Towards the sustainable implementation of Lean in hospitals

by

Bronwyn Joubert

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Supervisor: Prof. W. G. Bam

Co-supervisor: Prof. L. Louw

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Declaration

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Abstract

To meet increasing demands for delivering care with fewer resources, leaders of healthcare organisations are continually looking for ways to optimise healthcare operations and processes. Following significant success in improving quality while reducing costs in the manufacturing industry, healthcare facility managers started implementing “lean thinking”, a management philosophy focused on continuous improvement.

While lean success in healthcare has been widely reported, there are also frequent cases where healthcare facilities revert to the pre-implementation state after some time. An initial investigation into the application of lean in hospitals revealed a lack of holistic lean implementation and correctly targeted assessments as contributing factors to unsustainable implementation. However, there is a lack of knowledge of the supporting organisational factors required to support a holistic implementation long-term, and thus the factors that need to be assessed for implementation. Therefore, to foster sustained improvement outcomes, the primary aim of the research was to contribute toward an improved theoretical understanding of how to ensure lean’s implementation in hospitals is sustained. The secondary aim to guide the practical application of these findings was to develop an artefact that encapsulates the improved understanding and supports its implementation in hospitals.

A narrative literature review of lean and its application in hospitals was executed to explore the problem and develop objectives for a solution. It motivated the problem of incomplete and unsustainable implementations of lean and the lack of knowledge on how it can be achieved. Additionally, it identified the need for an assessment tool to determine the extent to which activities that would support this are being implemented. Systematic literature reviews were executed to answer the research questions. The factors that have been found to impact lean sustainability in hospitals were gathered, analysed, and synthesised to realise a collection of practices that aid the sustainability of lean in hospitals. Thereafter, a second systematic review of existing approaches to leanness assessment was executed to gather the practices required to implement lean holistically and to consider the possible approaches to structuring the assessment tool being developed.

The findings from the two reviews were then considered to develop a preliminary sustainable lean assessment tool (SLAT). A Delphi study was executed on the preliminary tool to verify and validate it. The tool was iteratively refined until the evaluation criteria were all satisfied, resulting in the final version of the tool. The resulting SLAT presents a tool consisting of all the practices required to sustainably transform into a lean hospital that hospitals can use to prioritise those needing improvement.

Opsomming

Die leiers van gesondheidsorg-organisasies is voortdurend op soek na maniere om gesondheidsorgwerksaamhede en -prosesse te optimaliseer, om aan die steeds toenemende vraag na die lewering van sorg met minder hulpbronne te voldoen. Ná die sukses van ‘soepel denke’ se implementering met gehalteverbetering terwyl koste verlaag word in die vervaardiginsbedryf, het bestuurders van gesondheidsorggeriewe dit ook begin implementeer. Dit is ŉ bestuursfilosofie wat op deurlopende verbetering gerig is.

Hoewel daar wyd oor die sukses van soepel denke in gesondheidsorg verslag gedoen is, was daar ook dikwels gevalle waar die gesondheidsorgfasiliteit ná ŉ ruk na die status voor implementering teruggeval het. ŉ Aanvanklike ondersoek na die toepassing van soepel denke in hospitale het onthul dat bydraende faktore tot onvolhoubare implementering die feit is dat soepel-implementering nie holisties geskied nie en assesserings nie op die regte teikens gemik word nie. Daar is egter te min bekend oor die organisatoriese steunfaktore wat nodig is om ŉ holistiese implementering oor die lang termyn te steun, en dus oor die faktore wat vir implementering geassesseer moet word. Die primêre doel van die navorsing was dus om by te dra tot ŉ verbeterde begrip van hoe om seker te maak dat soepel denke se implementering in hospitale deurgevoer word, om sodoende volhoubare verbeteringsuitkomste aan te moedig. Die sekondêre doel en om die praktiese toepassing van hierdie bevindings te rig, was om ŉ artefak te ontwikkel wat die verbeterde begrip saamvat en die implementering daarvan in hospitale ondersteun.

ŉ Narratiewe literatuuroorsig van soepel denke en die toepassing daarvan in hospitale is gedoen om die probleem te verken en oogmerke vir ŉ oplossing te ontwikkel. Dit het gelei tot die uitlig van die probleem van onvolledige en onvolhoubare implementerings van soepel denke en die gebrek aan kennis oor hoe dit bereik kan word. Dit het ook die behoefte aan ŉ assesseringshulpmiddel geïdentifiseer om vas te stel tot watter mate die werksaamhede wat dit sou ondersteun, geïmplementeer word.

Stelselmatige literatuuroorsigte is gedoen om die navorsingsvrae te beantwoord. Die faktore wat die volhoubaarheid van soepel denke in hospitale beïnvloed, is uitgeken, ontleed en gesintetiseer om ŉ versameling praktyke ter ondersteuning van die volhoubaarheid van soepel denke in hospitale op te lewer. Daarna is ŉ tweede stelselmatige oorsig van bestaande benaderings tot die assessering van soepelheid uitgevoer, om die praktyke wat nodig is om soepelheid holisties te implementeer, te identifiseer en om die moontlike benaderings tot die strukturering van die assesseringshulpmiddel wat ontwikkel moes word, in oënskou te neem.

Die bevindings uit die twee oorsigte is bestudeer om ’n voorlopige volhoubare-soepelheidsassesseringshulpmiddel (VSAH) te ontwikkel. ’n Delphi-studie is op die voorlopige hulpmiddel gedoen om dit te bevestig en te staaf. Die hulpmiddel is herhaaldelik verfyn totdat daar aan al die evalueringskriteria voldoen is, wat die finale weergawe van die hulpmiddel opgelewer het. Die gevolglike VSAH is ’n hulpmiddel wat bestaan uit al die praktyke wat nodig is om volhoubaar na ’n soepel hospitaal te transformeer en wat deur hospitale gebruik kan word om daardie aspekte wat verbetering vereis, te prioritiseer.

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List of Acronyms

AHP	Analytic hierarchy process
ANP	Analytic network process
ATA	Applied thematic analysis
CMM	Capability maturity model
D&D	Design and development
DEA	Data envelopment analysis
DEMATEL	Decision-making trial and evaluation laboratory
DMU	Decision making unit
DS	Design science
DSRP	Design science research process
DSS	Decision support system
ED	Emergency department
FCM	Fuzzy cognitive map
FDEA	Fuzzy data envelopment analysis
FLI	Fuzzy lean index
FPII	Fuzzy performance importance index
FSI	Fuzzy sustainability index
GTA	Graph-theoretic approach
HID	Health information department
IHI	Institute for Healthcare Improvement
IMVP	International Motor Vehicle Program
ISM	Interpretive structural modelling
IV	Interval-valued
IQR	Interquartile range
JIT	Just-in-time
KPI	Key performance indicator
LAT	Leanness assessment tool
LEAF-D	Lean Excellence Assessment Framework Driver
LMT	Lean maturity tracker

LOS	Length of stay
LSS	Lean Six Sigma
MD	Mehalanobis distance
MIT	Massachusetts Institute of Technology
MTBF	Mean time between failure
MTGS	Mahalanobis Taguchi Gram Schmidt
NHS	National Health Service
NHSII	NHS Institute for Innovation and Improvement
NNVA	Necessary but non-value added
NVA	Non-value added
OEE	Overall equipment effectiveness
OR	Operating room
PDCA	Plan-do-check-act
RCA	Root cause analysis
REC	Research and ethics committee
ROI	Return on investment
RTD	Real time delphi
RQ	Research question
SD	System dynamics
SLAT	Sustainable lean assessment tool
SLR	Systematic literature review
SME	Subject matter expert
SMED	Single minute exchange of dies
SO	Solution objective
SOP	Standard operating procedure
SPC	Statistical process control
TAT	Turnaround time
TMC	Toyota Motor Company
TPM	Total productive maintenance
TPS	Toyota Production System
TTM	Time-to-market

TQM	Total quality management
VA	Value-added
VOC	Voice of customer
VSM	Value stream mapping
WIP	Work in process

Glossary

Assessment parameters	The collection of measurable factors used by the tool to determine the sustainability level of the hospital.
Codes	A textual description of the semantic boundaries of a theme or component of a theme used for analysing data in a systematic literature review.
Lean philosophy	A continuous improvement philosophy focused on adding customer value, eliminating waste activities, and respect for people.
Lean principles	The building blocks of lean that characterise the philosophy.
Lean practice	An activity undertaken to implement lean principles.
Lean tools	Techniques used to support the implementation of lean practices.
Leanness	The degree to which and organisation adheres to the principles of lean.
Leanness assessment	An assessment of the extent to which the lean philosophy has been implemented in an organisation by means of implementing lean practices.
Sustainability practice	An activity undertaken to support lean sustainability
Theme	A unit of meaning that is observed (noticed) in the data by a reader of the text part of a systematic literature review.

Chapter 1 Introduction

Healthcare systems worldwide are facing increasing demands to deliver quality care with fewer resources (Blumenthal and Dixon, 2012; McWilliams *et al.*, 2019). Rapidly rising health expenditure fuelled by an ageing population and increasing population growth is adding strain to the already burdened healthcare system (Yu, Demirli and Bhuiyan, 2015; Crema and Verbano, 2016). The increased healthcare costs, along with many sources of inefficiencies and errors, cause a multitude of problems that need to be addressed to improve the current situation (Taner, Sezen and Antony, 2007). The recent coronavirus pandemic further highlighted the strain on healthcare systems and the importance of being able to rapidly make changes to all aspects of healthcare (Shah, Pereira and Tuma, 2021).

According to McWilliams *et al.* (2019), hospital care is the most significant contributor to health spending. Thus, the increasing pressure to respond to changing demands while reducing costs has led to many hospitals being redesigned for more efficient and effective care delivery within budget constraints (Alessandro, Malcolm and Jiju, 2013; Kinney *et al.*, 2017). To achieve the necessary quality and efficiency improvements in healthcare delivery, there has been increasing application of improvement strategies and tools (Walshe, 2009; Radnor, Holweg and Waring, 2012; Costa *et al.*, 2017). In a survey of 225 people involved in improving health and care across the United Kingdom, 51% of respondents said that quality improvement had been important during COVID-19, and 49% said the role of improvement methods and approaches increased in their organisation during the pandemic (Shah, Pereira and Tuma, 2021).

In recent years, the application of the lean philosophy, in particular, has been increasingly embraced (Yu, Demirli and Bhuiyan, 2015). *Lean philosophy*, or *lean thinking*, is often simply called “lean”, with the latter also adopted in the remainder of this document. Lean is a continuous improvement philosophy focused on adding customer value, eliminating waste activities, and respect for people (Lot *et al.*, 2018). It originated from the manufacturing industry but has been applied to various organisations, including those in the service sector (Bhamu and Sangwan, 2014). Its approach to doing more with less, and the specific focus on customer needs, make it an appealing philosophy to apply in healthcare (Costa *et al.*, 2017).

The interest in healthcare originated from the idea that it is intuitive, easy to use, and has compelling concepts particularly suited for hospitals (Rosa *et al.*, 2021). Hospitals implementing lean principles have stated it is the best overall approach compared to other methods because it values all members of the patient care team and can be implemented by anyone. Unlike other popular approaches, lean does not require advanced statistical methods, costly training, or expensive platforms and systems (NEJM Catalyst, 2018).

One of the first prominent appearances of lean in healthcare was in 2001 when Great Britain's National Health Service (NHS) adopted its principles. In 2002 the Joint Commission Institute in the USA further promoted its use to improve patient care while using fewer resources (Jones and Mitchell, 2006; Brandao de Souza, 2009; Radnor, 2010). Since then, lean's use in healthcare has grown considerably and has become one of the most popular approaches reported in literature for improving hospital operations.

Due to the popularity of employing lean in healthcare to improve operations, there has been growing evidence of its potential impacts, and successes have been widely reported (Tortorella *et al.*, 2019). However, authors have noted a bias towards publishing only the positive effects and a general lack of evidence of the longevity of these reported successes (Marsilio and Pisarra, 2021). Literature reviews investigating lean's application in healthcare have also highlighted that cases frequently show a partial implementation of the lean philosophy and restricted applications to single processes or departments (Zepeda-Lugo *et al.*, 2020; Marsilio and Pisarra, 2021; Rosa *et al.*, 2021).

