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Lean Six Sigma competency frameworks: evaluating the competencies required for the Lean Six Sigma Black Belt

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Abstract

Purpose – This study aims to describe, synthesize and integrate current Lean Six Sigma competence frameworks to provide a structured metamodel that improves comparability, credibility and application among certification programs. This research rigorously analyzes existing frameworks and aligns them with contemporary competency classification systems to support standardization and adaptation to current industry requirements in the absence of a globally agreed standard.

Design/methodology/approach – A strategic literature review identified 27 pertinent competency models, succeeded by a three-round Delphi study with 15 certified Lean Six Sigma Black Belts (LSSBBs). The Delphi study helped us reach expert consensus on the essential competencies and their required proficiency levels, and then position them within the European Qualifications Framework and the Dublin Descriptors. Qualitative data further strengthened the framework's empirical foundation and practical applicability. In particular, participants who finished a competency-based Lean Six Sigma Black Belt exam provided input and more than 200 usable responses were collected.

Findings – The findings show that there is a substantial agreement on technical skills like DMAIC, statistical methodologies, and problem-solving. However, there are differences in leadership, experimentation, and belt structures. Practitioner feedback indicated that competence-based evaluations are perceived as more authentic and demanding than multiple-choice tests. The final framework combines technical, methodological and behavioral abilities and has been tested in literature, by experts and by practitioners.

Originality/value – This research advances Lean Six Sigma competency management by explicitly framing the Black Belt role through educational competency frameworks, bridging the gap between education, certification and organizational excellence.

Keywords Lean Six Sigma, Black Belt competencies, Competency framework,
European qualifications framework (EQF), Dublin descriptors, Competence-based assessment, Industry 4.0

Paper type Research article

Introduction

After the Second World War, the conference of national standardizing organizations that established ISO was held in London from 14 to 26 October 1946. It was also in this year that the American Society for Quality Control (ASQC, changed to ASQ in 1997) was formed.

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The need for standardizing standards was obvious during the time of rebuilding the international community. Quality standards are defined as "documents that provide requirements, specifications, guidelines, or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose" (ASQ, 2022). ISO defines a standard as "the distilled wisdom of people with expertise in their subject matter and who know the needs of the organizations they represent" (ISO, 2021). More broadly, work on ISO-based quality systems and their integration with Lean and Lean Six Sigma shows that standardization can improve comparability and discipline, while also creating implementation and fit challenges across contexts (ISO 9000:2015; International Organization for Standardization, 2015; Stevenson and Barnes, 2001; Chiarini, 2011a; Karthi *et al*., 2011; Bacoup *et al*., 2018; Sá *et al*., 2020).

ISO 18404 has triggered debate among scholars, practitioners and standard developers about the feasibility and desirability of standardizing Lean Six Sigma competence and auditing it in practice (Antony *et al*., 2021, 2023; Oudrhiri *et al*., 2022; Sony *et al*., 2025). Prior work assessed the potential benefits and limitations of ISO 18404 and highlighted that the standard can be experienced as prescriptive and challenging to apply across diverse contexts (Antony *et al*., 2021, 2023). A subsequent response from contributors close to the development of ISO 18404 argued that earlier critiques relied on a selective interpretation of the standard and its intent (Oudrhiri *et al*., 2022). Overall, peer-reviewed empirical applications of ISO 18404 remain relatively limited compared with the widespread use of certification bodies of knowledge, and recent evidence suggests that applicability and uptake vary across settings (Sony *et al*., 2025).

Given the inconsistencies in existing Lean Six Sigma competency frameworks and the evolving demands of organizations and practitioners, this study seeks to explore the following research question:

(1) How can Lean Six Sigma competency frameworks be standardized and positioned to align with international qualification standards to support the evolving demands of organizations and practitioners?

The article is structured as follows. The next section explores the existing literature on the subject, establishing the foundation for the research objective. This is followed by Methodology and the Results. The proposed Metamodel is followed by the Conclusion.

Literature review

Despite its long history, there is no consensus on the standard for Lean Six Sigma and its certification (Antony *et al*., 2017; Hollingshed, 2021; Laureani and Antony, 2012). Although Lean and Six Sigma are historically independent business improvement methodologies, the synergies of combining them have led to the integrated methodology "Lean Six Sigma" starting from the beginning of this century (George, 2002). That integration has also been discussed conceptually, in service settings, and in deployment models that stress the need to align tools, organizational infrastructure and leadership (George and George, 2003; Salah *et al*., 2010; Hilton and Sohal, 2012). While Lean focuses on waste reduction in processes from customer's perspectives, Six Sigma focusses on the variance reduction and how this effects the process outcomes felt by the customer, thus combined to Lean Six Sigma as both methodologies are complementary in their nature (Antony *et al*., 2022; Arnheiter and Maleyeff, 2005; Arumugam *et al*., 2012). Nowadays, the predominant opinion is that Lean and Six Sigma are integrated into Lean Six Sigma (Antony *et al*., 2017; Snee, 2010) and are applied and studied as one (Lameijer *et al*., 2021).

The deployment of Lean Six Sigma is done by the Black Belts, who are trained in the stepwise breakthrough strategy. This is supported by an organizational infrastructure differentiating between the people accountable and responsible for the changes, like sponsors, champions and process owners (Chiarini, 2011b), and the people improving

processes at several levels requiring different knowledge and skills. Earlier work on Black Belt deployment and competency-based implementation similarly emphasizes the importance of role clarity, deployment capability and broad technical depth (Ingle and Roe, 2001; Huq, 2006; Pyzdek and Keller, 2018). In literature, commonly accepted roles for these Quality Management Professionals are the White Belt, Yellow Belt, Green Belt, Black Belt and Master Black Belt (Laureani and Antony, 2012). There are several bodies for certification and the most well-known are the American Society for Quality (ASQ), International Association for Six Sigma Certification (IASSC), the Council for Six Sigma Certification (CSSC) and the International Lean Six Sigma Institute, abbreviated as ILSSI (Salentijn, 2021). The Lean Competency System (LCS), which originated from the Lean Enterprise Research Centre (LERC) at Cardiff University, has its focus on Lean (Elias, 2016). Besides these independent certification bodies, there are also a lot of institutes or companies offering their own certification for their own programs. Table 1 provides a high-level comparison of major competency frameworks and standards included in this study.

