**A systematic review of the integration of Industry 4.0 with quality-related Operational Excellence methodologies**

**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 centred on operational principles opens up opportunities for future study with significant practical value.

**Keywords:** Industry 4.0, Total Quality Management, Lean Six Sigma, Business Process Management, Integration, Transformation, Systematic Literature Review

**Paper type:** Literature review

# Introduction

While Quality Management (QM) methodologies share a recognised tradition in Operations Management, Industry 4.0 (I4.0) is considered the next era ([Ghobadian and Gallear, 1997](#_ENREF_27); [Buer *et al.*, 2021](#_ENREF_10)). As a customer-focused approach, QM focuses on improving a company’s objective and subjective quality to gain competitive advantages ([Aquilani *et al.*, 2017](#_ENREF_4)). I4.0, on the other hand, introduces high-tech approaches through several soft- and hardware advancements ([Lu, 2017](#_ENREF_33)).

Only a few manufacturing organisations currently handle all essential components of QM, and enterprises are still stuck in Operational Excellence (OpEx) transitions ([Bloom *et al.*, 2014](#_ENREF_8); [Correani *et al.*, 2020](#_ENREF_15)). As a result, rather than managing individual transformations, the challenge is combining them ([Belhadi *et al.*, 2017](#_ENREF_6); [Buer *et al.*, 2021](#_ENREF_10)). Publications concerning QM and I4.0 integrations have increased dramatically since 2016 ([Dias *et al.*, 2021](#_ENREF_18)). Prior studies, however, concentrated on the ‘why’ and ‘what’ levels ([Chiarini, 2020](#_ENREF_12)). In contrast, research on practical integration techniques is limited and begins to explain the practical side of integrating QM with I4.0, which is considered the ‘how’ level ([Antony *et al.*, 2021](#_ENREF_3); [Sader *et al.*, 2021](#_ENREF_45)).

To address this gap, this study will use a systematic literature review (SLR) to synthesise the existing body of knowledge as a foundation for this new and operational perspective ([Tranfield *et al.*, 2003](#_ENREF_57)). 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 I4.0, 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 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 I4.0 integrations may be executed.

The rest of the paper is structured as follows. Section 2 describes the research strategy employed in this study. Section 3 summarises the content of selected publications. The literature review outcomes are discussed in Section 4, and further study areas are suggested. In section 5, the conclusions are provided.

# Methodology

This research aims to support academics and practitioners with a foundation concerning the practical execution of integrating QM with I4.0. SLRs are a proven approach to synthesise a body of knowledge in a high qualitative and replicable way within and outside the study field ([Tranfield *et al.*, 2003](#_ENREF_57); [Buer *et al.*, 2018](#_ENREF_11); [Danese *et al.*, 2018](#_ENREF_17)). The SLR approach used in this work is based on [Tranfield *et al.* (2003)](#_ENREF_57) and [Thomé *et al.* (2016)](#_ENREF_54), as summarised in Figure 1.



Figure 1. SLR process ([Tranfield *et al.*, 2003](#_ENREF_57); [Thomé *et al.*, 2016](#_ENREF_54))

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 I4.0 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 *et al.*, 2021](#_ENREF_18)). 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 *et al.*, 2021](#_ENREF_45); [Singh and Arora, 2022](#_ENREF_50)). Because the definition of I4.0 varies depending on the scope, for this research, I4.0 is defined as an integrated, adaptive, optimized, service-oriented, interoperable manufacturing process that is linked to algorithms, big data, and advanced technologies ([Lu, 2017](#_ENREF_33)). Cloud computing, cyber-physical systems (CPS), robots, additive manufacturing, augmented reality, industrial internet of things, and artificial intelligence are all constituent aspects of I4.0, as established by an ABC categorisation of citations in scholarly publications ([Pacchini *et al.*, 2019](#_ENREF_38)).

The scope was then transferred to inclusion and exclusion criteria in accordance with past research. The previously mentioned components of QM and I4.0 were used as the first searching criteria. 422 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 are 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 specialised variables such as integration type influenced data collecting 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 I4.0 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](#_ENREF_3)). Figure 2 shows how the upward trend will be broken owing to the termination of article selection in July 2021.