Some authors have tried to address the problems with lean in healthcare by offering guidelines for implementation (Rosa *et al.*, 2021). However, these approaches have focused more on implementing lean tools than the philosophy behind them. Lean tools are fundamental in supporting lean implementation, but at their core, they should embody its principles (Marsilio and Pisarra, 2021). Not extending the focus to implementing the philosophy underpinning lean activities could lead to an incomplete adoption of its principles, resulting in unrealised changes in the ways of thinking and doing and, consequently, a lack of sustainable transformation (Radnor and Boaden, 2008; Breuer, 2013).

Approaches considering the aspects needed for the complete adoption of the philosophy exist, but these have mainly been developed for the manufacturing industry. A similar focus has not been found in healthcare (Henrique *et al.*, 2020), despite several studies showing the importance of considering context and adapting it to the industry in which it is being applied (Eriksson, 2017; Sethi *et al.*, 2017).

The absence of lean sustainability in healthcare is additionally influenced by the lack of monitoring and continuous double-loop learning identified in this field (Guimarães and de Carvalho, 2014). Reponen *et al.*

(2021) stated that "… hospital leaders would benefit from periodically conducting a Lean implementation assessment to understand the extent of Lean implementation in their organization. This will help them in identifying areas in which to focus attention". An assessment tool that guides hospitals on what needs to be prioritised to align themselves with lean principles would thus support the practical implementation of this knowledge.

However, while holistically implementing lean may lead to improvements, this alone will not sustain them. Studies have shown that several supporting organisational factors are also needed for the long-term uptake of the lean philosophy (Hallam and Contreras, 2018; Rundall *et al.*, 2021). But lean sustainability in healthcare remains severely understudied (Henrique and Filho, 2020; Lindsay, Kumar and Juleff, 2020; Marsilio and Pisarra, 2021). Thus, the purpose of this study was to consolidate the existing knowledge on lean implementation in hospitals and find how its outcomes can be improved and maintained.

In this chapter, the research topic is introduced by outlining the problem focus (Section 1.1) and the research aim and questions formulated (Section 1.2). The study's scope (Section 1.3) and ethical considerations (Section 1.4) are then discussed, and the document outline is presented (Section 1.5).

1.1 PROBLEM STATEMENT

Despite the number of successful cases reported, some evidence suggests that the failure rate of lean programmes in healthcare is, in fact, high and that hospitals have struggled with implementing it sustainably (Henrique *et al.*, 2020; Rundall *et al.*, 2021). Studies detailing cases of lean application in hospitals have shown incomplete adoptions of the philosophy and a lack of follow-ups (Lindsay, Kumar and Juleff, 2020; Zepeda-Lugo et al., 2020). Additionally, in these studies, there is little dissemination of the implementation approach adopted (Henrique and Filho, 2020; Rosa *et al.*, 2021). Thus, not only is there increasing evidence of incomplete and unsustainable implementations of lean but a lack of knowledge on how to achieve and maintain improved outcomes.

1.2 RESEARCH AIM AND QUESTIONS

Towards fostering sustained improvement outcomes, the primary aim of this research is to contribute toward an improved theoretical understanding of how to ensure lean's implementation in hospitals is sustained. The secondary aim is to guide the practical application of these findings by developing an artefact that encapsulates the improved understanding and supports its implementation in hospitals.

The following research questions (RQs) need to be answered for the research aims to be achieved:

RQ1: How should lean be implemented in hospitals to ensure sustained performance gains?

RQ1a: How might lean holistically be implemented?

RQ1b: What aids a sustainable implementation of lean?

RQ2: What might an artefact entail that supports a long-term holistic implementation of lean in hospitals?

RQ2a: What is the ideal format for an artefact that could support holistic long-term implementation of lean in hospitals?

RQ2b: What output might the artefact present and how is it determined?

1.3 RESEARCH SCOPE

This research is focused specifically on the application of lean in hospitals. The scope is therefore limited to the facility level and does not consider the larger healthcare supply chain or other types of healthcare facilities. Additionally, no mixed methods such as agile lean or lean six sigma are considered. While there are similarities in their aims and philosophies, ultimately, different tools and techniques are employed in each. Considering other quality improvement approaches could lead to findings that do not apply to hospitals seeking to undergo a purely lean transformation.

1.4 ETHICAL CONSIDERATIONS

A Delphi study was executed to evaluate and refine the artefact developed. To complete it, opinions of experts who have practically worked with implementing lean in the context of hospitals needed to be obtained. In the interactions with the Delphi study participants, the ethical guidelines of the Research and Ethics Committee (REC) of Stellenbosch University were followed. Additionally, ethical clearance was obtained from the REC to conduct the Delphi study (Project number ING-2021-23303). Informed consent for participation was obtained using the prescribed REC participant consent form (presented in Appendix A).

While the participants required experience implementing lean in hospitals, they did not need to be associated with a specific healthcare facility. The Delphi study relied solely on the personal opinions and experiences of the participants involved and required no information or data from a particular healthcare facility. Therefore, the participants participated in the study as experts in their own right, not as representatives of the institution where they may work. Only feedback based on lean implementations for the general context was obtained.

1.5 DOCUMENT OUTLINE

This section provides a summary of the document that was structured to reflect the course of this study. A brief description of the contents of each chapter can be found below.

Chapter 1: Introduction

This chapter summarises the research problem context and its aims and objectives. The scope, ethical considerations, and document structure are also described.

Chapter 2: Research methodology

In this chapter, the research philosophy, approach, and strategy that was adopted to execute the research are discussed. The specific steps and the research methods applied to them were also provided.

Chapter 3: Problem and solution identification

This chapter provides a background to the study by investigating the concept of lean through a narrative review. It outlines its definitions, history, and underlying ideas to ensure an in-depth understanding of the philosophy on which the problem focuses. Once established, its application in healthcare was explored to identify critical issues with its implementation in this context. The problem areas identified in this stage guided the focus of the investigation that followed.

Chapter 4: Lean sustainability practices

An investigation into the factors inhibiting or aiding sustainable lean implementations through a systematic literature review (SLR) was executed in this chapter. The findings were synthesised and organised into a concise collection of practices necessary for a sustainable implementation of lean.

Chapter 5: Existing leanness assessment tools and methodologies

This chapter presents an analysis of the existing approaches to leanness assessment through another SLR to investigate what was needed to holistically implement the lean philosophy in general, an essential aspect of lean sustainability. The findings were synthesised, consolidated, and applied to a hospital setting.

The existing methodologies were also considered for their approach to determining leanness so the ideal structure and methods for the developed artefact could be determined. Doing this ensured that the model was structured logically and addressed any gaps that current methodologies may have. The completion of this review concluded the literature exploration phase of the study, following which the development phase commenced.

Chapter 6: Tool development

After relevant literature was studied, a tool was developed from the information presented in Chapters 4 and 5. The tool developed in this study is referred to as the SLAT (sustainable lean assessment tool). This chapter details the process used to structure the parameters on which the SLAT would be based and its general assessment approach and design. Aspects considered included, inter alia, the type of data to use, how this data is collected, the method for executing the assessment, and how the user interface would look.

Chapter 7: Tool evaluation

Once the initial tool had been established, it was further refined and evaluated by subject matter experts to validate the structure of the tool and its contents. Necessary amendments to the tool were made through iterations of a Delphi process, and the final tool was realised. The evaluation process and its outcomes are presented in this chapter.

Chapter 8: Discussion of findings

Following the completion of the tool evaluation, the findings are discussed. Thus, the practicality and generalisability of the results is considered in this chapter.

Chapter 9: Conclusions and recommendations

In the final chapter, the dissertation is concluded by offering an overview of the research presented, confirming the attainment of the research objectives, and summarising the contributions made by the study. Additionally, recommendations for future research are made.

Chapter 2 Research methodology

The steps that were taken to execute the research study and answer the research questions are detailed in this chapter. The chapter aims to explain and motivate the methodological decisions made in realising the aim of the study. In doing so, the philosophical assumptions of the research (Section 2.1), the overarching strategy employed (Section 2.2), and specific research methods adopted in executing this strategy (Section 2.3) are discussed. A conclusion of the chapter is provided in Section 2.4.

2.1 PHILOSOPHICAL ASSUMPTIONS

There are four possible primary worldviews (also referred to as paradigms) to take when conducting research, each comprising different philosophical assumptions. These are postpositivist, constructivist, transformative, or pragmatic (Creswell, 2014). The assumptions that make up a worldview give insight into how reality is defined in the research, determining what it seeks to understand and, in effect, the research design that most effectively captures this reality (Bell, Bryman and Harley, 2019). Consideration of the assumptions made ensures a credible research philosophy, which then forms the foundation for the choice of research approach, method, strategy, and design (Saunders, Lewis and Thornhill, 2019).

This research takes a pragmatic view, characterised by value-driven research initiated by a sense that something is wrong or out of place (Elkjaer and Simpson, 2011). Instead of focusing on methods, pragmatists emphasise the research problem and use all available approaches to derive adequate knowledge about the problem. Researchers thus liberally draw from quantitative and qualitative assumptions (Creswell, 2014). This tactic contrasts with other worldviews, which typically subscribe to a specific approach. While a range of methods, techniques, and approaches are available to choose from, multiple methods are not always employed. Instead, the method or methods that are most relevant and best meet the needs and purposes of the study are used (Saunders, Lewis and Thornhill, 2019). The approach chosen must enable the collection of credible and reliable data to advance the research and find practical solutions and outcomes, allowing pragmatists to achieve their aim of contributing practical solutions that inform future practice (Saunders, Lewis and Thornhill, 2019).

2.2 RESEARCH STRATEGY

In deciding the strategy that should guide the execution of the research, design science (DS) research was considered. DS is concerned with "devising artefacts to attain goals" (Simon, 1996). Where natural sciences attempt to understand reality, design science tries to "create things that serve human purposes" (March and Smith, 1995). The goal of design science is thus to improve the human condition by developing knowledge to solve real problematic situations (Denyer, Tranfield and van Aken, 2008). This research is centred around solving the problem of unsuccessful lean implementations, making DS particularly suited for this study. Its pragmatic approach to deriving solutions made it appropriate for attaining both the primary and secondary research aims.

The design science research process (DSRP) model presented by Peffers et al. (2006) for applying DS research in information systems is used to develop the overarching strategy for executing this study. The DSRP comprises six activities in a nominal sequence shown graphically in Figure *2.1*.

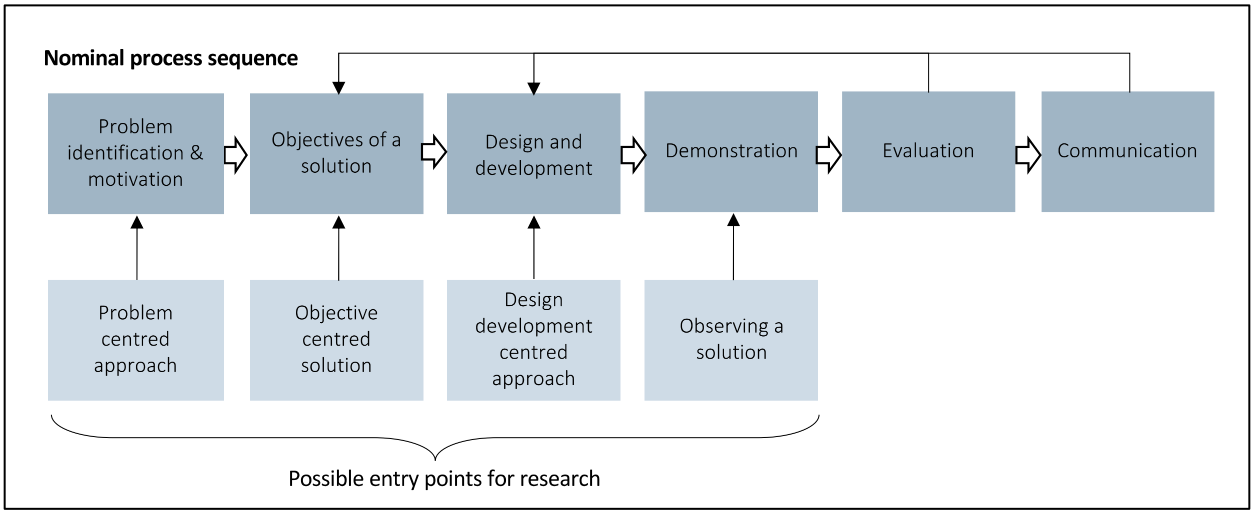

Figure 2.1 Design science research process (DSRP) model (Peffers *et al.*, 2006)

Although the steps are illustrated sequentially, they need not necessarily be executed this way. Peffers et al. (2006) state that depending on the nature of the research, the model can be implemented starting from different stages and moving outward from there. Figure *2.1* shows four typical entry points depending on four different approaches: a problem-centred approach, an objective-centred solution, a design- and development-centred approach, and observing a solution. In the case of this research, the solution approach is driven by the problem it is trying to solve. Thus, the research strategy begins with the problem identification and motivation step of the DSRP.

