for 15 percent of published articles each, and *Total Quality Management and Business*

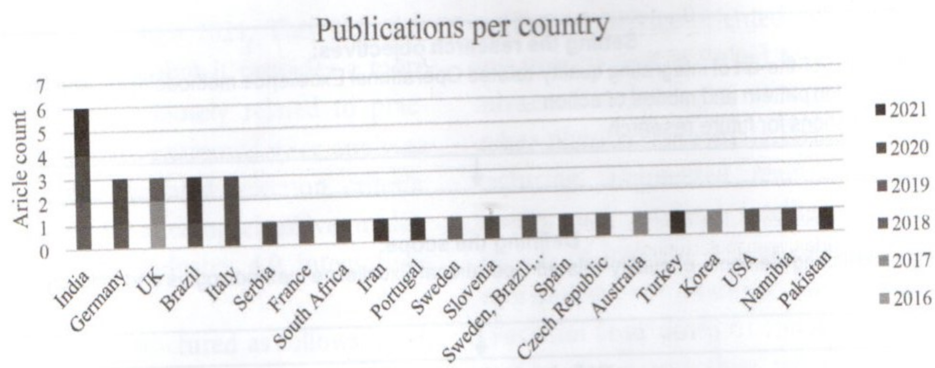

Figure 3. Publications per country.

Table 1. Most prolific authors.

Primary authors	Article count	Topics
Yadav N.	2	Impact of Industry 4.0, LSS, and quality management systems on organizational performance; Critical success factors for LSS in quality 4.0
Mishra S.	2	Automation's human and process characteristics; automation's technological dimensions

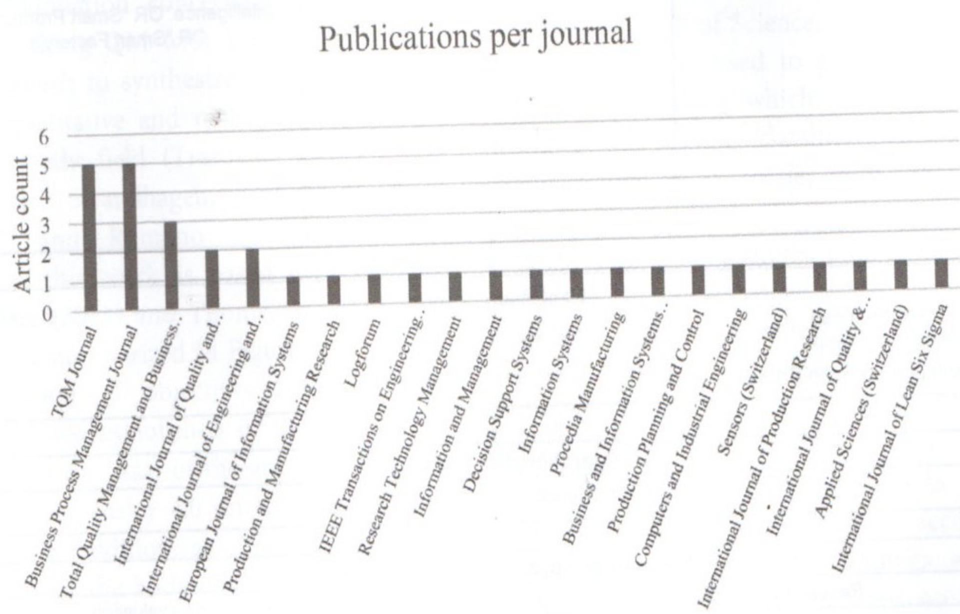

Figure 4. Publications per journal.

Excellence accounts for 9 percent of publications. Figure 4 lists the publications per journal.

Research methodologies

The field of QM and Industry 4.0 integrations is based on empirical and theoretical contributions. While the authors used a variety of approaches, literature reviews (32 percent) are the most common, followed by surveys (21 percent) and case studies (18 percent). Table 2 summarizes the applied methodologies.

A majority of qualitative studies may be predicted due to the current exploratory study stage. Case studies usually drive this stage of research. Nonetheless, the large number of surveys and literature reviews is remarkable in comparison to conclusions drawn from recent developments in Industry 4.0 as a comparable emerging research stream (Edmondson and McManus 2007; Nayernia, Bahemia, and Papagiannidis 2021).