Figure 2. Publications per year

Contributions from India, Germany, the United Kingdom, Brazil, and Italy, which account for 53% of published articles, are driving the upward trend. Articles published in the United States reach a high in 2020, explaining fifth place among contributing nations. Figure 3 lists the publications per country.

Figure 3. Publications per country

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

Table 1. Most prolific authors

|  |  |  |
| --- | --- | --- |
| Primary authors | Article count | Topics |
| Yadav N. | 2 | Impact of I4.0, Lean Six Sigma, and quality management systems on organisational performance; Critical success factors for Lean Six Sigma in quality 4.0 |
| Mishra S. | 2 | Automation's human and process characteristics; automation's technological dimensions |

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% of published articles each, and Total Quality Management and Business Excellence account for 9% of publications. Figure 4 lists the publications per journal.

Figure 4. Publications per journal

## Research methodologies

The field of QM and I4.0 integrations is based on empirical and theoretical contributions. While the authors used a variety of approaches, literature reviews (32%) are the most common, followed by surveys (21%) and case studies (18%). Table 2 summarises the applied methodologies.

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 |

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 I4.0 as a comparable emerging research stream ([Edmondson and McManus, 2007](#_ENREF_19); [Nayernia *et al.*, 2021](#_ENREF_37)).

## Themes of integration - what to integrate

### Total Quality Management

TQM is a comprehensive management concept centred on continuous improvement in all aspects of organisations. 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](#_ENREF_29)). This subsection presents prevalent integration themes to compile the present body of knowledge. Table 3 summarises the essentials of this subsection.

Table 3. Summary of TQM and I4.0 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 (2020)](#_ENREF_13); [D'Orazio *et al.* (2020)](#_ENREF_16); [Rosin *et al.* (2020)](#_ENREF_44); [Pagliosa *et al.* (2021)](#_ENREF_39); [Santos *et al.* (2021)](#_ENREF_47) | Concepts for incorporating new techniques into current processes and systems;  Involved resources and capabilities |
| I4.0 technologies | Augmented reality, robotics, and additive manufacturing | [Chiarini and Kumar (2020)](#_ENREF_13); [Pagliosa *et al.* (2021)](#_ENREF_39) |

TQM is influenced heavily by I4.0, mainly through automated and increased data collecting and processing, which may be boosted by cloud computing capabilities ([D'Orazio *et al.*, 2020](#_ENREF_16)). IIoT is a requirement for accurate data gathering ([D'Orazio *et al.*, 2020](#_ENREF_16)). This discovery and the importance of IIoT for big data analytics are confirmed by [Rosin *et al.* (2020)](#_ENREF_44). Furthermore, the advantages of quality monitoring through extensive records are discussed, and automatic fault rectification or self-optimisation becomes conceivable when a CPS is implemented ([Buer *et al.*, 2018](#_ENREF_11); [Pagliosa *et al.*, 2021](#_ENREF_39)). Higher data availability and automated real-time processing improve failure detection and lead time to potential root cause investigation ([D'Orazio *et al.*, 2020](#_ENREF_16)). TQM can also be supported by use cases of failure avoidance using machine learning approaches with visual recognition systems ([D'Orazio *et al.*, 2020](#_ENREF_16)). Other writers consider RFID because of its capacity for real-time data capturing, which improves the identification of process problems ([Anosike *et al.*, 2021](#_ENREF_1)). Furthermore, wireless sensor networks and middleware can improve data collection because of their interconnection. [Santos *et al.* (2021)](#_ENREF_47) summarise these findings by stating that data collection and integration are used to monitor and regulate quality ([Santos *et al.*, 2021](#_ENREF_47)). [Chiarini and Kumar (2020)](#_ENREF_13) validated these findings within multiple case studies.