In this step, the specific research problem being addressed must be defined, and the value that the solution to the problem will have must be justified. Peffers et al. (2006) argue that doing this accomplishes two things, it 1) motivates the need for research into a solution and acceptance of the results; and 2) creates an understanding of the reasoning associated with the researcher's understanding of the problem. Extensive exploration and identification of the problem are thus required to justify the solution needed and guide the research and design toward achieving it.

Secondly, the objectives the design must satisfy to solve the problem identified in the previous step need to be outlined. They can be qualitative or quantitative, depending on the nature of the solution (Peffers *et al.*, 2006). Therefore, once the problem's key causes were identified in the first step, how to approach a solution was explored.

Thirdly, following the conceptualisation of the necessary solution, a solution artefact's desired functionality and architecture must be determined, and the actual artefact must be created (Peffers *et al.*, 2006). Artefacts could be realised as constructs, models, methods, or instantiations (March and Smith, 1995).

The DSRP then demonstrates the developed solution, where the ability of the artefact to solve the problem it is aimed at must be shown. An experiment, simulation, case study, or any activity that similarly demonstrates this can be used. This step is followed by evaluation, where the artefact's ability to solve the problem is ascertained by comparing the demonstration results to the outlined objectives. In the case of this research, the evaluation consisted of both a verification and validation procedure. The verification evaluates whether the artefact developed complies with the regulations, specifications, or conditions imposed at the start of the development phase. Validation establishes evidence that the artefact accomplishes its intended use requirements. Thus, the findings from the evaluation were used to demonstrate that the tool meets the solution objectives. The demonstration and evaluation stages were therefore combined in the adopted research strategy.

The evaluation findings determine whether further improvements to the artefact are required or could be considered for subsequent projects (Peffers *et al.*, 2006). The route or alternative chosen is dependent on the nature of the research. This research revisited the artefact design after each evaluation round until the pre-defined criteria were met. Once this was achieved, the final version of the tool was realised, and the feedback loop closed.

Lastly, the problem and its importance, the artefact itself and its utility and novelty, the rigour of its design, and its effectiveness must be communicated to researchers and other relevant audiences, such as practised professionals, when appropriate. Communication in scholarly research can be done by using the DSRP to structure the paper (Peffers *et al.*, 2006). Thus, through presenting the final tool and completing this dissertation, the communication stage of the DSRP is executed. A discussion of the research findings and conclusion of the study additionally serve as the execution of this step.

The resulting research strategy adopted is shown in Figure *2.2* along with a depiction of how it relates to the DSRP stages from which it was derived. How the stages are linked to the dissertation chapters presented is shown in Table 2.1.

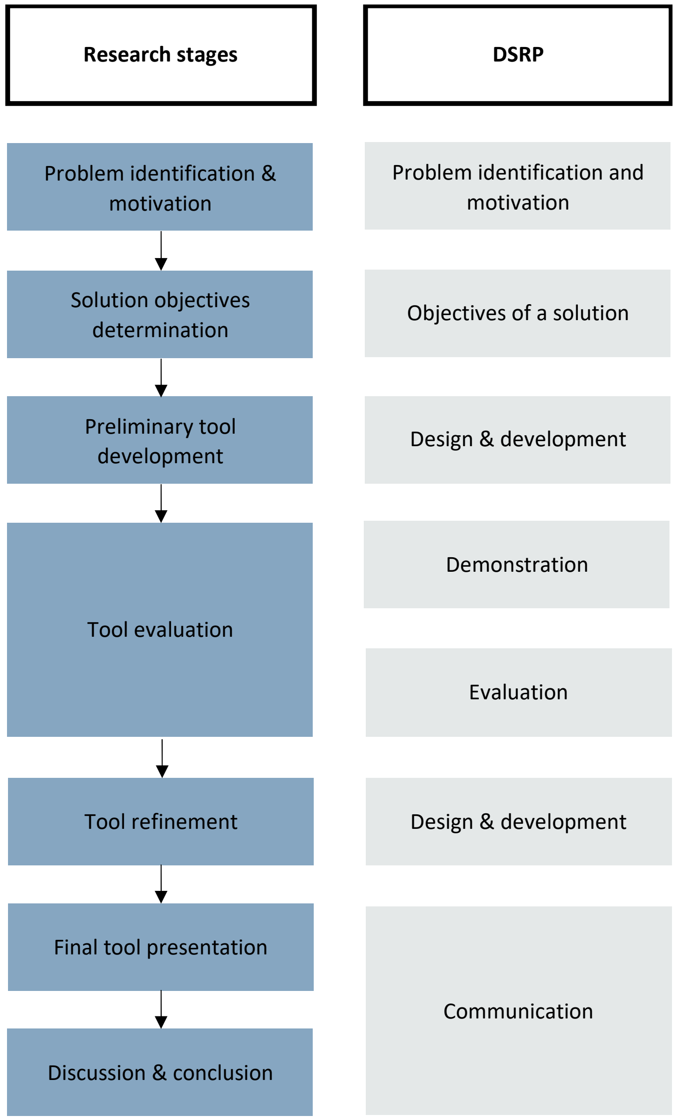

Figure 2.2 Adopted research strategy

2.3 RESEARCH METHODS

Research methods refer to how data is collected, analysed and interpreted (Creswell, 2014). A mixed methods approach using both qualitative and quantitative techniques was employed. The methods used to carry out the research strategy, the value they add, and in which stages they were applied are explored in this section.

2.3.1 LITERATURE REVIEWS

A review of prior, relevant literature is an essential feature of any academic project. It creates a foundation of knowledge upon which an understanding of the existing research area can be built (Webster and Watson, 2002; Snyder, 2019). Various approaches to executing a literature review exist, but the two types utilised in this research are narrative and systematic reviews. A systematic review follows explicit, rigorous, and transparent procedures to review existing literature (Greenhalgh *et al.*, 2005). It is thus generally used to answer a specific question or test a particular hypothesis (Thomé, Scavarda and Scavarda, 2016), while narrative reviews tend to be less focused and more wide-ranging (Bryman and Bell, 2014). Because a narrative review is less explicit about the studies included and summarises a larger amount of information, it is an excellent approach for gaining an initial understanding of the topic being explored and drawing conclusions about research gaps (Bryman and Bell, 2014; Sangwa and Sangwan, 2018). Thus, the narrative review was deemed most appropriate for the first two stages of the research, namely the problem identification and motivation, and determining the solution objectives.

Systematic literature reviews (SLRs), on the other hand, were utilised to support the design and development of the solution. An SLR is less of a discussion of previous writings and more of a scientific tool that can be used to locate and evaluate the relevant studies and analyse them to draw clear conclusions (Petticrew and Roberts, 2006; Thomé, Scavarda and Scavarda, 2016). Therefore, two SLRs were conducted in the design and development of the solution. The first investigated the factors that have been found to contribute to sustained lean implementation. The second evaluated existing approaches to leanness assessment so practices required for a holistic implementation of lean could be discovered, and the possible capabilities and methods for the assessment tool could be considered. Once the relevant studies have been selected, different research synthesis techniques can be used to analyse them (Bryman and Bell, 2014). The specific analysis approach chosen for each review is discussed in the chapters where they are reported.

For the procedure used to execute the SLRs, to ensure methodological rigour and reduce bias in their execution, an applied thematic analysis (ATA) was used in conjunction with the content analysis steps presented by Trakulsinti *et al.* (2018). ATA is an inductive framework developed by Guest, Macqueen and Namey (2012) for analysing qualitative research. This framework was chosen due to its flexible analytic approach and techniques that can be used, in addition to the fact that it was specifically designed to analyse textual data (Mackieson, Shlonsky and Connolly, 2019).

The ATA framework discusses planning and preparing for the analysis by establishing analytic objectives, writing an analysis plan, choosing an analytical approach, and bounding the analytical view (Guest, MacQueen and Namey, 2012). Once the planning has been done, the process of analysing the data through an iterative process of identifying features (i.e. themes) and defining boundaries around those features (i.e. text segmentation) is explained (Guest, MacQueen and Namey, 2012). To consider the overall process for gathering the data used for this analysis, the ATA was supplemented with Trakulsinti *et al.'s* (2018) content analysis steps to ensure rigour in the selection process.

The steps of content analysis used in Trakulsinti *et al.* (2018) include first ascertaining the inclusion and exclusion criteria for the studies to be considered. Secondly, the decisions regarding the search strategy employed to collect relevant articles and the information sources used for this search must be outlined. Thirdly, the study selection process using the previously defined eligibility criteria must be detailed. The final stage of the method employed by Trakulsinti et al. (2018) includes data extraction. Here is where the ATA is used. It was decided, however, to execute the ATA planning and preparation stage before data collection, as opposed to only after, once the data extraction proceeds. Thus, the overarching combined methodology used to execute the review, utilising elements from both the ATA and steps for an SLR, is shown in Figure *2.3*.

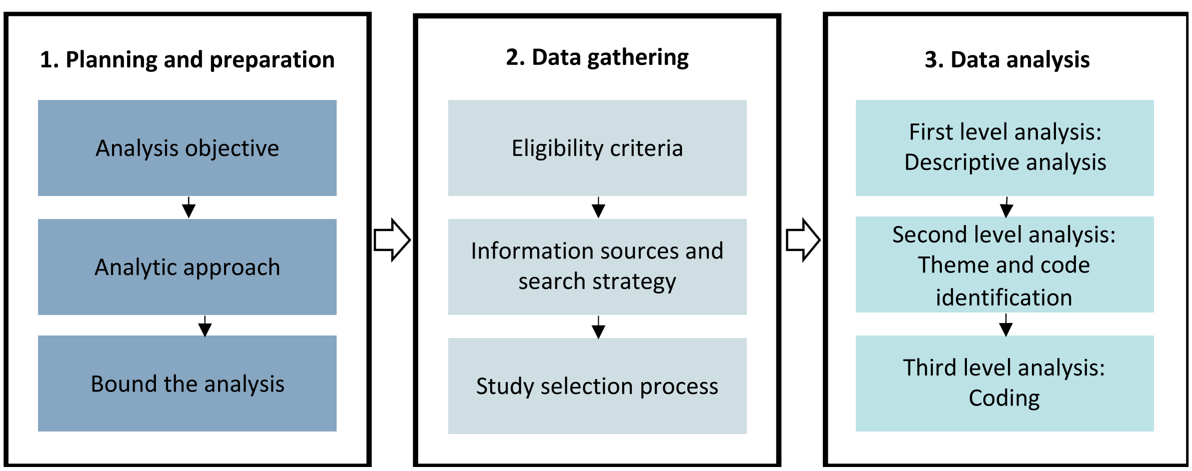

Figure 2.3 Process for executing a systematic review

2.3.2 DELPHI STUDY

The Delphi study (also referred to as the Delphi technique, procedure, process, or methodology) is a systematic and qualitative method of aggregating a group opinion or decision. It uses a series of iterative questionnaires sent to a panel of experts knowledgeable about a particular topic to reach an intended consensus (MacCarthy and Atthirawong, 2003; Seuring and Müller, 2008). The Delphi technique has four methodological features as outlined by Jünger *et al.* (2017):

1. A group of experts is questioned about the issue of interest;
2. The process is anonymous to avoid social pressure in cases where the problem is intractable or political and reduce the influence of dominant individuals;
3. The process is iterative in nature, comprising several rounds of enquiry; and
4. A summary of the group response from the previous round informs the design of subsequent ones.

A Delphi study can thus be used to obtain a reliable consensus of a group of experts while overcoming the negative effects of face-to-face group interactions, such as one person dominating the interaction and influencing the other responses (Dalkey and Helmer, 1963; MacCarthy and Atthirawong, 2003; Geist, 2010). Additionally, it is ideal for evaluation situations where not all participants are geographically accessible or readily available due to busy schedules (Geist, 2010).