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The Significance of knowledge codification and classification in Lean Six Sigma

Nonaka and Takeuchi (1995) assert that knowledge manifests in two fundamental forms: explicit and tacit. Explicit knowledge consists of organized material, including frameworks, procedures and standards, which can be recorded in certification programs and ISO recommendations (Davenport and Prusak, 1998). Contrary to explicit knowledge, tacit knowledge is developed by experience, intuition and problem-solving skills that are difficult to capture in words (McInerney, 2002). Determining the competences for professionals in process improvement applying Lean Six Sigma, the challenge is how to integrate these two forms of knowledge. Explicit knowledge can be written down, and tacit knowledge requires activation and experience (Baskerville and Dulipovici, 2006). The absence of a consistent standard for LSS certification results in discrepancies in the competencies of qualified Black Belts (Antony *et al*., 2017; Laureani and Antony, 2012).

By structuring LSS knowledge in a formal framework, we create a shared baseline. This improves comparability across certification programs. Knowledge taxonomies also facilitate knowledge transfer across institutions and organizations (Young and Chapman, 2010). Competency-based learning requires a clear framework that specifies what professionals

Table 1. Major competency frameworks and standards

Framework/ standard	Scope	Typical strengths	Typical gaps/limitations
ASQ SSBB BoK	Black Belt (LSS)	Detailed BoK incl. DFSS; widely used	Less explicit about competence levels and assessment approach
IASSC BoK	Black Belt (LSS)	Clear DMAIC focus; global reach	Less emphasis on leadership and organizational deployment
CSSC manual	Black Belt (LSS)	Practical training orientation	Variability in depth across topics
ILSSI BoK	Black Belt (LSS)	Broad topic coverage; exam-aligned	Competence levels not explicitly positioned to qualification frameworks
ISO 18404:2015	Lean + Six Sigma roles	International standard; explicit role definitions	Debated prescriptiveness; limited coverage of belt structure and some topics (e.g. DFSS/DoE)
Lean competency system (LCS)	Lean roles	Competence-level descriptors for Lean	Not a full LSSBB framework

should be able to do at each certification level (Lameijer *et al*., 2021). Moving from knowledge and skills to competence helps ensure people are prepared for their role in practice (Thomas *et al*., 2017). Adjacent work in quality management and competency management likewise suggests that formal competence frameworks can make expectations, development paths and role transitions more explicit (Martin *et al*., 2021; Vakola *et al*., 2007). Structuring competences allows organizations and professionals flexibility and the ability to adapt to changing circumstances and create a shared language and comprehension (Davenport and Prusak, 1998), enabling the successful implementation of continuous improvement (Snee, 2010). In an Industry 4.0 context, Lean Six Sigma training needs to go beyond knowledge alone. Professionals need to know how to use and apply new technologies or methods like Lean Six Sigma as part of the daily routine (Antony *et al*., 2022, 2024; Citybabu and Yamini, 2023). The European Qualifications Framework (EQF) and the Dublin Descriptors are two well-known reference points that we utilize to make it easier to compare the different levels of certification. Both discuss the competencies and skills students should acquire in educational institutions, vocational training, and professional certification (Bologna Working Group on Qualifications Frameworks, 2005; CEDEFOP, 2021; European Commission, 2022). We use EQF because it provides an established, transparent language for positioning professional certification requirements to internationally recognized competence levels, while still allowing contextual tailoring (Lester, 2015).

Methodology

This study adopted a three-stage mixed-methods design. In the first stage, the literature to date was reviewed and analyzed. In the second stage, a Delphi study was conducted to refine the findings into a meta-model synthesizing existing models and expert insights. To explore the application of the meta-framework, a pilot study was conducted in the third stage during the 2024–2025 Dutch ILSSI Black Belt exams, following competency-based education. These exams replaced traditional multiple-choice tests with competence-based assessments. Students' written evaluations ($n = 200$) were thematically analyzed. The literature review was based on the preferred reporting items for systematic reviews and meta-analyses statement, PRISMA (Moher *et al*., 2009), and the different phases were followed (Figure 1).

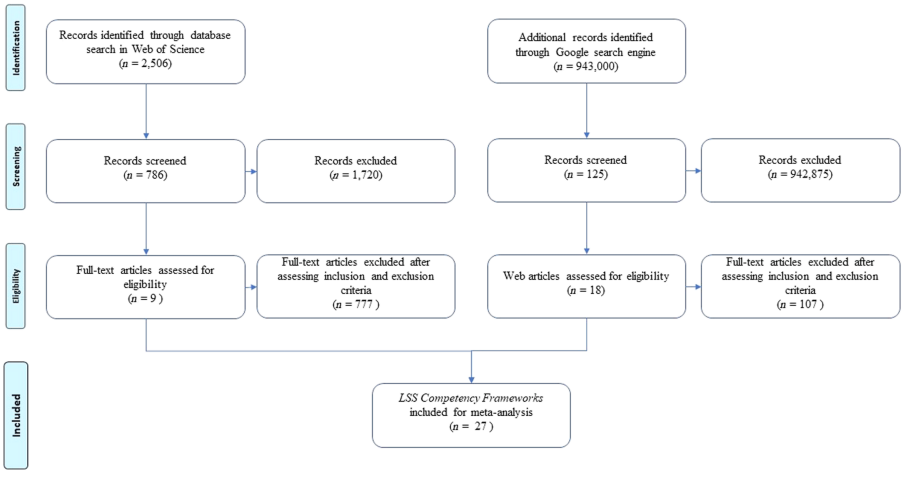

Figure 1. Preferred reporting items for systematic reviews and meta-analyses statement (PRISMA) selection process

To structure and analyze the LSS Competency Frameworks available to date, a systematic literature review (SLR) was performed in July 2022 and updated in January 2025.