Table 2. Research methodologies.

Methodology	Article count
Literature review	11
Survey	8
Case study	6
Interviews	2
Mixed methods	1
Grounded theory	1
Case study, action research	1
Delphi technique	1
Simulation	1
Action research	1
Ethnography	1

Table 3. Summary of TQM and Industry 4.0 integration.

Integration theme	Core content	Exemplary contributions	Knowledge gaps
Big data and integration	Cloud, IIoT, sensors, RFID, CPS, wireless networks, and automated and enhanced data collection and processing	Chiarini and Kumar (2021); D'Orazio, Messina, and Schiraldi (2020); Rosin et al. (2020); Pagliosa, Tortorella, and Ferreira (2019); Santos et al. (2021)	Concepts for incorporating new techniques into current processes and systems Involved resources and capabilities
Industry 4.0 technologies	Augmented reality, robotics, and additive manufacturing	Chiarini and Kumar (2020); Pagliosa, Tortorella, and Ferreira (2019)	

Themes of integration – what to integrate

Total quality management

TQM is a comprehensive management concept centered on continuous improvement in all aspects of organizations. The seven management concepts of leadership, training, employee relations, quality data and reporting, supplier quality management, product/service design, and process management are typically addressed (Kaynak 2003). This subsection presents prevalent integration themes to compile the present body of knowledge. Table 3 summarizes the essentials of this subsection.

TQM is influenced heavily by Industry 4.0, mainly through automated and increased data collecting and processing, which may be boosted by cloud computing capabilities (D'Orazio, Messina, and Schiraldi 2020). Industrial internet of things (IIoT) is a requirement for accurate data gathering (D'Orazio, Messina, and Schiraldi 2020). This discovery and the importance of IIoT for big data analytics are confirmed by Rosin et al. (2020). Furthermore, the advantages of quality monitoring through extensive records are discussed, and automatic fault rectification or self-optimization becomes conceivable when a cyber-physical system (CPS) is implemented (Buer, Strandhagen, and Chan 2018; Pagliosa, Tortorella, and Ferreira 2019). Higher data availability and automated real-time processing improve failure detection and lead time to potential root cause investigation (D'Orazio, Messina, and Schiraldi 2020). TQM can also be supported by use cases of failure avoidance using machine learning approaches with visual recognition systems (D'Orazio, Messina, and Schiraldi 2020). Other writers consider radio frequency identification (RFID) because of its capacity for real-time data capturing, which improves the identification of process problems (Anosike et al. 2021). Furthermore, wireless sensor networks and middleware can improve data collection because of their interconnection. Santos et al. (2021) summarize these findings by stating that data collection and integration are used to monitor and regulate quality (Santos et al. 2021). Chiarini and Kumar (2021) validated these findings within multiple case studies.

A separate research stream reviews the incorporation of specific Industry 4.0 technologies, such as robots, augmented reality, and additive manufacturing (Chiarini and Kumar 2021; Pagliosa, Tortorella, and Ferreira 2019). Advanced robotics eliminate faults, improve precision and accuracy, automate testing and inspections, and allow collaboration with operators (Pagliosa, Tortorella, and Ferreira 2019). In the event of a failure, additive manufacturing can assist in repairing damaged components or improving production processes such as machining and welding (Pagliosa, Tortorella, and Ferreira 2019). Finally, augmented reality applications may assist with workstation troubleshooting (Pagliosa, Tortorella, and Ferreira 2019). In this case, augmented reality can be considered a poka-yoke, especially during assembly and logistical tasks like picking, where employees must manage crucial product qualities or undertake essential quality procedures (Chiarini and Kumar 2021).

In conclusion, combining data collecting and processing for quality control and preventive measures is a key component of TQM and Industry 4.0 integration (D'Orazio, Messina, and Schiraldi 2020). In addition, specialized technologies are assessed and integrated into quality management strategies (Chiarini and Kumar 2021). In contrast to the widely held comprehensive view of TQM, it may be stated that soft elements and concepts for practical implementation are currently scarce (Kaynak 2003). Further exploratory research focusing on soft aspects and modes of action may improve the likelihood of successful integrations.