The Delphi study is markedly relevant in the case of this research focus, where higher evidence grade methods such as regression analysis or observational studies aren't feasible (Jünger *et al.*, 2017; Niederberger and Spranger, 2020). To execute such analysis, multiple case studies carried out over numerous years would be required to test impact on sustainability. Even then, the complexity of hospitals and additional organisational factors that contribute when implementing such changes would make it challenging to expressly prove causality. Thus, for these pragmatic reasons, Delphi is the most suitable approach. It utilises the knowledge that comes from years of relevant experience, providing valuable insights and findings.

The Delphi procedure begins by generating the information used for the initial questionnaire. Methods to inform the first Delphi round could include, amongst others, approaching the Delphi panel for ideas, executing literature reviews, or developing conceptual frameworks (Cantrill, Sibbald and Buetow, 1996;

Jünger *et al.*, 2017). In the case of this research, the SLRs (discussed in Section 2.3.1) were used. However, if the Delphi panel is used to generate ideas, the generative round would only occur after the panel has been formed. Next, the study preparation commences. This phase involves a careful panel selection process where criteria for potential respondents are defined, and any experts found to conform to such requirements are invited to participate in the study. The panel should comprise a group of people familiar with and knowledgeable about the problem domain being considered, and it is also vital that they be mutually anonymous (MacCarthy and Atthirawong, 2003). Thereafter, the first evaluation round can begin.

A typical Delphi round involves first constructing the questionnaire that will be used for that round. The construction uses the information obtained in the generative round. Thereafter, independent opinions from a group of experts are gathered in an assessment phase using the questionnaire. Once all the responses have been received, they are reviewed, and the data is aggregated into a summary report. The summary report is issued to each expert as feedback. The panellists then review the summary report, which includes a complete record of the opinions of the other panellists, and give an updated response, agreeing or disagreeing with the other experts' answers. The facilitator once again reviews the data and issues a second report. The process repeats until all participants reach a consensus, after which the study is concluded and results are reported (MacCarthy and Atthirawong, 2003). The steps used for the Delphi study are illustrated in Figure *2.4*., which was derived from various studies detailing a typical Delphi process (MacCarthy and Atthirawong, 2003; Geist, 2010; Jünger *et al.*, 2017).

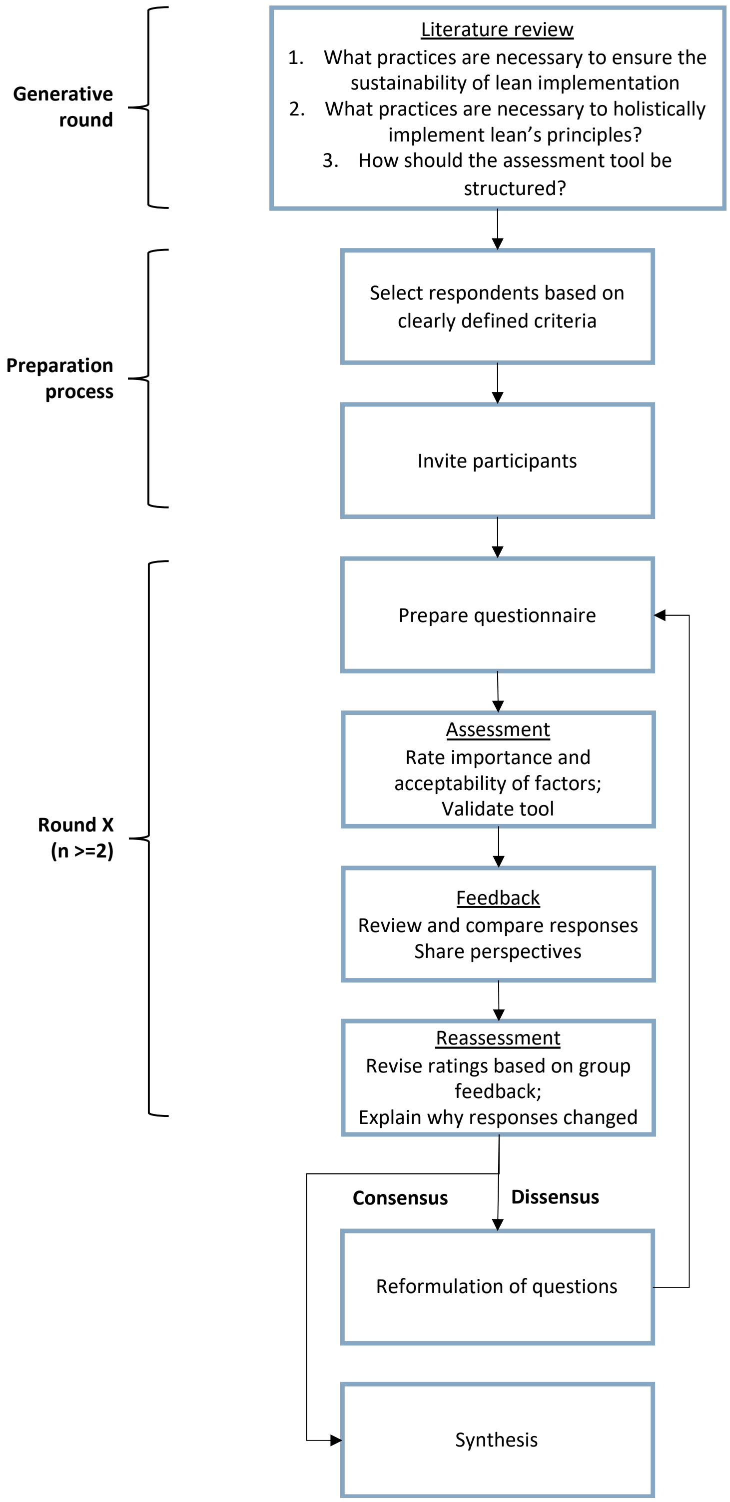

Figure 2.4 Delphi process

Finally, the methods used for each stage of the research strategy adopted are shown in Figure 2.5. Additionally, how they link to the dissertation chapters is shown in Table 2.1, along with references to any publications based on the work. How each method was executed is explored in the chapters where they are applied.

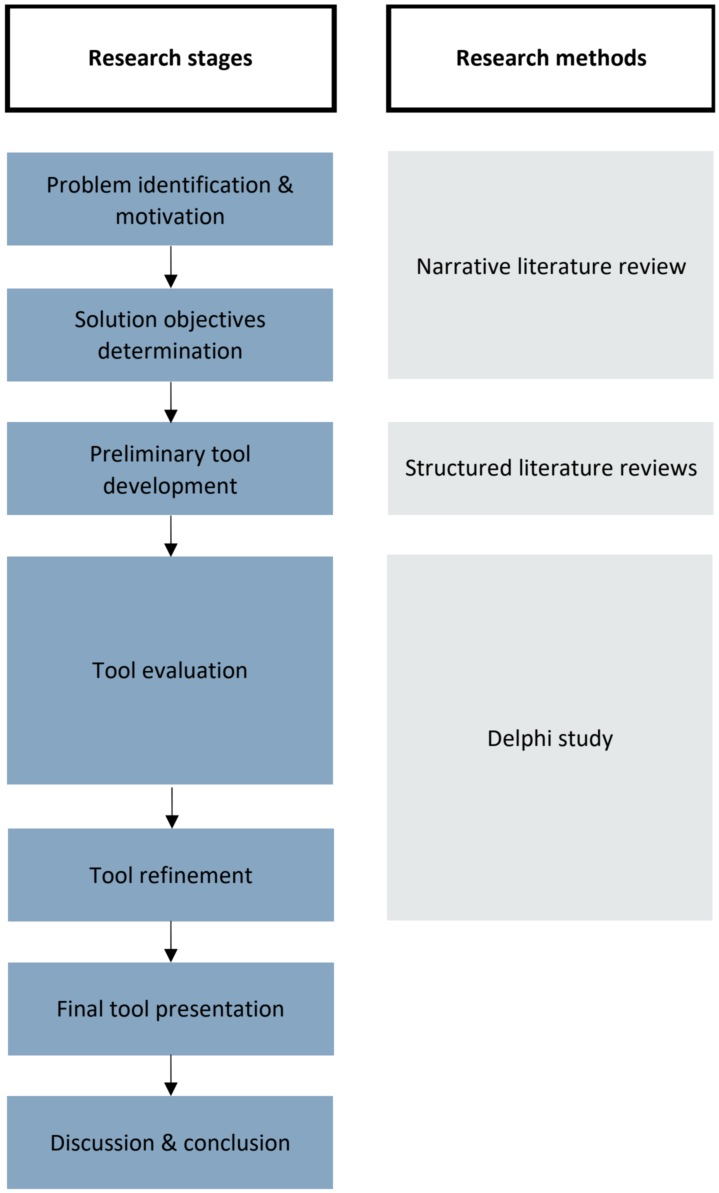

Figure 2.5 Research methods employed

Table 2.1 Document overview

Chapter	**Research strategy stage**	**Methods**	**Publication**[1]
Chapter 3	Problem identification & motivation	Narrative review	Joubert, B. & Bam, W., 2019. Review and classification of Lean project aims in hospitals. *2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC).* © 2019 IEEE
	Solution objectives determination		
Chapter 4	Preliminary tool development	Systematic literature review	N/A
Chapter 5			Joubert, B. & Bam, W., 2020. Towards a hospital leanness assessment tool: A review. *2020 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC).* © 2020 IEEE
Chapter 6			Joubert, B. & Bam, W., 2022. Development of a leanness assessment tool for hospitals. *2022 IEEE 28th ICE/ITMC & 31st IAMOT Joint Conference.* © 2022 IEEE
Chapter 7	Tool evaluation	Delphi study	Forthcoming
	Tool refinement		
	Final tool presentation		
Chapter 8	Discussion & communication	N/A	N/A
Chapter 9			

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2.4 CHAPTER 2: CONCLUSION

This chapter introduced the strategy employed for executing the research. It began by describing the underlying philosophical approach adopted and motivating the use of design science. The research strategy was then laid out, and the methods utilised for each stage of this process were discussed. Through a narrative review Chapter 3 identified and motivates a problem and determined objectives for the solution to this problem. Thus, detailing the first two stages of the strategy outlined in Chapter 2.

Chapter 3 Problem and solution identification

This chapter aims to investigate the problems hospitals face in implementing lean and determine a solution approach to address them. Thus, lean's underlying philosophy and principles were explored in Section 3.1. To provide further background on lean, how it originated and became the management strategy it is today is discussed in Section 3.2. How lean exists in the healthcare space and contrasts with the industry it originated from is then discussed in Section 3.3 to adequately understand the impact the inherent differences between manufacturing and healthcare have on its practical application in hospitals. The problems with lean's application in healthcare are then discussed in Section 3.4, which leads to the identification of a solution approach. The objectives for such a solution are outlined in Section 3.5 and the chapter is concluded in Section 3.6.

3.1 THE LEAN PHILOSOPHY

Lean is a popular philosophy widely used in many industries around the world to improve organisational performance. It is generally understood to increase productivity and reduce costs. But due to its wide application, no precise, definitive definition exists (Alessandro, Malcolm and Jiju, 2013; Costa *et al.*, 2017). Those found in literature are fluid and often vague, with varying aspects being emphasised across different sources (New *et al.*, 2016). The overall tenet, however, is that it is a continuous improvement approach focused on increased customer value, elimination of waste, and respect for people (Hines, Holweg and Rich, 2004; Bon and Kee, 2015; Naidoo and Mahomed, 2016; Balaji and Senthil Kumar, 2018). Radnor, Holweg and Waring (2012) define lean as "a management practice based on the philosophy of continuously improving processes by either increasing customer value or reducing non-value activities (Muda), process variation (Mura), and poor working conditions (Muri)".

Radnor, Holweg and Waring's (2012) definition highlights the three deviations from the efficient allocation of resources recognised by the lean philosophy. These sources of inefficiency, also seen as the "three sins of production", are classified as Muda, Mura, and Muri (Rinehart, Huxley and Robertson, 1997). Muda ("waste" in Japanese) are activities that do not contribute to creating value. Mura ("unevenness" in Japanese) is any variation leading to fluctuation or unbalanced situations in operation. Lastly, muri ("overburden" in Japanese) refers to activities putting employees or equipment under too much stress or strain (Rinehart, Huxley and Robertson, 1997). All three sources of inefficiency must be targeted for reduction when implementing lean.