The string used to search for academic articles was: ("Lean Six Sigma" OR "LSS" OR "Six Sigma") AND ("Black Belt" OR "competenc*" OR "competenc* framework" OR "body of knowledge" OR "certification" OR "ISO 18404"). The inclusion and exclusion criteria are mentioned in Table 2.

The comparative review focused on three dimensions: areas of agreement (e.g. technical/statistical capabilities and knowledge of process improvement), areas of divergence (e.g. leadership, change management and digital/Industry 4.0 competencies), and the degree to which frameworks combine tacit and explicit knowledge elements.

Using a benchmarking lens, we coded the frameworks and compared them across categories to see how well they consistently allow organized comparison of practitioner competencies. That benchmarking perspective is consistent with both classic and more recent benchmarking literature, which treats comparison not merely as ranking, but as a structured way to identify recurring practices, gaps and areas for adaptation (Camp, 1989; Castro and Frazzon, 2017). To refine these classifications into a validated meta-framework, a Delphi study with 15 experts was conducted. Details of this process, including the rounds, mapping to the EQF and Dublin Descriptors, and final consensus, are presented in the section Delphi Study. Based on the Delphi study with experts, a meta-model was developed and piloted during the academic year 2024–2025. During the pilot, evaluations were collected at the end of the examination. Handwritten responses were entered into Word by an administrative assistant and then analyzed through coding by a researcher. This yielded 200 useful results. A coding scheme was used to organize the analysis of the competency frameworks, classifying them into four groups: technical/statistical skills, methodological knowledge, leadership and change management skills and new skills emerging from Industry 4.0. The validity of the study was strengthened by combining a strategic literature review, a Delphi study, and piloting the resulting meta-model in professional practice.

Results

Given that the Black Belt plays a central role in an organization's improvement strategy (Antony and Karaminas, 2016; Hoerl, 2001; Harry, 1998; Ingle and Roe, 2001), this research focuses on how different competency frameworks define the necessary skills and knowledge for this role. Multiple academic studies, standards and other relevant works have been analyzed to determine what the standards are for a skilled Black Belt. All the articles and documents regarding the subject under research have been analyzed and categorized and the

Table 2. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
The objective of the presented LSS Competency Framework is to provide guidance on the LSS Competency Framework (prescribing) and	Research exploring or explaining LSS Competency Framework based on one, several, or many success or failure factors (incl. literature reviews on these factors and case studies)
Presence of specific knowledge and/or skills and/or competences and	Research exploring or explaining LSS Competency Frameworks as an antecedent for other organizational objectives (e.g. sustainability, safety standards)
Differentiation of the competences over categories like for example the DMAIC	Published in sources other than peer-reviewed academic, practitioner, or textbook publications and/or other than English or Published by an independent or academic body, not using the publication for the promotion of the own (commercial) products.

results can be found in Appendix A. The outcomes of this literature review form the basis for the expert validation in Stage 2 (Delphi).

This provides a clear overview for understanding both the similarities and differences between the several standards. Most of them emphasize technical capabilities, like applying statistics and the DMAIC for problem solving (e.g. ASQ, CSSC, IASSC), while others focus more on change management and leadership (e.g. Antony *et al*., 2018; Hallam *et al*., 2018; Laureani and Antony, 2021; Vakola *et al*., 2007). Additionally, some models suggest a more holistic and evolving role for Black Belts in modern business environments due to developments like Industry 4.0 (Chiarini, 2020; Citybabu and Yamini, 2023; Antony *et al*., 2024).

Using Sanghi's (2007) approach to competency mapping, we identified the core competencies that recur across Lean Six Sigma frameworks. In short, the overlap is strong, but the emphasis differs per framework, which is in line with broader work on competency management in both quality and organizational change domains (Huq, 2006; Martin *et al*., 2021).

(1) Technical skills: statistical analysis and process control (covered by all frameworks; see also Pyzdek and Keller, 2018).

(2) DMAIC and Lean tools: included in all frameworks, but with varying depth (Antony, 2020; Uluskan, 2016).

(3) Problem-solving and decision-making: root cause analysis and process improvement appear in all frameworks; decision-making is more explicitly emphasized in ASQ.

(4) Leadership and change management: project leadership and team management are present across frameworks, but interpreted differently; the same holds for change management and broader organizational change (Laureani and Antony, 2021; Vakola *et al*., 2007).

Delphi study

The Delphi method was chosen as it enables a structured way for experts to build consensus. This is especially useful for complex topics where the evidence base is fragmented and key terms are used inconsistently. A three-round design was used to iteratively refine competency statements and their positioning, until stability in the panel's ratings and comments was reached (Hsu and Sandford, 2007; Okoli and Pawlowski, 2004).

Building on the European Qualifications Framework (EQF) and the Dublin Descriptors, the Delphi panel positioned Lean Six Sigma Black Belt competencies at EQF Levels 6–7, aligning them with the corresponding Dublin Descriptors. Appendix B and Appendix C, respectively, include the levels for the EQF and the Dublin Descriptors. Fifteen Lean Six Sigma Black Belts (LSSBBs) underwent a three-round Delphi assessment to guarantee the validity and robustness of the competency mapping. Selected members of the expert panel were chosen based on their certification status and Lean Six Sigma implementation and training experience, guaranteeing that the insights acquired were both academically grounded and practical. The profiles of the LSSBBs are included in Appendix D.

The Delphi study was conducted in three rounds. In Round 1, experts assessed whether the proposed Dublin Descriptors and related competency profiles aligned with Lean Six Sigma Green Belt (LSSGB) and Black Belt (LSSBB) requirements. In Round 2, the panel mapped the competencies to the European Qualifications Framework (EQF), providing an internationally comparable classification. In Round 3, the model was refined by the experts. This process resulted in consensus on twelve core competencies, mapped to the appropriate EQF levels. While there was strong consensus on problem diagnosis, statistical tools, DMAIC and process change management, divergent views arose on innovation, communication, cooperation and

ethics. The expert-driven approach guarantees that the proposed competency model reflects both academic rigor and practical applicability, bridging the gap between theoretical learning and industry needs. On the numerous important skills that LSS practitioners should have, the Delphi panel agreed strongly:

(1) Problem Identification and Diagnosis. The capacity to separate symptoms from root causes and apply methodical problem-solving techniques.