Lean Six Sigma

LSS originally is a systematic strategy used by improvement specialists to enhance organizational performance and accomplish strategic goals by minimizing variance in processes (Schroeder et al. 2008). Furthermore, LSS intends to maximize shareholders' value by addressing costs, speed, quality, and customer satisfaction by merging lean and Six Sigma approaches (Laureani and Antony 2012; Fonseca and Domingues 2018). While the integration of LSS with Industry 4.0 has not yet been fully explored, it is

Table 4. Summary of LSS and I4.0 integration.

Integration theme	Core content	Exemplary contributions	Knowledge gaps
The use of big data in LSS projects	Big data, real-time data, IIoT, sensors, linking multiple systems, RFID tags, or condition monitoring, new analytical capabilities,	Antony et al. (2019); Ganjavi and Fazlollahtabar (2021); Santos et al. (2021)	Limited sample sizes in terms of regions and firm sizes, mostly manufacturing; integration of LSS with Industry 4.0
Integration of Industry 4.0 features and DMAIC stages in LSS projects; Algorithms and machine learning in LSS projects	integration, architectures (e.g., RAMI 4.0), modification of ERP/MES/ SCADA systems, PDM/PLM	Chiarini and Kumar (2021)	Investigate when Industry 4.0 and LSS should be integrated; investigate the skills that LSS practitioners should develop
As part of a holistic management system: LSS, Industry 4.0, and TQM; New success factors	Employee adaptability (change readiness), cross-functional understanding, and technological affinity, as well as decision-making kinds, knowledge worker availability, and social interaction	Ganjavi and Fazlollahtabar (2021); Yadav, Shankar, and Singh (2021)	Creating a hierarchical link between new success criteria

thought to be one of the upcoming vital issues. Table 4 aggregates the essentials of this subsection.

In general, big data integration in LSS is one of the most popular measures among prevalent contributors (Antony et al. 2019; Yadav, Shankar, and Singh 2021). This is concretized by further publications, as the inclusion of extensive data, or real-time data, may be achieved by IIoT, the use of sensors, possibly at each manufacturing stage, or by linking multiple systems (Ganjavi and Fazlollahtabar 2021; Santos et al. 2021). The substantial data collection might lead to previously unseen quality insights or preventive process changes. As a result, exact recording of product states and physical locations via RFID tags or monitoring conditions, such as vibration, pressures, and temperature, are possible LSS analysis variables (Chiarini and Kumar 2021; Ganjavi and Fazlollahtabar 2021). Finally, if LSS can build on CPS, a horizontal/vertical integration will allow even more quality-related data to be collected. These can be shared from machines to operators across different shifts, as demonstrated by Ganjavi and Fazlollahtabar (2021). Furthermore, the authors confirmed that big data improves LSS by including simulation in the design of experiments to reduce physical trial runs.

Aside from big data, LSS is a data-driven strategy that includes statistical analysis, which may be automated or advanced by developing software, algorithms, and machine learning models (Chiarini and Kumar 2021). Traditional LSS systems may become overburdened due to additional process data streams. Other authors empirically verified the utility of machine learning models, such as decision tree algorithms (Giannetti and Ransing 2016). Chiarini and Kumar (2021) derived an initial allocation of Industry 4.0 elements integrated with LSS, as shown in Table 5.

LSS may be regarded as a management system component that includes TQM when viewed as its whole. Quality 4.0 and Industry 4.0 integration result

Table 5. Allocation of Industry 4.0 elements to DMAIC (Chiarini and Kumar 2021).