Another way of conceptualising lean is through the identification of its principles. These, again, vary among different authors, but the most widely cited principles were those outlined by Womack and Jones (1996), which are also sometimes viewed as the steps required to execute lean. They include:

1. **Value specification**: Specify the product or service's value to the customer.
2. **Identify value streams**: Identify the value stream for each product or service providing the identified value, and minimise (or eliminate where possible) the non-value-adding steps.
3. **Make value flow continuously:** Standardise processes so that they run more smoothly and barriers to the flow of product or information are eliminated, thus freeing up time for creativity and innovation.
4. **Pull value**: Introduce "pull" between all steps where continuous flow is impossible. Demand must be dictated by the customer, triggering events backwards through the value chain.
5. **Seek perfection**: Continuously improve so that non-value-adding activities are consistently being removed, reducing the number of steps, amount of time, and information needed to serve the customer.

Some of the terms from the definition above are explained to provide clarity. The "value streams" that must be identified for the product or service refer to an optimised end-to-end group of actions that enables its delivery to the customer. "Flow" refers to arranging activities so that no discontinuities exist in the value stream. Finally, introducing "pull" means that only what is needed will be produced, therefore making the customer's needs the primary decision driver (Karvonen *et al.*, 2012).

The principles of lean highlight that value and how the customer perceives it must drive operation. In addition to goals such as reducing costs and improving productivity, the focus of the lean philosophy is on enhancing the value experienced by the customer (Selvaraju, Ramakrishnan and Testani, 2012). Critical to lean's implementation is thus the identification and definition of what value is. The needs, wants, meaning, and experiences of the product or service across the entire chain of internal and external customers must be accumulated to determine this (Welo and Ringen, 2017).

"Value" is most commonly defined as any action or process the customer is willing to pay for (Karvonen *et al.*, 2012; Matawale, Datta and Mahapatra, 2015). The expenditure of resources for anything other than value creation is thus considered a waste (Matawale, Datta and Mahapatra, 2015). Fiore (2005), however, adds two further requirements. He states that value is created if a specific operation or process meets the following three criteria: (1) The customer is willing to pay for the activity; (2) It transforms the physical shape of the object or product; and (3) It is done correctly the first time. Waste, by his definition, is therefore created when an operation fails to meet any of those requirements (Fiore, 2005). Whichever way the organisation defines value, the critical point is that any activities not directly contributing to its creation must be minimised or eliminated where possible. Activities contributing directly to the satisfaction of client needs are thus classified as value-added activities, and non-value-added activities are those that yield no value and therefore viewed as unnecessary (Karvonen *et al.*, 2012; Matawale, Datta and Mahapatra, 2015). By eliminating these non-value-added elements, or wastes, greater value is given to the customer.

Waste can be divided into two types: Type 1 waste, called enabling activities, are activities which do not directly create value but are necessary to support value creation in the organisation and thus cannot be eliminated. These are typically activities such as administration, management, and mandatory testing (Welo and Ringen, 2017). Type 2 is pure waste, and the lean philosophy recognises eight types of pure waste: defects, overproduction, transportation, inventory, motion, waiting, over-processing, and underutilisation of people (Hines and Rich, 1997; Welo and Ringen, 2017). The eighth waste of underutilised employees has been a more recent consideration and was only later added to the list of seven wastes, particularly for service and information industries (Vinodh and Balaji, 2011; Sethi *et al.*, 2017).

Various practices, tools, and techniques are associated with the lean philosophy that can be implemented to realise its overall goals, such as enhancing organisational performance by improving productivity, cost-effectiveness, and quality (Doolen and Hacker, 2005; Shah *et al.*, 2013; Matawale, Datta and Mahapatra, 2015; Omogbai and Salonitis, 2016). The extensive collection of tools forming part of lean is an accumulation of solutions for various problems over decades (Wan and Chen, 2009). Some of these tools include Total Quality Management (TQM), total productive maintenance (TPM), 5S, Kanban, continuous improvement (kaizen), just-in-time (JIT), poka-yoke, value stream mapping (VSM), and many others (Sahoo *et al.*, 2008; Bon and Kee, 2015; Balaji and Senthil Kumar, 2018). Based on the work of Dean and

Bowen (1994), the principles of lean are what characterise the philosophy and can be seen as the "building blocks" of lean (Åhlström, 2004). The practices are then the activities undertaken to implement these principles, while the tools are the techniques used to support these practices (Dean and Bowen, 1994).

It is important to note that lean does not mean all processes are simply streamlined to do everything as fast as possible. Instead, it is about doing things at the right pace to produce what is required when it is required, according to customer demand (Selvaraju, Ramakrishnan and Testani, 2012; Ali and Deif, 2014). This approach ensures customer demand is met on time with minimal waste (Shams Bidhendi, Goh and Wandel, 2019).

In summary, lean is a philosophy for structuring, operating, controlling, managing, and continuously improving systems (Detty and Yingling, 2000). It does this by transforming the entire organisation's operations, creating a culture of change amongst all workers.

3.2 HISTORY OF LEAN

Although lean today is an approach applied in many industries worldwide, it was initially developed in the automotive industry. It is primarily based on a production philosophy from the Toyota Motor Company (TMC) in Japan (Ulhassan *et al.*, 2013; Thanki and Thakkar, 2014; Bon and Kee, 2015). Towards the end of the 1940s, Toyota was facing severe cash flow problems after the end of World War II due to shortages of raw materials, money, and workers (Pavnaskar, Gershenson and Jambekar, 2003; Weloa, Tonninga and Rølvåga, 2013; Bon and Kee, 2015). Drastic changes needed to be made to survive in a challenging environment where resources were limited, and waste could not be afforded. It was at this critical period that the Toyota Production System (TPS) was developed. Ohno, who played a crucial role in the development of the TPS, then published the TPS in Japan in 1978 (Pavnaskar, Gershenson and Jambekar, 2003; Wan and Chen, 2009; Bon and Kee, 2015).

The improvements that this new way of approaching production brought, which strongly contrasted with the traditional mass production practices at the time, caught the attention of western industries (Bon and Kee, 2015). In 1988 studies into the significant difference between traditional mass production and the TPS started taking place at the Massachusetts Institute of Technology (MIT) as part of the International Motor Vehicle Program (IMVP). It was here where the term "lean" was first used by Krafcik (1988) to describe the TPS due to its ability to "do more with less" (Buesa, 2009; Shetty, Ali and Cummings, 2010).

It was not until Womack and Jones (1991) used the term in their book 'The machine that changed the world', however, that the lean philosophy as it is understood today was widely popularised (Taj, 2005; Shetty, Ali and Cummings, 2010; Gupta and Kundra, 2012; Bon and Kee, 2015). In their book, lean was the common heading used for the set of techniques explained to have led to the success of Japanese auto manufacturers. The book discusses the departure from the traditional mass-production system initiated by the TPS. Lean manufacturing is lean because it uses less of everything compared to mass production, which is characterised by high-volume production with limited variety (Vinodh and Balaji, 2011). Womack and Jones (1996) defined lean as: "[…] a way to specify value, line up value-creating action in the best sequence, conduct those activities without interruption whenever someone requests them, and perform them more and more effectively. In short, lean thinking is lean because it provides a way to do more and more with less and less – less human effort, less human equipment, less time, and less space – while coming closer and closer to providing customers with exactly what they want." (Alessandro, Malcolm and Jiju, 2013).

Womack and Jones' second book 'Lean thinking' further studied the adoption of lean in other companies (Taj, 2005; Weloa, Tonninga and Rølvåga, 2013). It was here where lean manufacturing was presented as more than just a technique but a way of thinking. They emphasised that its implementation requires a systemic approach to create a culture of continuous improvement across the entire organisation (Taj, 2005). While many of the techniques discussed in the book were already well known, the systemic approach where lean forms part of an overall production strategy was new. However, because there was no guided systematic way to apply lean principles in practice, it added some confusion regarding how to implement it in such a way (Weloa, Tonninga and Rølvåga, 2013).

Nevertheless, following the publication of these books and the increased popularity of the approach, many organisations adopted the philosophy, and the benefits of practically implementing its theory, principles, and methodologies became fully recognised (De Meyer and Wittenberg-Cox, 1992). Since then, lean has grown significantly, and over the years, there have been many examples of the benefits that lean's application has had in manufacturing (Weloa, Tonninga and Rølvåga, 2013; Martinez, 2018). Lean thus started being applied outside the manufacturing and expanded far beyond the automotive industry where it originated. Today it is widely used and accepted across many industries worldwide, including manufacturing, aerospace, banking, healthcare, and even non-profit organisations (Hines, Holweg and Rich, 2004; Doolen and Hacker, 2005; Maasouman and Demirli, 2016). While the application of lean today spans multiple sectors, most cases still relate to manufacturing processes, and therefore, its research also primarily concentrates on this sector (Martinez, 2018).

3.3 LEAN IN HEALTHCARE

Due to increasing issues regarding patient safety, the escalation of medical costs, and the increasing number of medical errors, the quality of healthcare services has globally become a significant concern (Almutairi, Salonitis and Al-Ashaab, 2019). Hospitals are therefore coming under increasing pressure to reduce costs, improve efficiency, and increase the quality of care provided to patients to improve healthcare delivery. This pressure has prompted leaders of healthcare organisations to redesign many aspects of hospital operations and processes and has led them to seek solutions to guide these changes. Well-established management strategies are thus increasingly being considered to achieve the necessary improvements (Walshe, 2009; Radnor, Holweg and Waring, 2012; Costa *et al.*, 2017). Due to multiple success stories of lean's implementation in healthcare, there has recently been increasing interest in the application of lean within this setting (S Wu, Liu and Belson, 2010; Yu, Demirli and Bhuiyan, 2015; Toussaint and Berry, 2019).

Although lean is widely applied to healthcare systems worldwide today, it is difficult to pinpoint when it emerged in this sector. Wide-spread evidence of lean's application appeared in the late 1990s and early 2000s when the Virginia Mason Medical Centre began implementing lean principles (Nelson-Peterson and Leppa, 2007; Brandao de Souza, 2009). The Institute for Healthcare Improvement (IHI) also began promoting the application of lean principles in healthcare in the early 2000s and has developed and implemented various improvement initiatives based on lean principles. In 2001 Great Britain's National Health Service (NHS) was the first high-profile application of lean in healthcare in Europe. Thereafter, in 2002 the Joint Commission Institute implemented it in the USA to provide more value to patients while simultaneously using fewer resources (Brandao de Souza, 2009; Seyedi *et al.*, 2013; Mazzocato *et al.*, 2014).

Since then, lean has become the healthcare improvement approach most commonly used and reported in literature (Walshe, 2009). A review of the use of business process improvement methodologies from the private sector (such as lean, six sigma, business process re-engineering, and other process improvement techniques) in public services revealed that lean currently has the greatest uptake. It found that 51% of publications focused on lean as opposed to other improvement methodologies from the private sector, with 35% of the articles stating their use in health services. These findings show the prominence of business process improvement methodologies in healthcare and the significant interest in the lean philosophy specifically (Radnor, 2010).

Fosdick and Uphoff (2007) found hospitals, in particular, to be excellent candidates for its application. However, the constant human interaction present throughout the process makes it one of the most complex types of service organisations (Institute of Medicine, 2000). Healthcare is also inherently different from manufacturing in almost all aspects, including its purpose, the nature of tasks, the people involved, and how value is perceived (Welo and Ringen, 2017). Thus, it can be challenging to apply lean correctly in this context.

One of the most significant differences between manufacturing and hospitals is the conceptualisation of value (Welo and Ringen, 2017). Due to the nature of healthcare, most hospital processes have no physical end product, making the identification of what does and does not contribute toward value more challenging (Selvaraju, Ramakrishnan and Testani, 2012).

Additionally, in clinical care delivery, there are both external customers (patients, families, payers, and regulators) and internal customers (physicians, nurses, clerks, and other workers involved in the care processes) (Kim *et al.*, 2006). Here, the case with external customers is significantly different from manufacturing, where the customer and commissioner are the same. In the context of a public hospital, those who pay for and receive care are not necessarily the same, and customers are critical in determining “customer value” (Radnor, Holweg and Waring, 2012). Thus, hospitals struggle with deciding what constitutes “value” and whether they should define it according to what patients want, those who commission services on behalf of their patients, or representatives in the government (Radnor, Holweg and Waring, 2012).

Recognising these differences and their impact on lean implementation is essential when undergoing the transformation process. Aherne and Whelton (2010) presented the following examples from healthcare for the different types of activities used for lean-related analyses:

- Value-added activities: diagnosis and treatment of an illness or injury.
- Non-value-added but necessary activities (Type 1 wastes): update to patient documentation that does not directly affect the level of care a patient will receive but is required for a complete patient file.
- Non-value-added activities (Type 2 wastes): waiting to be seen, waiting for a procedure, or being inspected several times. These are examples of pure wastes classified as "waiting" and "over-processing". For a further comparison of the different Type 2 wastes, Table *3.1* compares examples as they exist in manufacturing and healthcare, thus highlighting the various ways value can be created in each sector.