(2) Competency in applying statistical tools and process control techniques will help one drive decisions.

(3) Using DMAIC, Lean tools and Design of Experiments (DoE), among other methodologies, solution design and implementation help to maximize processes.

(4) Process change management is the application of improvements in an organizational context that guarantees scalable and sustainable nature of process changes.

(5) Research and analytical skills include the capacity to investigate extensively, examine facts and create insightful analysis.

(6) Supporting teams by means of cooperative efforts and directing process improvement projects helps to engage stakeholders and play advisory roles.

Although most competencies were agreed upon, on innovation, cooperation, communication and ethics the opinions differed (Figure 2).

The Delphi results imply that, depending on the complexity of the position, LSSGB competencies match EQF Level 5 and LSSBB competencies match Levels 6 and 7 (Figure 3). EQF Level 5 (LSSGB) operational and tactical competencies driven by implementing systematic approaches in specified surroundings. EQF Level 6 (LSSBB: Standard Role) Competencies stressing independent analysis, decision-making and leadership within process improvement teams. Strategic competencies encompassing organization-wide Lean Six Sigma deployment and enterprise-level process transformation comprise EQF Level 7 (LSSBB: Advanced Role/Master Black Belt).

Competencies provide a high-level overview of what someone can do or is capable of, and consist of the dimensions knowledge, skills, responsibility and autonomy. Collectively, these dimensions present an organized way of viewing the ways in which competencies show up in order to organize education programs (Table 3).

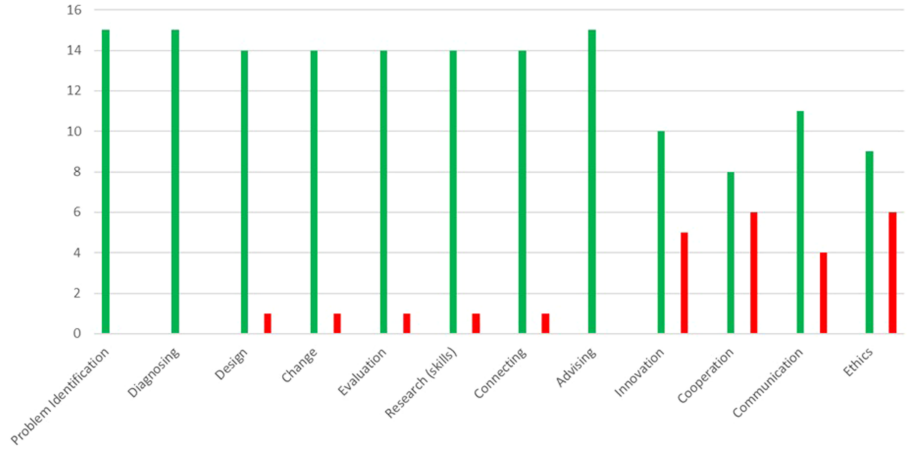

Figure 2. Dublin descriptors applied to the LSSGB and LSSBB

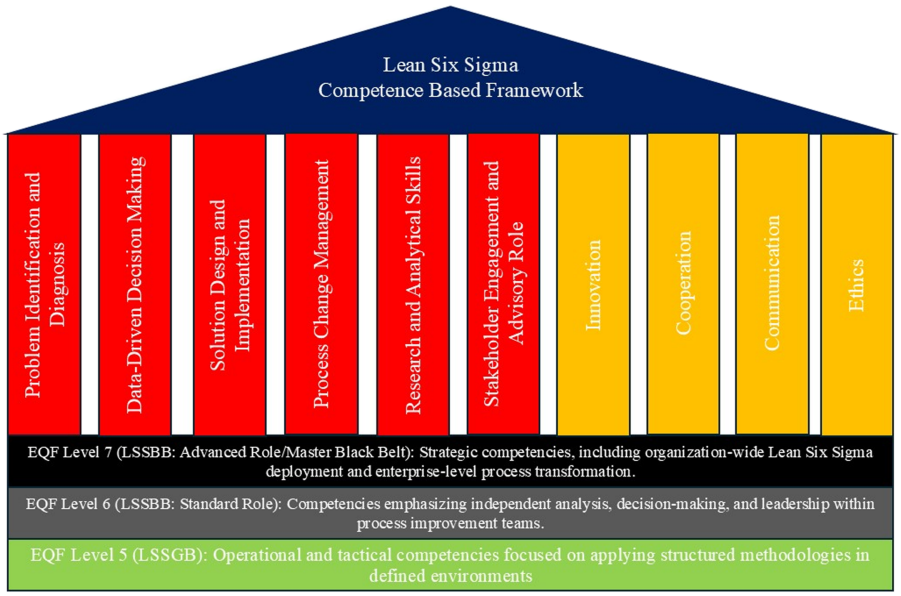

Figure 3. Lean Six Sigma competence-based framework

Pilot study

To test the model in real life, a pilot study was conducted to test the competence-based framework. For this goal, the multiple-choice exams for the Black Belt on behalf of ILSSI in the Netherlands were replaced by competence-based assessments. This move toward more application-oriented assessment is consistent with broader work on competence-based and practice-oriented assessment design in professional education (Brinkman-Staneva, 2015; Rodriguez-Paz and Sayeg-Sánchez, 2023).

Relevance and Authenticity: A majority of students, approximately two-thirds of all responses, emphasized the authenticity of the competence-based exam. The exam is generally perceived as more realistic, challenging and relevant than traditional multiple-choice tests. For example P1 wrote: “The exam forces me to apply Lean Six Sigma concretely in practical situations, which I find more challenging but also more instructive than memorizing answers.” Real-life scenarios make the cases more realistic. As P2 stated: “The cases resemble situations in my daily work, which makes me feel competently assessed. It requires not only knowledge, but also insight and understanding of application.” Still, some students struggled with this concrete application to practical situations. For example, P3 stated: “At times I missed more direct questions about definitions, but I see the value of the broader, application-oriented approach that demands more than factual recall”.