A separate research stream reviews the incorporation of specific I4.0 technologies, such as robots, augmented reality, and additive manufacturing ([Chiarini and Kumar, 2020](#_ENREF_13); [Pagliosa *et al.*, 2021](#_ENREF_39)). Advanced robotics eliminate faults, improve precision and accuracy, automate testing and inspections, and allow collaboration with operators ([Pagliosa *et al.*, 2021](#_ENREF_39)). In the event of a failure, additive manufacturing can assist in repairing damaged components or improving production processes such as machining and welding ([Pagliosa *et al.*, 2021](#_ENREF_39)). Finally, Augmented Reality applications may assist with workstation troubleshooting ([Pagliosa et al., 2021](#_ENREF_39)). 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, 2020](#_ENREF_13)).

In conclusion, combining data collecting and processing for quality control and preventative measures is a key component of TQM and I4.0 integration ([D'Orazio *et al.*, 2020](#_ENREF_16)). In addition, specialised technologies are assessed and integrated into quality management strategies ([Chiarini and Kumar, 2020](#_ENREF_13)). 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](#_ENREF_29)). 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 organisational performance and accomplish strategic goals by minimising variance in processes ([Schroeder *et al.*, 2008](#_ENREF_48)). Furthermore, LSS intends to maximise shareholders’ value by addressing costs, speed, quality, and customer satisfaction by merging Lean and Six Sigma approaches ([Laureani and Antony, 2012](#_ENREF_31); [Fonseca and Domingues, 2018](#_ENREF_22)). While the integration of LSS with I4.0 has not yet been fully explored, it is thought to be one of the upcoming vital issues. Table 4 aggregates the essentials of this subsection.

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, integration, architectures (e.g. RAMI 4.0), modification of ERP/MES/SCADA systems, PDM/PLM | [Antony *et al.* (2019)](#_ENREF_2); [Ganjavi and Fazlollahtabar (2021)](#_ENREF_25); [Santos *et al.* (2021)](#_ENREF_47) | Limited sample sizes in terms of regions and firm sizes, mostly manufacturing; integration of LSS with I4.0 |
| Integration of I4.0 features and DMAIC stages in LSS projects; Algorithms and machine learning in LSS projects | [Chiarini and Kumar (2020)](#_ENREF_13) | Investigate when I4.0 and LSS should be integrated; investigate the skills that LSS practitioners should develop |
| As part of a holistic management system: LSS, I4.0, 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)](#_ENREF_25); [Yadav *et al.* (2021)](#_ENREF_62) | Creating a hierarchical link between new success criteria |

In general, big data integration in LSS is one of the most popular measures among prevalent contributors ([Antony *et al.*, 2019](#_ENREF_2); [Yadav *et al.*, 2021](#_ENREF_62)). This is concretised 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](#_ENREF_25); [Santos *et al.*, 2021](#_ENREF_47)). The substantial data collection might lead to previously unseen quality insights or preventative 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, 2020](#_ENREF_13); [Ganjavi and Fazlollahtabar, 2021](#_ENREF_25)). 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)](#_ENREF_25). 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, 2020](#_ENREF_13)). 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](#_ENREF_28)). [Chiarini and Kumar (2020)](#_ENREF_13) derived an initial allocation of I4.0 elements integrated with LSS, as shown in Table 5.

Table 5. Allocation of I4.0 elements to DMAIC ([Chiarini and Kumar, 2020](#_ENREF_13))

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

LSS may be regarded as a management system component that includes TQM when viewed as its whole. Quality 4.0 and I4.0 integration result in a more significant performance boost than single effect assessments ([Yadav *et al.*, 2020](#_ENREF_61)). Research derived operational aspects such as collaboration with external agencies, participation in business excellence awards, KPI-based benchmarking, a continuous improvement culture, and training of internal consultants as success factors ([Yadav *et al.*, 2021](#_ENREF_62)). Only slight overlaps occur compared to [Antony *et al.* (2019)](#_ENREF_2), who derived classical LSS success factors highlighting the changing needs of I4.0 integrations. However, earlier success factors remain relevant ([Antony *et al.*, 2019](#_ENREF_2); [Yadav *et al.*, 2021](#_ENREF_62)). Further details are provided by [Bhat *et al.* (2021)](#_ENREF_7), who discuss the sociotechnical elements of decision-making styles, knowledge worker availability, social interaction, and the sociocultural 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.