Other forms of 'value' in public hospitals that would address customers other than patients could include considerations such as adherence to policy, laws, and equity. Radnor (2010) suggests that the recognition of 'value' and drivers toward it should thus be the focus in public services instead of just the customer.

Table 3.1 Examples of lean wastes in manufacturing and healthcare

Type of waste	**Manufacturing examples**	**Healthcare examples**
Defects	Defective product (Spagnol, Min and Newbold, 2013)	Wrong medication or adverse drug interaction (Graban, 2009). Repeating tests due to correct information not being provided (Westwood, James-Moore and Cooke, 2007).
Over-production	Production ahead of demand (Gupta and Kundra, 2012)	Requesting unnecessary tests from pathology (Westwood, James-Moore and Cooke, 2007).
Transportation	Moving products not required to perform processing (Gupta and Kundra, 2012)	Transporting a patient from one ward to another (Wickramasinghe, 2014). Unnecessary movement of staff and materials (Spagnol, Min and Newbold, 2013).

Inventory	Not processing work-in-progress products and holding high levels of inventory or an excess of components (Gupta and Kundra, 2012; Spagnol, Min and Newbold, 2013)	Excess stock in storerooms is not being used (Westwood, James-Moore and Cooke, 2007). Patients waiting to be discharged (Westwood, James-Moore and Cooke, 2007).
Motion	People moving more than what is required for processing (Gupta and Kundra, 2012)	Nurse walking to several rooms searching for supplies (Graban, 2009).
Waiting	People waiting for parts or products from the previous production step.	Patient waiting to be treated (Graban, 2009). Waiting for nurses (Westwood, James-Moore and Cooke, 2007).
Over-processing	Overly complex solutions are used for simple procedures, or poor tool or product design resulting in inappropriate processing (Hines and Rich, 1997; Gupta and Kundra, 2012)	Asking for patient details multiple times. Repeated clerking of patients (Westwood, James-Moore and Cooke, 2007). Using the wrong set of tools, procedures or systems (inappropriate processing) (de Carvalho, Ramos and Paixão, 2014).
Underutilisation of people	Unused creativity (Gupta and Kundra, 2012)	Employees have ideas for improving the system but are not given the opportunity to act on those ideas (Nicholas, 2012).

3.4 PROBLEMS WITH LEAN IN HEALTHCARE

Throughout literature, there is a general acknowledgement of the potential benefit of applying lean in healthcare services (Brandao de Souza, 2009; Holden, 2011; Sobek II, 2011; Tortorella *et al.*, 2019). Outcomes such as reduced length of stay, reduced waiting times, cost reduction, and capacity increases have frequently been reported (Mazzocato *et al.*, 2010; Holden, 2011; Sobek II, 2011; Wood, 2014; Costa and Godinho Filho, 2016). These reported successes have contributed to the increased application of lean in healthcare.

However, systematic reviews have noted a significant lack of published literature that criticises lean implementation or focuses on its problems and difficulties (Brandao de Souza, 2009; Poksinska, 2010; Costa and Godinho Filho, 2016). Authors found that the lack of reported null or negative effects is more likely due to a publication bias than universal positive effects (Vest and Gamm, 2009; Wright and McSherry, 2013; Woodnutt, 2018). Studies documenting positive relationships between lean and hospital performance are favoured because hospitals that fail to achieve intended changes do not come forward to analyse the reasons behind these failures (Dickson *et al.*, 2009).

Furthermore, authors have commented that the studies that show these positive results often use poorly validated measurements, subjectively assess outcomes, use small samples sizes, limit the application to specific hospital units, lack control or comparison groups, and use short timeframes to confirm the effects (Vest and Gamm, 2009; Mazzocato *et al.*, 2010; Poksinska, 2010; Holden, 2011; Deblois and Lepanto, 2016; Kaplan *et al.*, 2020; Rundall *et al.*, 2021). Therefore, despite the number of successful cases that have been reported, there is little evidence that these efforts are creating any long-term change (Vest and Gamm, 2009; Bhasin, 2012a; Wright and McSherry, 2013; D'Andreamatteo *et al.*, 2015; McCann *et al.*, 2015; Woodnutt, 2018). Some evidence suggests that the failure rate of lean programmes in healthcare is, in fact, high and that organisations are struggling to sustain their results (Vest and Gamm, 2009; Sobek II, 2011; Gonzalez-Aleu *et al.*, 2018; Rundall *et al.*, 2021).

Sustained lean can be conceptualised as the state where it has become so integrated with the hospital that it has become a routine part of care delivery. It means a fundamental change in the way of thinking and attitudes has occurred to the point where the new way of working has become the norm, and the systems surrounding them have also transformed. Improved outcomes are thus maintained, and the hospital does not revert to the way it was before (Maher, Gustafson and Evans, 2010; Flynn *et al.*, 2019).

As defined by Murman *et al.* (2002), a lean enterprise can be seen as "an integrated entity that efficiently creates value for its multiple stakeholders by employing lean principles and practices". Similarly, Sharma and Shah (2016) describe a lean enterprise as "an improvement in the way of performing operations at different levels and functions using lean principles and practices". The lean transformation thus aims to reach a "perfect lean state", characterised by minimum resources and maximum performance through the complete adoption of lean principles (Cil and Turkan, 2013). The transformation towards such a holistic ideal state of lean, however, is a complex and time-consuming process that requires change in every function of the organisation (Narang, 2008).

To consider the process of transforming into a lean enterprise, Narayanamurthy and Gurumurthy (2016b) outlined a higher-level framework applicable to both manufacturing and services, indicating three stages that must be executed when adopting lean, which are illustrated in Figure 3.1. The first stage, lean implementation readiness, involves determining how prepared an organisation is to change internally and externally to adapt to the changes involved with implementing lean practices. Stage 2, lean implementation, indicates the implementation of lean thinking and practices in an organisation. The final stage, lean implementation assessment, involves the evaluation of the extent of leanness and benefits attained from its implementation. This stage informs the implementation strategy and must be performed regularly to continuously improve the current implementation of lean (Narayanamurthy and Gurumurthy, 2016b).

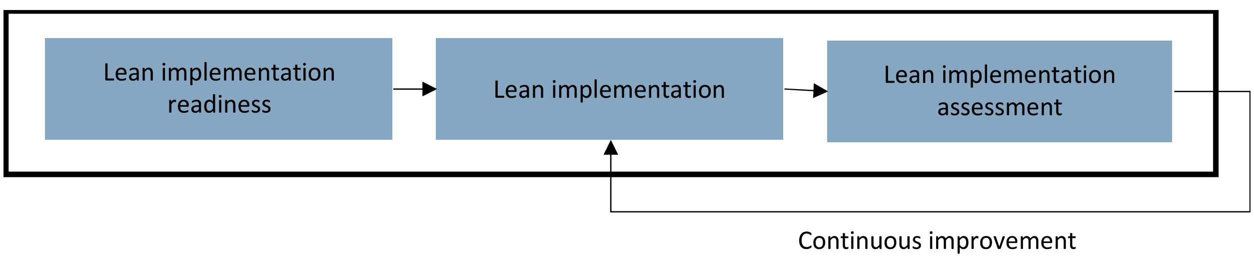


Figure 3.1 Basic lean transformation framework (Narayanamurthy and Gurumurthy, 2016b)

Lean assessments are thus imperative to the effective management of lean, and neglecting, or doing them incorrectly, can significantly contribute to failed or unsustainable lean transformations. A holistic lean assessment should focus on evaluating 1) the impact of lean in the organisation and 2) to what degree it has been adopted within the organisation (Lemieux, Pellerin and Lamouri, 2013). In particular, assessment tools focused on the latter are commonly used to help sustain lean implementation in the manufacturing industry (Taj, 2005; Srinivasaraghavan and Allada, 2006; Vinodh and Vimal, 2012; Sangwa and Sangwan, 2018). This form of assessment is termed a "leanness" assessment, where leanness is the degree to which organisations adhere to the principles of lean (Saleeshya and Binu, 2019). Leanness assessment, therefore, evaluates the extent to which the lean philosophy has been implemented in an organisation (Wong, Ignatius and Soh, 2014) and indicates the degree to which lean transformation has occurred. It is important to note that this is different from the first type of assessment, called lean performance assessment (also sometimes referred to as lean effectiveness assessment), which assesses improvements in organisational outcomes resulting from lean initiatives (Lemieux, Pellerin and Lamouri, 2013). While this is important for tracking improvements, the results are limited to the effects of lean and do not give insights into its implementation (Al-Ashaab *et al.*, 2016). Information on the degree of lean transformation is necessary to guide the implementation process. Greater attention to assessment approaches reflecting the extent to which lean has been implemented is therefore deemed essential to identify how it can be implemented more holistically (Gupta and Kundra, 2012; Al-Ashaab *et al.*, 2016).

The literature on lean healthcare, however, lacks methods that can be used to evaluate lean's implementation. Although leanness assessment methods are widely spread across manufacturing industries, they are not common in healthcare (Henrique *et al.*, 2020). Additionally, due to the increasing application of lean in healthcare, there is a growing demand for literature adapting the lean theory to the healthcare environment (Schonberger, 2018; Smith, Hicks and McGovern, 2020). The inherent differences between healthcare and the manufacturing sector mean the approach to implementing lean cannot simply be copied into hospitals, as the context in which it is applied can significantly influence how well it is adopted (Eriksson *et al.*, 2016). The approach needs to be adapted to fit the specific environment (Poksinska, 2010; Selvaraju, Ramakrishnan and Testani, 2012; Sethi *et al.*, 2017). Thus, the factors for a holistic implementation of the lean philosophy under such conditions require further attention (Holden, 2011; Leggat *et al.*, 2015).

However, although leanness is an important factor in successfully adopting lean, authors overwhelmingly report that the successful implementation of lean practices depends not only on the correct application of tools but also on several supporting organisational factors (Sobek II, 2011; Rundall *et al.*, 2021). A tailored leanness assessment ensures a complete lean transformation by guiding a holistic implementation of the philosophy but does not necessarily help sustain this transformation. While lean tools and techniques are important, practices that will support continuous implementation are even more important for long-term change (Mazzocato *et al.*, 2010; Poksinska, 2010; Rundall *et al.*, 2021).

Therefore, focusing assessment methods on ensuring only thorough adoption of the lean philosophy could ignore the other organisational factors needed to support its long-term implementation. But because healthcare facilities are still struggling with implementation and sustainability issues, there is a lack of focus on these aspects in literature. The patterns, factors, and mechanisms that may influence this have not been identified (Flynn *et al.*, 2019). Therefore, along with the need for a leanness assessment customised to the healthcare context, a need to expand this assessment also to include practices that help sustain it is identified. Consequently, more rigorous and holistic research about underlying factors influencing the success and sustainability of lean in healthcare is required.

3.5 SOLUTION OBJECTIVES

The findings from the exploration of the literature on lean's application in healthcare showed that there is significant potential for its application in hospitals but that many healthcare centres are still struggling with realising successful and sustainable results. Understanding what is needed to ensure sustainable implementation of lean is essential for managing and improving its implementation, but sustainability remains an understudied area of implementation research (Lindsay, Kumar and Juleff, 2020; Marsilio and Pisarra, 2021). The majority of previous research on lean implementation in healthcare has not addressed the sustainability of successes or what influenced any long-term effects (Holden, 2011; Sobek II, 2011; Radnor and Osborne, 2013; Andersen and Røvik, 2015), highlighting a gap in the literature that needs to be addressed.

Additionally, the lack of assessment tools to evaluate lean implementation makes it difficult to assess to what extent a hospital has implemented lean principles and practices and how this compares to other organisations (Tortorella *et al.*, 2019). Information from these assessments is critical for lean sustainability (Costa and Godinho Filho, 2016). But rather than focusing only on the holistic implementation of lean principles, a need for an assessment tool focused on all practices needed to sustain such an implementation was identified. For the development of this tool, it was also noted that the unique challenges healthcare faces in comparison with other industries in its application of lean need to be considered (Henrique *et al.*, 2020).