Application and Critical Thinking: More than half of the students highlighted that the competence-based exam required them to reason and apply concepts rather than simply memorize facts. As P4 remarked: “The exam forces me to apply Lean Six Sigma concretely in practical situations, which I find more challenging but also more instructive than memorizing answers.” P5 added: “It is no longer about reproducing knowledge but about showing that you can apply it.” Still, some valued the choices forced on MC more: “For some questions I would have preferred more structure, multiple choice feels more comfortable for this (P6).” The competence-based nature stimulates critical thinking and the application of Lean Six Sigma concepts rather than merely testing factual knowledge.

Table 3. LSS competency framework for the LSSBB

Dublin descriptor	Level 2	Knowledge	Skills	Responsibility and autonomy
Knowledge and insight	The LSSBB has demonstrable knowledge and understanding of LSS that builds on and exceeds the level of the LSSGB; usually operates at a level where, with the support of specialized manuals, there are some aspects that require knowledge of the latest developments in the field of expertise	The LSSBB has an advanced knowledge of improving and designing processes with Lean and/or Six Sigma, involving a critical understanding of underlying theories and principles like TPS, TPM, TQM, Lean Thinking, SPC, Six Sigma, DoE, ToC etc	The LSSBB has advanced skills and demonstrated mastery and innovation, required to solve challenges and problems in both new and existing processes optimizing value applying methods like DMAIC, DMADV, IDOV, A3, Kaizen, PDCA, QFD etc.	The LSSBB manages complex technical or professional activities or projects, taking responsibility for decision-making in optimizing processes, improve quality, reduce variance; take responsibility for employee and customer involvement, optimizing stakeholder value and sustainability
Applying knowledge and insight	The LSSBB is able to apply knowledge and insight in such a way that it shows a professional approach to business process improvement including its design, and also has competencies for advanced problem solving using process and data techniques	The LSSBB knows advanced tools and techniques like Advanced SPC, Measuring and modelling relationships between variables, designing and executing experiments, Shainin Key Variables Search Technique (KVST), Complex Value Stream Mapping, OEE etc	The LSSBB has advanced skills and demonstrated mastery and innovation, required to solve challenges and problems in both new and existing processes understanding relationships between independent and dependent variables including their moderators	The LSSBB manages complex technical or professional activities or projects, taking responsibility for decision-making in "Organization-Wide Planning and Deployment", "Organizational Process Management and Measure", "Team management and Stakeholder management"
Judgement	The LSSBB is able to collect and interpret relevant data (usually in the field of expertise) with the aim of business improvement including its design, taking into consideration social, scientific or ethical aspects	The LSSBB knows advanced tools and techniques to analyze, diagnose and create a culture of continuous improvement from both the foundations by the Toyota Way, "Six Sigma Breakthrough Cookbook" as the groundings on quality management including the learnings of Deming, Juran and Crosby	The LSSBB has advanced skills and demonstrated mastery and innovation, to use data in different settings and different contexts like manufacturing and services, private and public sector, large enterprises and SMEs	The LSSBB manages complex technical or professional activities and projects and focuses on long-term sustainable results, improving businesses in a sustainable way, considering both hard and soft business outcomes and takes responsibility for People, Profit and Planet

(*continued*)

Table 3. Continued

Dublin descriptor	Level 2	Knowledge	Skills	Responsibility and autonomy
Communication	The LSSBB is able to communicate information, ideas and solutions to an audience consisting of specialists or nonspecialists, both at an executive level and the Gemba	The LSSBB knows advanced tools and techniques to present, communicate and connect people considering the organization's process maturity and adapting solutions to it, having knowledge on change management and change at an individual, team and corporate level	The LSSBB has advanced skills and demonstrated mastery and innovation to use several communication styles to connect to several stakeholders, and is able to connect, identify and prioritize benefits due to the Lean and/or Six Sigma Projects enhancing business results and relevancy to the business	The LSSBB manages complex technical or professional activities and projects and is able to implement and sustain results in the organization in a systematic approach creating support and involvement by stakeholders
Learning skills	The LSSBB has the necessary learning skills to enter into a follow-up study that presupposes a high level of autonomy	The LSSBB knows advanced tools and techniques to distinguish between qualitative and quantitative methods and apply them accordingly, including data governance and digital data sources used in modern process improvement (e.g. process mining, automation data)	The LSSBB has 21st Century Skills and can apply digital and data-enabled improvement approaches (Quality 4.0), including data literacy, basic automation awareness and the effective use of analytics and AI-supported tools within DMAIC	The LSSBB takes responsibility for own development and competences, contributes to sustainable improvement (People, Profit, Planet), and develops the capability to lead improvement in digitally enabled environments

Comparison with Multiple Choice: Almost half of the students compared the competence-based exam with traditional multiple-choice tests. Many emphasized that the absence of guessing was a strength, as it demanded genuine understanding, though some also noted it made the exam more difficult when they were uncertain. As P7 wrote: "The absence of the option to guess, forces genuine knowledge, but it also makes it harder when in doubt."

Perceived Challenges: Around two out of five students reported difficulties with the competence-based format. They pointed to the open-ended nature of the questions, time pressure, and the absence of clear grading rubrics as particular challenges. As a student stated: "I find weighing different scenarios useful, although at times I felt uncertain about what the 'intended' solution was (P8)." Despite challenges, most students endorsed the new exam as a more valid representation of Lean Six Sigma practice: "Tougher, but this is what prepares you for the real world (P9)."

Discussion

This study responds to persistent variation in Lean Six Sigma Black Belt competency expectations across certification bodies and the continuing debate about whether competence can be standardized and audited. By synthesizing 27 frameworks, validating core competencies through a Delphi panel, and piloting a competence-based assessment, the study offers a structured meta-model that complements both certification bodies' bodies of knowledge and the international standard ISO 18404.