Finally, [Ganjavi and Fazlollahtabar (2021)](#_ENREF_25) provide insights on operationalisation 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 preventative models.

In conclusion, the field of LSS and I4.0 integration research is based on experimentally validated findings, and industry-related applications highlight the value of combining LSS and I4.0. Operational modalities and sociotechnical and sociocultural factors also provide insight into merging LSS with I4.0. Furthermore, governance mechanisms were mentioned as being essential but remain vague.

### Business Process Management

Business Process Management (BPM) helps businesses analyse and improve their processes, which are constituted of dynamically coordinated activities or tasks performed in a sequential order to deliver value ([Trkman, 2010](#_ENREF_58)). The essentials of this subsection are aggregated in Table 6.

Table 6. Summary of BPM and I4.0 integration

|  |  |  |  |
| --- | --- | --- | --- |
| Integration theme | Core content | Exemplary contributions | Knowledge gaps |
| BPM as an integration moderator | Process modelling, ERP, and MES integration | [Xu *et al.* (2018)](#_ENREF_60); [Pagliosa *et al.* (2021)](#_ENREF_39); [Rey *et al.* (2021)](#_ENREF_43); [Santos *et al.* (2021)](#_ENREF_47) | Integrating diverse models into a unified framework for vertical and horizontal process integration |
| Process automation and workflow management | Workflow management software, automation software (Celonis, UIpath), ERP connectivity, and standardised/flexible procedures | [van der Aalst *et al.* (2018)](#_ENREF_59); [Xu *et al.* (2018)](#_ENREF_60); [Mishra *et al.* (2019a)](#_ENREF_34); [Mishra *et al.* (2019b)](#_ENREF_35) |
| Process mining and optimisation | Data gathering, simulation, | [Pagliosa *et al.* (2021)](#_ENREF_39); [Tran *et al.* (2021)](#_ENREF_56) | Concepts of operationalisation |
| Agile BPM | Processes that are adaptable for rapid and continual development | [Sehlin *et al.* (2019)](#_ENREF_49); [Baiyere *et al.* (2020)](#_ENREF_5) | Methods for adaptive process modelling, infrastructure flexibility, actor capabilities, and generalisation |

[Xu *et al.* (2018)](#_ENREF_60) compiled a basis for integrating BPM and I4.0 based on an SLR. The authors consider BPM a vital feature of I4.0 since it allows for the orchestration of processes in end-to-end integration. The authors argue that this is required for future I4.0 aspects such as artificial intelligence, machine learning, or cloud computing. [Fischer *et al.* (2020)](#_ENREF_20) verified the use of BPM to establish digital transformation foundations and capabilities, such as modelled processes or employee awareness. Furthermore, [Rey *et al.* (2021)](#_ENREF_43) 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 an MES, a navigation system, and sensor-based operator identification ([Rey *et al.*, 2021](#_ENREF_43)). Further authors support the importance of BPM in I4.0 integrations such as CPS and the inclusion of other I4.0 aspects like e-kanbans, real-time data collection, and advanced HMI ([Sanders *et al.*, 2016](#_ENREF_46); [Pagliosa *et al.*, 2021](#_ENREF_39)). The authors conclude that thorough business processes constitute a necessary basis ([Sanders *et al.*, 2016](#_ENREF_46); [Pagliosa *et al.*, 2021](#_ENREF_39)).

Aside from integration, [Xu *et al.* (2018)](#_ENREF_60) identified workflow management as a prominent subject for process monitoring, control, and optimisation. Based on a cross-industry study, [Mishra *et al.* (2019a)](#_ENREF_34) identified robotic process automation (RPA) as a prominent integration topic. RPA automates process executions based on earlier simplification, standardisation, and reengineering efforts ([van der Aalst *et al.*, 2018](#_ENREF_59)). 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 *et al.*, 2019a](#_ENREF_34)). Additional issues such as cultural and behavioural change require expenditures in creating digital capabilities. Early deployment should focus on procedures where people operate like robots ([Mishra *et al.*, 2019b](#_ENREF_35)). For example, successful applications examine the use of RPA in master data management ([Radke *et al.*, 2020](#_ENREF_42)).