I4.0 elements	LSS DMAIC phases
MES/SCADA	Define-Measure-Control
PDM/PLM	Define-Measure-Control
Big data collection and analytics	Measure-Analyze-Improve
AI and machine learning	Define-Measure-Analyze-Improve-Control
3D printing, additive manufacturing	Improve
Smart products and customer interaction	Measure-Analyze-Improve-Control
RFID	Measure-Control
Smart sensors	Measure-Control
Collaborative and Autonomous Mobile Robots	Improve
AR and Smart Human Interfaces	Measure-Analyze-Improve-Control

in a more significant performance boost than single-effect assessments (Yadav, Shankar, and Singh 2020). Research derived operational aspects such as collaboration with external agencies, participation in business excellence awards, key performance indicator (KPI)-based benchmarking, a continuous improvement culture, and training of internal consultants as success factors (Yadav, Shankar, and Singh 2021). Only slight overlaps occur compared to Antony et al. (2019), who derived classical LSS success factors highlighting the changing needs of Industry 4.0 integrations. However, earlier success factors remain relevant (Antony et al. 2019; Yadav, Shankar, and Singh 2021). Further details are provided by Bhat, Bhat, and Gijo (2021), who discuss the sociotechnical elements of decision-making styles, knowledge worker availability, social interaction, and the socio-cultural variables of employee adaptiveness, cross-functional understanding, and technological affinity. Because both contributions to CSF are experimentally based, further research is required to reach a scholarly consensus.

Table 6. Summary of BPM and Industry 4.0 integration.

Integration theme	Core content	Exemplary contributions	Knowledge gaps
BPM as an integration moderator	Process modeling, ERP, and MES integration	Xu, Xu, and Li (2018); Pagliosa, Tortorella, and Ferreira (2019); Rey et al. (2021); Santos et al. (2021)	Integrating diverse models into a unified framework for vertical and horizontal process integration
Process automation and workflow management	Workflow management software, automation software (Celonis, Ulpath), ERP connectivity, and standardized/flexible procedures	van der Aalst, Bichler, and Heinzl (2018); Xu, Xu, and Li (2018); Mishra, Sree Devi, and Badri Narayanan (2019a); Mishra, Sree Devi, and Badri Narayanan (2019b)	
Process mining and optimization	Data gathering, simulation	Pagliosa, Tortorella, and Ferreira (2019); Tran, Ruppert, and Abonyi (2021)	Concepts of operationalization
Agile BPM	Processes that are adaptable for rapid and continual development	Sehlin, Truedsson, and Cronemyr (2019); Baiyere, Salmela, and Tapanainen (2020)	Methods for adaptive process modeling, infrastructure flexibility, actor capabilities, and generalization

Finally, Ganjavi and Fazlollahtabar (2021) provide insights on operationalization routines. Problems in processes should be instantly alerted to responsible operators, who should then begin root cause problem-solving based on recent information and data. Furthermore, the authors concluded that rules must be carefully constructed according to the range of freedom for independent judgements in autonomous machines and preventive models.

In conclusion, the field of LSS and Industry 4.0 integration research is based on experimentally validated findings, and industry-related applications highlight the value of combining LSS and Industry 4.0. Operational modalities and sociotechnical and sociocultural factors also provide insight into merging LSS with Industry 4.0. Furthermore, governance mechanisms were mentioned as being essential but remain vague.

Business Process Management

Business process management (BPM) helps businesses analyze and improve their processes, which are constituted of dynamically coordinated activities or tasks performed in a sequential order to deliver value (Trkman 2010). The essentials of this subsection are aggregated in Table 6.

Xu, Xu, and Li (2018) compiled a basis for integrating BPM and Industry 4.0 based on an SLR. The authors consider BPM a vital feature of Industry 4.0 since it allows for the orchestration of processes in end-to-end integration. The authors argue that this is required for future Industry 4.0 aspects such as artificial intelligence, machine learning, or cloud computing. Fischer et al. (2020) verified the use of BPM to establish digital transformation foundations and capabilities, such as modeled processes or employee awareness. Furthermore, Rey et al. (2021) illustrated the use of BPM and the notation of BPMN V2 in one case study of co-working robots being integrated physically and digitally through a BPM suite. The virtual integration comprises a manufacturing execution system (MES), a navigation system, and sensor-based operator identification (Rey et al. 2021). Further authors support the importance of BPM in Industry 4.0 integrations such as CPS and the inclusion of other Industry 4.0 aspects like e-kanbans, real-time data collection, and advanced HMI (Sanders, Elangeswaran, and Wulfsberg 2016; Pagliosa, Tortorella, and Ferreira 2019). The authors conclude that thorough business processes constitute a necessary basis (Sanders, Elangeswaran, and Wulfsberg 2016; Pagliosa, Tortorella, and Ferreira 2019).