The tool needs to be tailored to the hospital context and developed so that it can be used by the people implementing lean in the facility to guide the lean transformation. The proposed tool thus aims to allow hospital managers to identify the most critical areas of improvement for lean's implementation through performing a self-assessment guided by a tool interface. This assessment enables an appropriate prioritisation for the lean improvement in which the hospital context is taken into account. Thus, the solution objectives (SOs) with regards to the assessment tool are as follows:

SO1: Assess the extent to which practices that support the sustainable implementation of lean and lean's principles have been adopted.

SO2: Comprise of all the practices necessary to support the sustainable implementation of lean in a hospital setting.

SO3: Provide a result reflecting the hospital's capability to sustain lean and the extent to which it is lean that can be tracked over time.

SO4: Provide information that can be used to inform lean improvement decisions.

SO5: Provide a self-assessment interface that is easy for hospital managers to use and understand.

Confirmation that these SOs were met is shown through the validation procedure executed in Chapter 7.

3.6 CHAPTER 3: CONCLUSION

Chapter 3 further explored the problem by first examining the concept of lean and its history, highlighting the differences between its origin in manufacturing and healthcare. A further discussion on the application of lean in healthcare identified three main areas of improvement: lean implementation, lean evaluation, and lean sustainability. The need for an assessment tool developed specifically for hospitals that highlights how to holistically and sustainably implement lean was identified through an exploration of the problem. Thereafter, five objectives for the development of such a solution were outlined. Thus, concluding the first two research staged. The next stage involved developing the preliminary tool. Chapter 4 begins this process by executing a systematic review to investigate what is needed for sustainable implementation of lean in hospitals, which will form the content of such a tool.

Chapter 4 Lean sustainability practices

As a starting point to the solution development, that which would support long-term lean implementation needs to be identified. From this, a set of sustainability practices can be developed, which is defined as the activities that would support lean sustainability if undertaken by the hospital. Therefore, a meta-analysis was performed to identify what has been found in literature to support such an implementation. The elements found in literature, which have not yet been synthesised into practices, are referred to as factors. Executing a meta-analysis ensures a methodological consideration of the theoretical findings, and that a systematic approach to finding relevant literature is followed. The review aims to answer the following questions:

1. What are the practices that aid the sustainable implementation of lean in hospitals?
2. What practices inhibit the sustainable implementation of lean in hospitals?

This chapter begins by discussing the methodology followed in executing the review in Section 4.1. The analysis results are then shown in Section 4.2 and a discussion of each practice determined to aid lean sustainability is presented in Section 4.3. Lastly, the chapter is concluded in Section 4.4.

4.1 METHODOLOGY

To ensure that this review is executed with rigour and without bias, the applied thematic analysis (ATA) was utilised. ATA is an inductive framework developed by Guest, Macqueen and Namey (2012) for analysing qualitative research. This framework was employed due to the flexibility in the analytic approach and techniques that can be used, in addition to the fact that it was specifically designed for use in the analysis of textual data (Mackieson, Shlonsky and Connolly, 2019). The overarching methodology used to execute this review is shown in Figure 4.1.

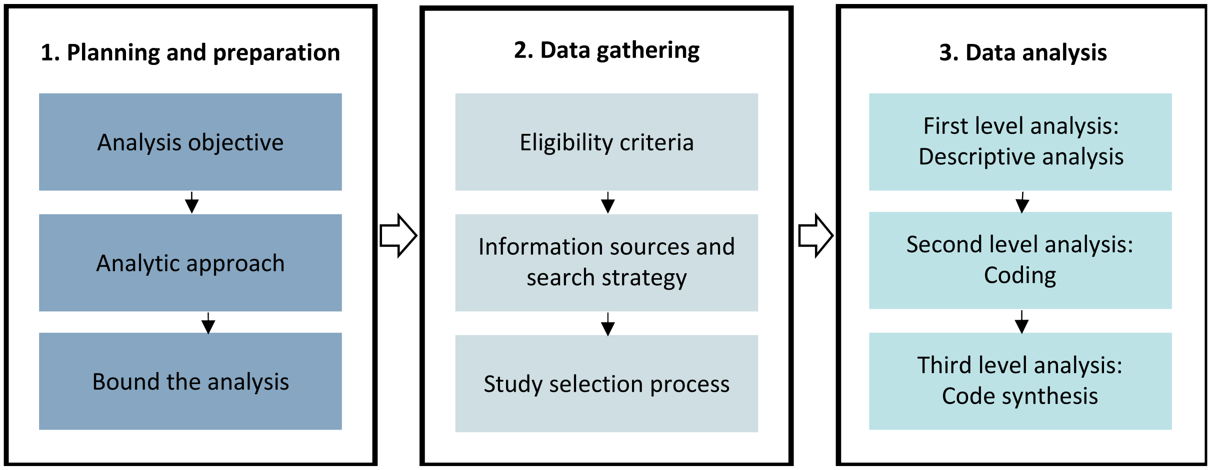


Figure 4.1 Meta-analysis methodology

4.1.1 PLANNING AND PREPARATION

The analysis plan begins by establishing the analytic objectives (Section 4.1.1.1). Once the analysis objective has been identified, the primary analytical approach followed to achieve the objective must be chosen (Section 4.1.1.2). Next, the specific data that will be used for the analysis, as well as why this type of data was chosen, must be determined and part of "bounding the view" (Section 4.1.1.3). Lastly, once the boundaries of the analysis have been defined, how the text will be coded must be established. The coding process decision can be made as part of the analysis plan, while the data is being generated, or after it has been collected, processed, and cleaned (Guest, MacQueen and Namey, 2012). In the case of this review, the specifics of the coding process were only decided after the data collection took place and is thus described in Section 4.1.3, where the data analysis procedure is explained.

4.1.1.1 Analytic objectives

It is essential to establish a clear analytic objective before collecting and analysing the data, as this in part determines the analysis plan developed. This analysis, therefore, aims to uncover practices that should be put in place to support a hospital's ability to sustain lean's implementation, so that the parameters for a tool focused on assessing the degree to which these have been implemented can be developed.

4.1.1.2 Analytic approach

The three broad approaches to analysis within qualitative research include exploratory, explanatory, or confirmatory analysis (Guest, MacQueen and Namey, 2012). In the case of this study, the codes and analytic categories were not determined prior to data collection. Instead, the analysis sought to derive codes from the data, so an inductive approach was needed. The fluid and dynamic nature of the explorative approach thus made it the ideal choice.

4.1.1.3 Bounding the analytic view

Bounding the analytic view involves specifying what data will be used to answer the research questions, the domain of inquiry used, and the questions that will be asked. All of which are driven by the objective of the analysis. The data sources considered in this analysis were published literature intended to address factors inhibiting or sustaining lean's implementation in hospitals. The studies thus specifically had to be focused on the application of lean in hospitals and explicitly investigate sustainability factors because it is a meta-analysis. A detailed explanation of the data collection process in Section 4.1.2 shows how the analytic view was bounded, and the analysis of these data sources is executed in Section 4.1.3.

4.1.2 DATA COLLECTION

The data collection was conducted by employing the first three steps of content analysis used in Trakulsinti *et al.* (2018). These steps include firstly ascertaining the inclusion and exclusion criteria for the studies to be considered, which are detailed in Section 4.1.2.1. Secondly, the search strategy employed to collect relevant articles must be decided, as well as the information sources to be used to execute it. These decisions are outlined in Section �. Once the search has been completed, the study selection process must be outlined using the previously defined eligibility criteria. This process, showing how the final studies used for this review were identified, is shown in Section 4.1.2.3. The final stage of the method employed by Trakulsinti *et al.* (2018), data extraction, falls in line with the data analysis stage of the ATA and is thus addressed in the data analysis detailed in Section 4.1.3.

4.1.2.1 Eligibility criteria

By clearly defining the eligibility criteria for articles being considered for this analysis, only articles relevant to the study's aims were included (Brandenburg *et al.*, 2014). The aim of this analysis meant articles focusing on the factors that inhibit or aid the sustainability of lean's implementation in a hospital were included in the review. Studies that similarly focused on determining factors contributing to lean success, as opposed to sustainability, were also included if lean sustainability was considered necessary for its success. In cases where sustainability was considered separately, only the factors discussed as part of that discussion were included. Lastly, if the article's focus was on lean-based programmes or specific lean tools such as Kaizen, these were also included.

Articles were excluded from the review based on the following criteria:

- The study focused on weight, weight-loss, or body composition;
- Studies with a medical or health focus;
- The article was focused on an industry outside of healthcare;
- The study was focused on lean's application in hospitals but showed no specific focus on the sustainability aspects of its implementation;
- Studies not focusing on lean specifically, such as those considering Lean Six Sigma (LSS) and other management philosophies or quality improvement approaches in general;
- Studies focusing on the overall sustainability of the hospital's performance or environmental sustainability, and not the sustainability of the implementation of lean itself;
- Studies determining the factors contributing to the success of lean that only focused on the successful implementation or dissemination of lean and did not consider its sustainability; and
- Framework, tools, or methodologies developed for lean's implementation or assessment with no sustainability aspect.

Studies focusing on other quality improvement approaches were not considered despite the similarities in their aims and methods because although there are similarities between them, they are distinct constructs with clear differences in the kinds of problems they deal with (Deblois and Lepanto, 2016; Henrique and Filho, 2020). Thus, they ultimately employ different tools and techniques. For example, while lean focuses on eliminating waste, Six Sigma seeks to reduce process variation by using statistical tools to identify and eliminate defects. Unlike Six Sigma, lean does not require advanced statistical methods or expensive platforms and systems to be implemented (NEJM Catalyst, 2018). Thus, considering other quality improvement approaches could lead to findings that do not apply to hospitals seeking to undergo a purely lean transformation, which was the focus of this research.

4.1.2.2 Information sources and search strategy

The electronic platforms Scopus, Web of Science, PubMed, and Science Direct were used to retrieve literature for the study. Scopus was first used to consider various search terms and determine the most applicable one for the remaining search platforms. The following options were considered:

1. (lean AND hospital AND sustain*)
2. (lean AND hospital AND (sustain* OR continu*))
3. (lean AND hospital AND (sustain* OR maintain OR "long term" OR longterm OR ongoing OR prolong OR retain OR preserve))

The first search string considered resulted in 242 articles being retrieved, of which 54 were accepted according to the eligibility criteria outlined in Section 4.1.2.1. Thereafter, to ensure the maximum number of relevant articles are included, search terms to obtain studies that may deal with the correct subject matter, but uses terms other than 'sustain' or 'sustainability', were also considered. The term 'continu*' was added to appeal to studies referring to lean's sustainability as continuous improvement or continued application, resulting in an additional 305 articles. Of these articles, however, only 3% were deemed relevant to the subject matter being considered and accepted, significantly lower than the 22% acceptance rate from the first string. The significant number of articles added mainly consisted of case studies detailing the experience with lean and the results achieved, without any focus on lean's sustainability. A collection of additional terms synonymous with "sustain" was also considered for the third string. This addition resulted in 223 more articles being retrieved than the first string tested, of which only two were accepted (less than 1% acceptance rate). The additional articles predominantly comprised medical articles revolved around weight and body composition.

Following the test on the three different search strings, it was determined that the term 'sustain*' alone was adequate in retrieving the relevant literature pertaining to the field of research being considered. The further addition of other terms considered did not contribute enough articles of value to validate the large number of additional articles that would be retrieved from their inclusion. Therefore, the search string (lean AND hospital AND sustain*) was used for the remaining search platforms.

4.1.2.3 Study selection process

A total of 804 articles were initially retrieved from executing a search with the string previously discussed, 242 of which were from Scopus, 335 from PubMed, 34 from ScienceDirect, and 193 from Web of Science. After all the duplicates were removed, 475 unique results remained. These results included six conference proceedings, meaning 469 articles formed the list of studies for consideration after they were removed. The titles and abstracts of these articles were then reviewed to find those where the search terms resulted in articles discussing health, medical, or body-weight related topics not concerned with the study focus. 213 such articles were found and removed, leaving 256 articles for consideration. A further review of the remaining articles revealed several studies not focusing on lean; specifically, they could be discussing general continuous improvement methodologies or those using mixed methods such as lean six sigma. Any articles not focusing specifically on lean were thus removed, resulting in 196 remaining. Thereafter, it was found that there were some articles not focused on hospitals or their operation, such as articles dealing with the construction process of building a hospital or other similar unrelated industries. Articles not related to the healthcare industry or hospital operations were thus removed, resulting in 185 articles remaining. Of these articles, there were a number of studies that dealt with the implementation of lean in hospitals. Still, when it came to the sustainability aspect of the study, it was not lean's sustainability being considered, but rather things such as environmental sustainability or hospital performance sustainability. Instances of this were found in 17 studies. Thus 168 articles remained after they were removed. Thereafter, the abstracts and, where necessary, full texts were observed to more precisely determine the focus of the articles. Any articles not pertaining to the inclusion criteria and focus of the review were removed. The final result is a total of 51 articles focused on determining the factors that inhibit/enable sustainable implementation of lean in hospitals. The study selection process can be seen in Figure *4.2*, where the number of included and excluded studies are shown in each step.