Comparison with ISO 18404 shows overlap in core technical and change-related competencies (e.g. problem diagnosis, data acquisition and analysis, project management and stakeholder management). However, several widely used frameworks and academic studies emphasize additional areas that are less explicit in ISO 18404, including belt-structure design (e.g. Yellow Belt), structured experimentation (DoE/DFSS) and broader leadership and facilitative capabilities required to mobilize and sustain change. These differences support viewing ISO 18404 as a useful reference point rather than a complete representation of contemporary Black Belt competence. Positioning competencies against EQF levels and the Dublin Descriptors strengthens comparability by linking certification expectations to established learning-outcome descriptors. This helps clarify the distinction between a "standard" Black Belt role (often aligned with EQF Level 6) and more advanced, enterprise-level deployment responsibilities (often aligned with EQF Level 7).

The results also indicate a growing expectation that Black Belts can operate in data-rich and digitally enabled environments. While traditional frameworks focus on statistical tools and DMAIC, current practice increasingly requires data literacy, governance awareness and the ability to work with digital diagnostics and AI-supported analysis (often discussed under Quality 4.0) (Citybabu and Yamini, 2023; Antony *et al*., 2024). We therefore include digital and data-enabled improvement competencies as an explicit cluster in the proposed framework.

Practical implications

The framework can be used in several ways. For certification bodies and training providers, it helps to compare curricula and assessments using the same "language", and to make competence levels explicit, for example, through EQF positioning. For organizations and HR, it gives a clear structure for role profiles, hiring criteria and development paths for improvement professionals, which is consistent with adjacent competency-framework work in quality management and organizational change (Martin *et al*., 2021; Vakola *et al*., 2007). For candidates, it works as a simple mirror: where are the gaps in technical, methodological, leadership and digital skills, and what learning would actually close them? And for exam and assessment designers, it supports tasks and rubrics that test application and judgment in realistic situations, instead of testing memory.

Limitations and directions for further research

This study has a few clear limitations. First, both the Delphi panel and the pilot were mainly conducted in a Dutch context. That context can shape how people look at role expectations and what they consider a "good" assessment format. Second, the evidence base is a mix of peer-reviewed research and practitioner and certification documents. That is also how competence is described and codified in practice, but it can mean that the dominant voices of providers are reflected more strongly than others. Third, digital competencies are still an emerging domain and the target is moving fast, so parts of this area may change quickly. Future research could validate the framework across countries and sectors, test predictive validity by linking competency profiles to project and organizational outcomes, and study how competence-based assessment reliability can be improved through clearer rubrics and assessor training. Further work is also needed to refine and update the digital/Quality 4.0 cluster as standards such as ISO 9001 evolve.

Conclusion

This study set out to deal with a very concrete issue: despite the centrality of the Black Belt role, there is no broadly shared competency framework that is both explicit and usable across providers. We therefore brought together 27 existing models, translated them into a single meta-model, tested its content through a Delphi study with certified experts, and then piloted the framework in a practice setting. Across models and experts, the technical core is remarkably stable. Competencies around DMAIC, statistical thinking, and structured problem solving attracted strong agreement. The picture becomes less uniform once leadership and change management enter the framework. Experts recognize these competencies as essential, but differ in how they should be specified and assessed in a way that is fair and comparable. The same holds for emerging digital and Industry 4.0-related skills: they are increasingly expected, yet still developing in terms of shared definitions and level descriptions.

A key contribution of this work is that the framework is not only a list of competencies, but also a levelled interpretation. By positioning Black Belt competencies explicitly against the European Qualifications Framework (EQF) and the Dublin Descriptors, the framework supports clearer benchmarking across training programs and certification bodies. The pilot adds an important practical signal: competence-based assessment was experienced as more authentic and more relevant than multiple-choice testing, but also more demanding. It shifts the emphasis from recognizing "the right answer" to demonstrating application and judgment.

Supplementary material

The supplementary material for this article can be found online

References

Antony, J. (2020), *The Ten Commandments of Lean Six Sigma*, Emerald Publishing, Bingley.

Antony, J. and Karaminas, H. (2016), "Critical assessment on the Six Sigma Black Belt roles/responsibilities, skills and training: a global empirical study", *International Journal of Quality and Reliability Management*, Vol. 33 No. 5, doi: 10.1108/IJQRM-08-2014-0106.

Antony, J., Snee, R. and Hoerl, R. (2017), "Lean Six Sigma: yesterday, today and tomorrow", *International Journal of Quality and Reliability Management*, Vol. 34 No. 7, pp. 1073-1093, doi: 10.1108/ijqrm-03-2016-0035.

Antony, J., Gupta, S., Sunder, M.V. and Gijo, E.V. (2018), "Ten commandments of Lean Six Sigma: a practitioners' perspective", *International Journal of Productivity and Performance Management*, Vol. 67 No. 6, pp. 1033-1044, doi: 10.1108/ijppm-07-2017-0170.

Antony, J., McDermott, O., Powell, D. and Sony, M. (2022), "The evolution and future of Lean Six Sigma 4.0", *The TQM Journal*, Vol. 35 No. 4, pp. 1030-1047, doi: 10.1108/tqm-04-2022-0135.

Antony, J., McDermott, O., Sony, M., Cudney, E.A., Snee, R.D. and Hoerl, R.W. (2021), "A study into the pros and cons of ISO 18404: viewpoints from leading academics and practitioners", *The TQM Journal*, Vol. 33 No. 8, pp. 1845-1866, doi: 10.1108/tqm-03-2021-0065.

Antony, J., McDermott, O., Sony, M., Powell, D., Snee, R.D. and Hoerl, R.W. (2023), "Global study into the pros and cons of ISO 18404: a convergent mixed method study and recommendations for further research", *International Journal of Quality and Reliability Management*, Vol. 40 No. 2, pp. 517-541, doi: 10.1108/ijqrm-10-2021-0356.

Antony, J., Vinodh, S. and Chakraborty, A. (2024), "Guest editorial: 'integration of Lean Six Sigma with industry 4.0 to augment organizational efficiency and effectiveness'", *International Journal of Lean Six Sigma*, Vol. 15 No. 5, pp. 965-967, doi: 10.1108/ijlss-09-2024-258.