Aside from integration, Xu, Xu, and Li (2018) identified workflow management as a prominent subject for process monitoring, control, and optimization. Based on a cross-industry study, Mishra, Sree Devi, and Badri Narayanan (2019a) identified robotic process automation (RPA) as a prominent integration topic. RPA automates process executions based on earlier simplification, standardization, and reengineering efforts (van der Aalst, Bichler, and Heinzl 2018). The study proposes that RPA may be used for processes that are likely to stay constant and require process modifications to be made without considerable coding capabilities (Mishra, Sree Devi, and Badri Narayanan 2019a). Additional issues such as cultural and behavioral change require expenditures in creating digital capabilities. Early deployment should focus on procedures where people operate like robots (Mishra, Sree Devi, and Badri Narayanan 2019b). For example, successful applications examine the use of RPA in master data management (Radke, Dang, and Tan 2020).

In contrast to RPA, which addresses rigid process modeling for automation, Baiyere, Salmela, and Tapanainen (2020) used ethnography to derive so-

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Table 7. Modes of action in integrating QM with Industry 4.0.

Cluster	Core content
Implementation strategies	Problem-solving methodologies (e.g., PDCA, DMAIC), Industry 4.0 implementation on a point-by-point basis, pilot-based approaches
Barriers	Financial constraints, a lack of management support, a lack of awareness, hesitant behavior, digitalization or automation of wasteful activities, technological complexity introduced to shopfloor processes, lack of resources and competencies, time, data quality, digital knowledge and skills, governance structures
Success factors	Behavioral and cultural change, leadership support, interfunctional team development, training activities, employee involvement and empowerment, process changes without advanced coding skills, balance between process modeling and flexibility, efficient and reliable data warehouse systems, data gathering and storage resources, computational power, resource availability, management competence
Capabilities	Organization: Organizational structures of ambidexterity, adaptability, and agility, innovation/continuous improvement culture, data-driven decision-making, increased communication from and to workers, supportive learning environment and leadership style, employee awareness Resources: Automatic data gathering and analysis, process modeling and notations (e.g., BPMN) vs light touch processes, infrastructural flexibility, profound business processes, network integration, interoperability, orchestrate ability, retrofit-ability of machines, preparation/availability of digitally experienced managers, workforce transformation (development vs recruiting), cross-functional team composition, processes for balancing exploitation and exploration Capabilities: Coding/software development, data-based and complex problem solving, data science, algorithm operationalization, data/process mining, digitalization/IT, simulation, BPM-related skills, data protection and IT security, production technologies, modern interfaces, routines for integrating, reconfiguring external and internal competencies and resources, readiness of technologies, processes, and people

called light touch processes, infrastructural flexibility, and the need for attentive rather than procedural actors as development routes in light of Industry 4.0 integration. Contrary predictions for the future of BPM include repurposing resources to boost adaptability, considerable experimentation, and ambidexterity (Baiyere, Salmela, and Tapanainen 2020). As a result, the balance between process modeling and flexibility has to be explored further.

In addition to RPA, process mining may be derived as an integration subject (Tran, Ruppert, and Abonyi 2021). Process mining examines as-is process flow using data, for example, acquired from MES, and potentially enhanced process monitoring (Tran, Ruppert, and Abonyi 2021). The authors indicate that data gathering based on process mining or querying is one of the advantages of integration (Sanders, Elangeswaran, and Wulfsberg 2016; Polyvyanyy et al. 2017; Tortorella et al. 2020). The quality of information is determined by the rate of integration and the transparency of process executions (Polyvyanyy et al. 2017). This subject may be expanded to include big data analytics and process simulation methodologies (Queiroz et al. 2020; Pagliosa, Tortorella, and Ferreira 2019).