In contrast to RPA, which addresses rigid process modelling for automation, [Baiyere *et al.* (2020)](#_ENREF_5) used ethnography to derive so-called light touch processes, infrastructural flexibility, and the need for attentive rather than procedural actors as development routes in light of I4.0 integration. Contrary predictions for the future of BPM include repurposing resources to boost adaptability, considerable experimentation, and ambidexterity ([Baiyere *et al.*, 2020](#_ENREF_5)). As a result, the balance between process modelling and flexibility has to be explored further.

In addition to RPA, process mining may be derived as an integration subject ([Tran et al., 2021](#_ENREF_56)). Process mining examines as-is process flow using data, e.g. acquired from MES, and potentially enhanced process monitoring ([Tran et al., 2021](#_ENREF_56)). The authors indicate that data-gathering based on process mining or querying is one of the advantages of integration ([Sanders *et al.*, 2016](#_ENREF_46); [Polyvyanyy *et al.*, 2017](#_ENREF_40); [Tortorella *et al.*, 2021](#_ENREF_55)). The quality of information is determined by the rate of integration and the transparency of process executions ([Polyvyanyy *et al.*, 2017](#_ENREF_40)). This subject may be expanded to include big data analytics and process simulation methodologies ([Queiroz *et al.*, 2020](#_ENREF_41); [Pagliosa *et al.*, 2021](#_ENREF_39)).

Concerning requirements for integration, the authors derived characteristics for engaging resources like IT skills, particularly data science ([Queiroz *et al.*, 2020](#_ENREF_41)). Resources must be adapted, necessitating recruiting BPM-related skills, such as organisational and process understanding, IT security and data protection, IT expertise, production technologies, modern interfaces, and problem-solving ([Kazancoglu and Ozkan-Ozen, 2018](#_ENREF_30)). Rather than particular skillsets, [Sjödin *et al.* (2018)](#_ENREF_51) identified company culture, digitalisation capabilities, and the capacity to include external talents as integration moderators. In contrast, other authors emphasise cross-functional interaction and re-learning paths for personnel ([van der Aalst *et al.*, 2018](#_ENREF_59); [Radke *et al.*, 2020](#_ENREF_42)). Finally, strong change management and governance are critical factors ([Mishra *et al.*, 2019a](#_ENREF_34); [Mishra *et al.*, 2019b](#_ENREF_35); [Radke *et al.*, 2020](#_ENREF_42)).

In brief, the role of BPM in I4.0 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 *et al.*, 2018](#_ENREF_59); [Baiyere *et al.*, 2020](#_ENREF_5)). 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 operationalising or generalising best practices.

## Modes of action – how to integrate

Research is beginning to uncover how businesses modify their processes and routines to integrate QM with I4.0 ([Buer *et al.*, 2021](#_ENREF_10); [Collis and Anand, 2021](#_ENREF_14)).

Based on the articles covered by this SLR, four clusters were identified through inductive coding with relevance to how integrations can be executed: Implementation strategies, barriers, success factors, and capabilities. The following table aggregates these findings.

Table 7. Modes of action in integrating QM with I4.0

|  |  |
| --- | --- |
| Cluster | Core content |
| Implementation strategies | Problem-solving methodologies (e.g., PDCA, DMAIC), I4.0 implementation on a point-by-point basis, pilot-based approaches |
| Barriers | Financial constraints, a lack of management support, a lack of awareness, hesitant behaviour, digitalisation or automation of wasteful activities, technological complexity introduced to shopfloor processes, a lack of resources and competencies, time, data quality, digital knowledge and skills, governance structures, lack of resources and competencies |
| Success factors | Behavioural and cultural change, leadership support, inter-functional team development, training activities, employee involvement and empowerment, process changes without advanced coding skills, balance between process modelling and flexibility, efficient and reliable data warehouse systems, data gathering and storage resources, computational power, resource availability, management competence |
| Capabilities | Organisation: Organisational 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 modelling 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 operationalisation, data/process mining, digitalisation/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 |

The derived modes of action synthesise 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](#_ENREF_52)). 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](#_ENREF_12); [Chiarini and Kumar, 2020](#_ENREF_13)). Further exploratory research is required to derive concrete implementation pathways, such as the sand cone model for Lean Management ([Bortolotti *et al.*, 2015](#_ENREF_9)).