Arnheiter, E.D. and Maleyeff, J. (2005), "The integration of lean management and Six Sigma", *The TQM Magazine*, Vol. 17 No. 1, pp. 5-18, doi: 10.1108/09544780510573020.

Arumugam, V., Antony, J. and Douglas, A. (2012), "Observation: a lean tool for improving the effectiveness of Lean Six Sigma", *The TQM Journal*, Vol. 24 No. 3, pp. 275-287, doi: 10.1108/17542731211226781.

ASQ (2022), "What are quality standards?", available at: https://asq.org/quality-resources/learn-about-standards (accessed 14 May 2022).

Bacoup, P., Michel, C., Habchi, G. and Pralus, M. (2018), "From a quality management system (QMS) to a lean quality management system (LQMS)", *The TQM Journal*, Vol. 30 No. 1, pp. 20-42, doi: 10.1108/tqm-06-2016-0053.

Baskerville, R. and Dulipovici, A. (2006), "The theoretical foundations of knowledge management", *Knowledge Management Research and Practice*, Vol. 4 No. 2, pp. 83-105, doi: 10.1057/palgrave.kmrp.8500090.

Bologna Working Group on Qualifications Frameworks (2005), *A Framework for Qualifications of the European Higher Education Area*, Ministry of Science, Technology and Innovation, Copenhagen, available at: https://ehea.info/media.ehea.info/file/WG_Frameworks_qualification/71/0/050218_QF_EHEA_580710.pdf (accessed 8 February 2025).

Brinkman-Staneva, M. (2015), "The complexities of assessments in professional hospitality education", *Quality Assurance in Education*, Vol. 23 No. 4, pp. 339-352, doi: 10.1108/qae-04-2015-0016.

Camp, R.C. (1989), *Benchmarking: the Search for Industry Best Practices that Lead to Superior Performance, Chapter 1*, ASQC Quality Press, Milwaukee, WI.

Castro, V. and Frazzon, E.M. (2017), "Benchmarking of best practices: an overview of the academic literature", *Benchmarking: An International Journal*, Vol. 24 No. 3, pp. 750-774, doi: 10.1108/bij-03-2016-0031.

CEDEFOP (2021), "European qualifications framework (EQF)", available at: https://www.cedefop.europa.eu/en/projects/european-qualifications-framework-eqf (accessed 8 February 2025).

Chiarini, A. (2011a), "Integrating lean thinking into ISO 9001: a first guideline", *International Journal of Lean Six Sigma*, Vol. 2 No. 2, pp. 96-117, doi: 10.1108/20401461111135000.

Chiarini, A. (2011b), "Japanese total quality control, TQM, Deming's system of profound knowledge, BPR, Lean and Six Sigma", *International Journal of Lean Six Sigma*, Vol. 2 No. 4, pp. 332-355, doi: 10.1108/20401461111189425.

Chiarini, A. (2020), "Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research", *The TQM Journal*, Vol. 32 No. 4, pp. 603-616, doi: 10.1108/tqm-04-2020-0082.

Citybabu, G. and Yamini, S. (2023), "Lean Six Sigma 4.0 – a framework and review for Lean Six Sigma practices in the digital era", *Benchmarking: An International Journal*, Vol. 31 No. 9, pp. 3288-3326, doi: 10.1108/bij-09-2022-0586.

Davenport, T.H. and Prusak, L. (1998), *Working Knowledge: How Organizations Manage what they Know*, Harvard Business School Press, Boston.

Elias, S. (2016), "The equation of lean", *Lean Competency System*, available at: https://www.leancompetency.org/lcs-articles/the-equation-of-lean (accessed 7 August 2022).

European Commission (2022), "The bologna process and the European higher education area", *European Education Area*, available at: https://education.ec.europa.eu/education-levels/higher-education/inclusive-and-connected-higher-education/bologna-process (accessed 7 August 2022).

George, M.L. (2002), *Lean Six Sigma: Combining Six Sigma Quality with Lean Production Speed*, McGraw-Hill Publishing, NY.

George, M.L. and George, M. (2003), *Lean Six Sigma for Service*, McGraw-Hill, New York, NY.

Hallam, C.R.A., Valerdi, R. and Contreras, C. (2018), "Strategic lean actions for sustainable competitive advantage", *International Journal of Quality and Reliability Management*, Vol. 35 No. 2, pp. 481-509, doi: 10.1108/ijqrm-10-2016-0177.

Harry, M.J. (1998), "Six Sigma: a breakthrough strategy for profitability", *Quality Progress*, Vol. 31 No. 5, p. 60.

Hilton, R. and Sohal, A. (2012), "A conceptual model for the successful deployment of Lean Six Sigma", *International Journal of Quality and Reliability Management*, Vol. 29 No. 1, pp. 54-70, doi: 10.1108/02656711211190873.

Hoerl, R.W. (2001), "Six Sigma black belts: what do they need to know?", *Journal of Quality Technology*, Vol. 33 No. 4, pp. 391-406, doi: 10.1080/00224065.2001.11980094.

Hollingshed, M. (2021), "Standardizing Six Sigma green belt training: identification of the most frequently used measure phase DMAIC tools", *International Journal of Lean Six Sigma*, Vol. 13 No. 2, pp. 276-294, doi: 10.1108/ijlss-12-2020-0220.

Hsu, C.-C. and Sandford, B.A. (2007), "The Delphi technique: making sense of consensus", *Practical Assessment, Research and Evaluation*, Vol. 12 No. 10, pp. 1-8.

Huq, Z. (2006), "Six-Sigma implementation through competency based perspective (CBP)", *Journal of Change Management*, Vol. 6 No. 3, pp. 277-289, doi: 10.1080/14697010600941825.

Ingle, S. and Roe, W. (2001), "Six sigma black belt implementation", *The TQM Magazine*, Vol. 13 No. 4, pp. 273-280, doi: 10.1108/09544780110391666.

International Organization for Standardization (ISO) (2015), *ISO 9001:2015 – Quality Management Systems – Requirements*, ISO, Geneva, available at: https://www.iso.org/standard/62085.html (accessed 8 Feb 2025).