Concerning requirements for integration, the authors derived characteristics for engaging resources like IT skills, particularly data science (Queiroz et al. 2020). Resources must be adapted, necessitating recruiting BPM-related skills, such as organizational and process understanding, IT security and data protection, IT expertise, production technologies, modern interfaces, and problem-solving (Kazancoglu and Ozkan-Ozen 2018). Rather than particular skillsets, Sjödin et al. (2018) identified company culture, digitalization capabilities, and the capacity to include external talents as integration moderators. In contrast, other authors emphasize cross-functional interaction and re-learning paths for personnel (van der Aalst, Bichler, and Heinzl 2018; Radke, Dang, and Tan 2020). Finally, strong change management and governance are critical factors (Mishra, Sree Devi, and Badri Narayanan 2019a; Mishra, Sree Devi, and Badri Narayanan 2019b; Radke, Dang, and Tan 2020).

In brief, the role of BPM in Industry 4.0 integrations presents a contrarian viewpoint, with classic and less flexible BPM techniques being slowly developed or novel ways based on aware actors and so-called light touch processes being introduced (van der Aalst, Bichler, and Heinzl 2018; Baiyere, Salmela, and Tapanainen 2020). A conclusion on these two seemingly opposing techniques will take further investigation and may depend on a company's circumstances. Furthermore, implementation methods and required skillsets were obtained, allowing the potential for future research to derive more thorough perspectives aimed at operationalizing or generalizing best practices.

Modes of action – how to integrate

Research is beginning to uncover how businesses modify their processes and routines to integrate QM with Industry 4.0 (Buer et al. 2021; Collis and Anand 2021).

Based on the articles covered by this SLR, four clusters were identified through inductive coding with relevance to how integrations can be executed:

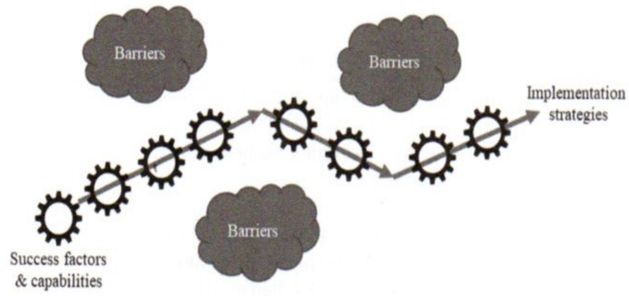

Figure 5. Integration process.

implementation strategies, barriers, success factors, and capabilities. Table 7 aggregates these findings.

The derived modes of action synthesize implementation strategies, success factors, and resources and capabilities. In terms of implementation models, there is no consensus in the literature, and most models represent the authors' first perspective, as expressed by themselves (Sony 2020). By contrasting these initial models, an iterative procedure can be derived at the most basic level of academic agreement. As a result, businesses grow from novice to intermediate to advanced integration levels with increasing technological complexity (Chiarini 2020; Chiarini and Kumar 2021). Further exploratory research is required to derive concrete implementation pathways, such as the sand cone model for lean management (Bortolotti et al. 2015).

Furthermore, the most agreed finding concerning resources and competencies seems to be a lack of managerial and staff digital knowledge (Gfrerer et al. 2021). This follows a natural logic, since businesses have been involved in quality-driven transitions for decades, and it might be related to the critical discovery that Industry 4.0 limits people's participation due to its technological complexity. However, pathways to overcome this integration barrier will require further inquiry and research-derived foundational factors to be elaborated on.

Dynamic capabilities (DC) theory broadly intends to explain sustainable organizational development (Collis and Anand 2021). If contrasted with the concept of DC, the findings can be transferred to an integration process. Fundamentally, the derived success factors and capabilities may be understood as gear wheels of implementation strategies, allowing to navigate around barriers in an iterative way (Teece 2018). Figure 5 summarizes this basic understanding as a foundation for further explication in future research.

Discussion and future research

This SLR aims to provide a practical perspective by synthesizing the "what" and "how" of integrating QM with Industry 4.0 to enrich the literature base with specific references for practitioners seeking practical and applicable solutions. First, since 2016, the number of articles published on integrating QM with Industry 4.0 has risen substantially, with 34 articles included in this SLR and two-thirds of publications published during 2020 and 2021. These figures demonstrate the rising importance for academics and business people.