Furthermore, the most agreed finding concerning resources and competencies seems to be a lack of managerial and staff digital knowledge ([Gfrerer *et al.*, 2021](#_ENREF_26)). 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 I4.0 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 organisational development ([Collis and Anand, 2021](#_ENREF_14)). 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](#_ENREF_53)). Figure 5 intends to summarise this basic understanding as a foundation for further explication in future research.

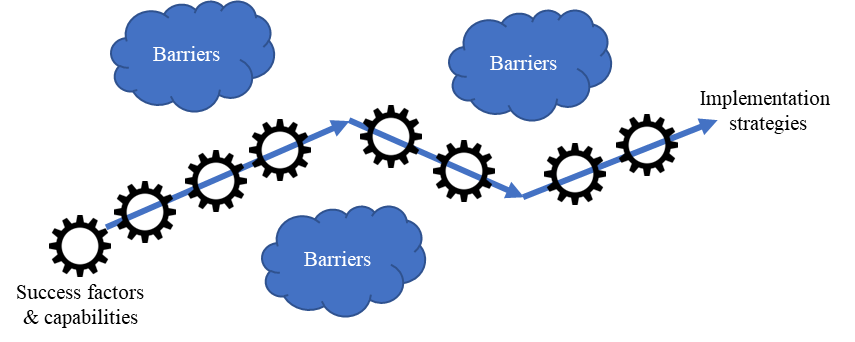


Figure 5. Integration process

# Discussion and future research

This SLR aims to provide a practical perspective by synthesising the "what" and "how" of integrating QM with I4.0 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 I4.0 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](#_ENREF_12); [Dias *et al.*, 2021](#_ENREF_18)). Previous research established different perspectives, e.g. by relating excellence models of EFQM 2020 or QM models of ISO 9001:2015 to I4.0 integrations. In common seems the knowledge gap of practical guidelines to inform an execution, especially in the face of requirements of specific organisations ([Fonseca *et al.*, 2021](#_ENREF_21); [Murthy *et al.*, 2021](#_ENREF_36); [Fonseca *et al.*, 2022](#_ENREF_23)). Future research could build on practical perspectives as outlined by 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](#_ENREF_29); [Sader et al., 2021](#_ENREF_45)). Furthermore, the considered I4.0's aspects demonstrate a tendency toward advanced technology applications and an underrepresentation of enterprise architectures or horizontal/vertical integration ([Frank *et al.*, 2019](#_ENREF_24); [Yli-Ojanperä *et al.*, 2019](#_ENREF_63)). This discovery is essential due to its significant role in I4.0 transformations ([Liao and Wang, 2021](#_ENREF_32)).

Third, while academic research has covered much ground in explaining the what of integrating QM with I4.0, 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 realise 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 summarised in the table below.

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 I4.0 on the level of its constituting elements; Including soft aspects |
| How | Lack of generalisation, 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 I4.0. As a result, a relationship is formed between what aspects organisations should integrate and how integrations may be carried out. According to the findings, integrations do not currently cover the fundamental components of QM and I4.0. For example, the present literature base does not adequately capture the importance of enterprise architectures as constituent aspects of I4.0. Significant operational gaps have been observed with respect to how organisations may implement QM and I4.0 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 I4.0 integrations. Second, by explicating resources, capabilities, and other characteristics of how integrations may be carried out, as 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 organisations 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 I4.0, only scholarly works that explored both paradigms were evaluated, and transferrable ideas from research focusing on either QM or I4.0 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.

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