ISO (2021), "Standards. ISO", available at: https://www.iso.org/standards.html (accessed 8 February 2025).

ISO 9000:2015(EN) (2015), "Quality management systems fundamentals and vocabulary", available at: https://www.iso.org/obp/ui/#!iso:std:45481:en (accessed 8 February 2025).

Karthi, S., Devadasan, S.R. and Murugesh, R. (2011), "Integration of lean six-sigma with ISO 9001: 2008 standard", *International Journal of Lean Six Sigma*, Vol. 2 No. 4, pp. 309-331, doi: 10.1108/20401461111189416.

Lameijer, B., Pereira, W. and Antony, J. (2021), "The implementation of Lean Six Sigma for operational excellence in digital emerging technology companies", *Journal of Manufacturing Technology Management*, Vol. 32 No. 9, pp. 260-284, doi: 10.1108/jmtm-09-2020-0373.

Laureani, A. and Antony, J. (2012), "Standards for Lean Six Sigma certification", *International Journal of Productivity and Performance Management*, Vol. 61 No. 1, pp. 110-120, doi: 10.1108/17410401211188560.

Laureani, A. and Antony, J. (2021), "Introduction to leadership for Lean Six Sigma", *Leading Lean Six Sigma*, pp. 1-12.

Lester, S. (2015), "The European qualifications framework: a technical critique", *Research in Post-Compulsory Education*, Vol. 20 No. 2, pp. 159-172, doi: 10.1080/13596748.2015.1030251.

Martin, J., Elg, M., Gremyr, I. and Wallo, A. (2021), "Towards a quality management competence framework: exploring needed competencies in quality management", *Total Quality Management and Business Excellence*, Vol. 32 Nos 3-4, pp. 359-378, doi: 10.1080/14783363.2019.1576516.

McInerney, C. (2002), "Knowledge management and the dynamic nature of knowledge", *Journal of the American Society for Information Science and Technology*, Vol. 53 No. 12, pp. 1009-1018, doi: 10.1002/asi.10109.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G. and The PRISMA Group (2009), "Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement", *PLoS Medicine*, Vol. 6 No. 7, e1000097, doi: 10.1371/journal.pmed.1000097.

Nonaka, I. and Takeuchi, H. (1995), *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*, Oxford University Press.

Okoli, C. and Pawlowski, S.D. (2004), "The Delphi method as a research tool: an example, design considerations and applications", *Information and Management*, Vol. 42 No. 1, pp. 15-29, doi: 10.1016/j.im.2003.11.002.

Oudrhiri, R., Al-Balushi, M., Anwyl, S., Bendell, A., Chamie, S., Coleman, S.Y., Hayman, M., Hilton, R., Melhem, O.A., Patel, J., Ward, S., White, S. and Whitehouse, P. (2022), "The place of ISO 18404:2015 in organisational improvement", *The TQM Journal*, Vol. 35 No. 4, pp. 841-871, doi: 10.1108/tqm-08-2021-0243.

Pyzdek, T. and Keller, P. (2018), *The Six Sigma Handbook*, McGraw-Hill Education, New York.

Rodriguez-Paz, M.X. and Sayeg-Sánchez, G. (2023), "Development of Lean Six Sigma competencies through guided learning sequences", *2023 ASEE Annual Conference & Exposition*.

Sá, J.C., Vaz, S., Carvalho, O., Lima, V., Morgado, L., Fonseca, L. and Santos, G. (2020), "A model of integration ISO 9001 with lean Six Sigma and main benefits achieved", *Total Quality Management and Business Excellence*, Vol. 33 Nos 1-2, pp. 218-242, doi: 10.1080/14783363.2020.1829969.

Salah, S., Rahim, A. and Carretero, J.A. (2010), "The integration of Six Sigma and lean management", *International Journal of Lean Six Sigma*, Vol. 1 No. 3, pp. 249-274, doi: 10.1108/20401461011075035.

Salentijn, W. (2021), *Lean Six Sigma*, Noordhoff, Groningen.

Sanghi, S. (2007), *The Handbook of Competency Mapping: Understanding, Designing and Implementing Competency Models in Organizations*, 2nd ed., SAGE Publications, New Delhi, pp. 127-143.

Snee, R.D. (2010), "Lean Six Sigma – getting better all the time", *International Journal of Lean Six Sigma*, Vol. 1 No. 1, pp. 9-29, doi: 10.1108/20401461011033130.

Sony, M., Ramadan, M.A., Antony, J., Al Dhaheri, M.K., McDermott, O. and Cudney, E.A. (2025), "Assessing ISO 18404 standard applicability in the service sector: a qualitative study", *The TQM Journal*, Vol. 37 No. 3, pp. 726-746, doi: 10.1108/tqm-12-2023-0403.

Stevenson, T.H. and Barnes, F.C. (2001), "Fourteen years of ISO 9000: impact, criticisms, costs, and benefits", *Business Horizons*, Vol. 44 No. 3, pp. 45-51, doi: 10.1016/s0007-6813(01)80034-3.

Thomas, A.J., Francis, M., Fisher, R. and Byard, P. (2017), "Implementing Lean Six Sigma to overcome the production challenges in an aerospace company", *Production Planning and Control*, Vol. 28 No. 3, pp. 199-210, doi: 10.1080/09537287.2016.1165300.

Uluskan, M. (2016), "A comprehensive insight into the Six Sigma DMAIC toolbox", *International Journal of Lean Six Sigma*, Vol. 7 No. 4, pp. 406-429, doi: 10.1108/ijlss-10-2015-0040.

Vakola, M., Eric Soderquist, K. and Prastacos, G.P. (2007), "Competency management in support of organisational change", *International Journal of Manpower*, Vol. 28 Nos 3/4, pp. 260-275, doi: 10.1108/01437720710755245.

Young, J. and Chapman, E. (2010), "Generic competency frameworks: a brief historical overview", *Education Research and Perspectives*, Vol. 37 No. 1, pp. 1-24, doi: 10.70953/erpv37.10001.

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