Second, the results of this SLR establish a relationship between integration themes (what) and modes of action (how). This operational perspective is a unique contribution with more practical value since it enables actual change, which cannot be accomplished without addressing the how level. It also responds to recent research requests by pooling the operational integration level knowledge base (Chiarini 2020; Dias, Carvalho, and Sampaio 2022). Previous research established different perspectives, for example, by relating excellence models of EFQM 2020 or QM models of ISO 9001:2015 to Industry 4.0 integrations. In common seems the knowledge gap of practical guidelines to inform an execution, especially in the face of requirements of specific organizations (Fonseca, Amaral, and Oliveira 2021; Murthy, Sangwan, and Narahari 2021; Fonseca et al. 2022). Future research could build on practical perspectives, as outlined in this article by combining with research on excellence models or QM norms to offer a more holistic approach from strategic to operational levels.

Additionally, soft elements and operational integration strategies, in particular, are underrepresented in the reflection of the holistic concept of TQM (Kaynak 2003; Sader, Husti, and Daroczi 2021). Furthermore, the considered Industry 4.0's aspects demonstrate a tendency toward advanced technology applications and an underrepresentation of enterprise architectures or horizontal/vertical integration (Frank, Dalenogare, and Ayala 2019; Yli-Ojanperä et al. 2019). This discovery is essential due to its significant role in Industry 4.0 transformations (Liao and Wang 2021).

Third, while academic research has covered much ground in explaining the what of integrating QM with Industry 4.0, contributions at the how-level remain few. The benefits of data-driven techniques, such as big data analysis, algorithms, or simulation, are frequently mentioned, but how to realize them remains vague. As a result, this SLR provides a new and more practical perspective by explicating clusters for paths of concurrent integrations. However, the contribution must be elaborated to derive weighted and sequential paths.

Finally, while each subsection highlighted knowledge gaps for the integration subjects, the key knowledge gaps discovered by this SLR from an operational viewpoint are summarized in Table 8.

Table 8. Future research opportunities.

Focus	Gap/limitation	Future research opportunities
What	Primarily higher-level concepts and less reflecting process and routine adaptations, limited sample sizes, manufacturing focus, not all constituting elements (e.g., TQM) reflected yet	Expand research status and further explore the integration of QM and Industry 4.0 on the level of its constituting elements; Including soft aspects
How	Lack of generalization, only vague frameworks/ operational concepts for executing an integration	Explore integration pathways, expand modes of action, involved resources, processes, and capabilities in concrete frameworks

Conclusions and limitations

This SLR examines the existing body of knowledge on integrating QM with Industry 4.0. As a result, a relationship is formed between what aspects organizations should integrate and how integrations may be carried out. According to the findings, integrations do not currently cover the fundamental components of QM and Industry 4.0. For example, the present literature base does not adequately capture the importance of enterprise architectures as constituent aspects of Industry 4.0. Significant operational gaps have been observed with respect to how organizations may implement QM and Industry 4.0 integrations. Initial contributions assess the importance of resources, skills, and implementation models, but complete assessments of enabling procedures, routines, and advantageous implementation sequences require more explication and evaluation.

This research contributes to theory by presenting a holistic view of QM and Industry 4.0 integrations. Second, by explicating resources, capabilities, and other characteristics of how integrations may be carried out, it is a starting point for future investigations. Qualitative research might address this using a theoretical lens such as DC. In terms of a practical contribution, this research offers a new perspective of a red thread that spans from what organizations can do to how they can do it. Based on the aggregated modes of action, practitioners can integrate these aspects within their integration processes and increase the likelihood of success.

This research has significant limitations. First, due to the search criteria and databases employed, potentially valuable studies might be not considered. Second, only English literature published in high ranking and practitioner journals was taken into account. Furthermore, because this SLR focused on integrating QM and Industry 4.0, only scholarly works that explored both paradigms were evaluated, and transferrable ideas from research focusing on either QM or Industry 4.0 were excluded.

Because of the apparent knowledge gaps, the authors plan to contribute through a mixed-methods study focusing on how manufacturing companies may execute concurrent integrations.

Disclosure statement

No potential conflict of interest was reported by the authors.

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