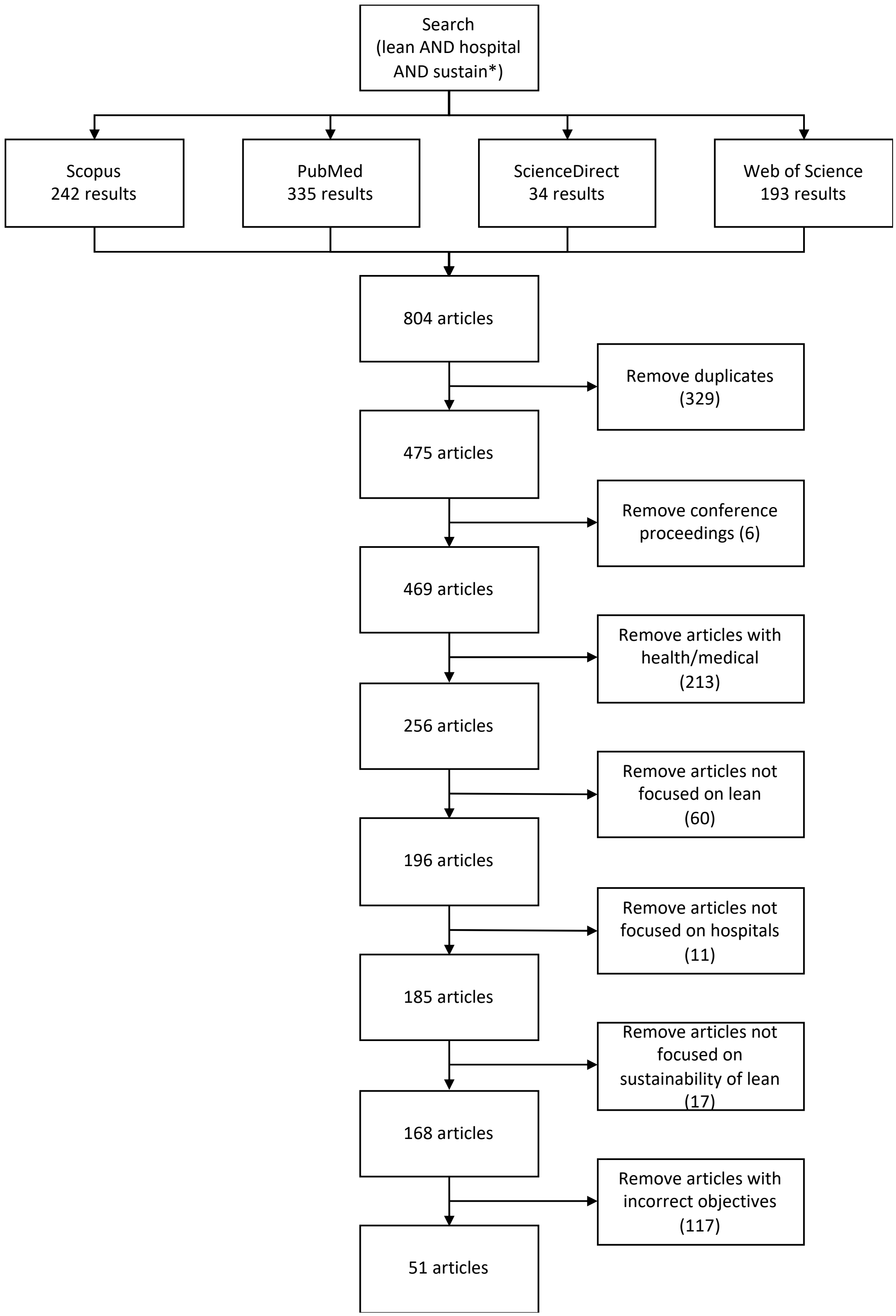


Figure 4.2 Study selection process

The choice of search terms, such as the use of “hospitals” instead of “healthcare” and only using “sustain*” could lead to some relevant articles with the correct focus being excluded. Such as that published by Leite, Bateman and Radnor (2020), which identified ostensible barriers to lean sustainability in healthcare. Similarly, because the search was executed in June 2021, any relevant studies published after this date were not included in the review. However, any more recent articles or ones found with a similar focus after the study selection had taken place were still considered. In all of these cases, no new information was obtained. Thus, data saturation was achieved with the original collection of articles. The remainder of the chapter is based on only those articles, and any additional studies found were used to supplement the discussion of the findings presented in Section 4.3.

4.1.3 DATA ANALYSIS

The final selection of 51 articles shown in Section 4.1.2.3 forms the basis of the data analysis. The ATA framework makes use of themes and codes to develop descriptive and explanatory models. It does this by emphasising the empirical investigation of how these codes and themes are combined. The different combinations are then explored through a targeted review of the associated text to develop these models. Guest, Macqueen and Namey (2012) defines a theme as a "unit of meaning that is observed (noticed) in the data by a reader of the text", while a code is a "textual description of the semantic boundaries of a theme or component of a theme". A theme can generate multiple codes, and thus the code represents a greater level of abstraction.

The three components that must be considered to ensure a systematic data analysis are: 1) the tools that are going to be used for the coding process, 2) the codebook development process, and 3) if more than one coder is working on the data, steps must be taken to ensure that there is an agreement regarding when is appropriate to use each code. The third component is not considered because only one coder was used to code the data. Regarding the tools used for the coding process, Atlas.ti was used for coding, while Excel spreadsheets were used to record the text associated with the different codes and track the analysis process. Lastly, the codebook exists to reduce ambiguity in the coding process. It is generally developed iteratively by sorting the observed meaning in the text being analysed into categories, types, and relationships of meaning. The text is then reread, analysed, and coded into these categories, types, and relationships (Guest, MacQueen and Namey, 2012). The codebook is modified as new information and insights are gained.

The codebook development happened in three stages, as shown in Figure 4.1. The first level of analysis included the initial read-through of all the articles, only extracting the following descriptive data:

1. **Qualitative approach:** The approach used to determine what inhibited or supported lean sustainability, such as case studies, literature reviews, Delphi studies, or action research.
2. **Context of the study**: The country the study was executed in or the hospital unit on which it was focused.
3. **Units of study**: The number of units studied to make their conclusions, such as the number of articles analysed, hospitals observed, or professionals interviewed.

Thereafter, the practices that improve a hospital's ability to sustain lean and the factors that impeded this were coded. Coding of these practices was done at a low level of abstraction, as the general themes had yet to emerge. Thus, every time a practice was mentioned, a code was used to record it. A pre-existing code would be used if the concept had already been encountered. Coding was done until all practices in all articles had been identified, resulting in 140 unique codes. Each code and their references shown in Table B.1 in Appendix B).

Following the second round of analysis, the codes had to be analysed for similarities and synthesised into a more concise list of concepts, which formed the final codebook. The final list of codes is shown in the codebook in Table 4.1, along with a description of each.

Table 4.1 Meta-analysis codebook

Theme	Codes	Code definition
Descriptive	Qualitative approach	**Definition:** The approach used by authors of the study to gather their findings. **When to use:** The study mentions the way data was gathered or analysed to identify factors that contribute to / inhibit sustainability of lean in hospitals. **When not to use:** The study mentions approaches used by cases being studied/ observed, or any time the study mentions any qualitative approach not relating to that which is being used by the authors themselves.

	Context	**Definition:** Context in which the study was conducted **When to use:** The type of hospital being considered by the study, the country to which the factors relate, or the area of the hospital it relates to (if limited to a specific area) **When not to use:** When context is mentioned that does not relate to the study findings or contribute to the factors discussed.
	Units of study	**Definition:** The units of study considered to find that which influences the sustainability of lean. **When to use:** When the number of units relating to the qualitative approach used is mentioned. For example, in studies using direct observation, it would be the units or hospitals observed. For those making use of a systematic review, it would be the number of studies considered. The units that qualitative approach used to reach its conclusions must be coded here. **When not to use:** When any secondary units of study are mentioned. Only the units considered by the study itself to gather the findings being reviewed must be noted here.
Sustainability practice	See Table B.1 in Appendix B.	**Definition:** Practices found by the study to contribute to, or inhibit, the sustainability of lean in hospitals. **When to use:** The study mentions any kind of practice or factor that is considered to aid lean sustainability. If anything is noted as something that inhibits lean's sustainability, the antithesis of such a practice must be coded. **When not to use:** Practices relating to other aspects of lean's implementation in hospitals, such as successful implementation (unless sustainability is specifically mentioned as an aspect of sustainability). Only practices relating to its sustainability in particular must be coded.

4.2 RESULTS

Following the data analyses executed in Section 4.1.3, a list of codes with associated text was obtained. To develop a more consolidated list of practices, the codes firstly had to be grouped into similar categories to form the different assessment areas. Thereafter, the text associated with each code was used to create the description of each practice. The list of sustainability areas, the practices that make up these areas, and their descriptions, are shown in Table 4.2. The codes that were combined to form each area and their practices can be seen in Table B.1 in Appendix B.

Table 4.2 Lean sustainability areas and practices

Areas	Practices
Measurement system	**Measurement system:** Performance is continuously monitored and audited to measure current state progress and provide a full picture of the process and clinical outcomes. The data is used to guide activities and ensure improvements are being implemented, that work standards are in place, and to identify any problems that arise after implementations.
Lean tools and principles	**Holistic implementation of lean philosophy:** Lean principles are adhered to, and lean tools and techniques (such as kaizen events, A3 method, 5S, Gemba walks, standard work, visual management, etc.) are routinely used and applied.
Knowledge and competency	**Training doctors, staff, and management** to be knowledgeable and competent in the lean philosophy, its principles, and tools for practices. Staff thus understand the lean terminology & language, that lean is a long-term perspective, and are equipped with the skills to use and understand the data from measurements and feedback. Managers are additionally trained on change management concepts and are equipped with the skills to change.
	Training is tailored to the hospital's context and adapted to trainees' work conditions.
Communication and feedback	**Visible communication of information:** A well-functioning communication system that transmits data collected by the measurement system and other information needed for managing the lean implementation is present in order to provide constructive feedback to all stakeholders and maximise learning. Communication is widespread, transparent, and visible to the entire hospital.
	Communicate reasons for change and improvement successes: Change vision (including explicit goals and strategy to achieve them), change initiatives, progress of individual processes, results of lean implementation,

	and successes are communicated by leadership to the whole hospital to align and engage people in change.
Leadership	**There is leadership buy-in:** Top management understands the benefits of lean and is assured of its effectiveness.
	Long-term committed and actively involved management: Management actively participates in day-to-day continuous improvement activities, spends time providing guidance, leadership, and oversight of staff (both frontline and medical) and jointly work with them to resolve problems and implement improvements. Leaders use their time to work and prioritise lean initiatives in addition to routine activities.
	Visible and stable support: The management/leadership guidance and support of the change program is visible and stable over time.
	Availability of resources: Management ensures sufficient resources are available for implementation, such as adequate human resources to support it and funding for training and education, external consultants, resources for data analysis, workshops, or incentives.
Workforce empowerment	**Participation:** Professionals at all levels of the organisation (frontline staff and clinical staff, management, physicians, etc.) are committed and engaged in the design and implementation of lean. This means real-time, active participation, cooperation, and responsibility in the process. Every person is encouraged to continuously identify value in their work environment and contribute to generating solutions to problems.
	Ownership: There are clear accountability structures that ensure long-term accountability at both operational and administrative levels. Operational accountability means there is process ownership for the quality of their work and for continually improving their work and workplace. They take ownership of the changes, the lean implementation, and their area of application.
Culture	**Long-term and continuous implementation:** Lean is viewed as a continuous, long-term approach. It is thus practised day after day, decisions are made based on long-term thinking instead of short term gains, the commitment to improvement work continues even when results are not immediately shown, and actions are continuously reassessed to identify further improvement opportunities.
	There is a culture change: All stakeholders adopt the new mentality of making quality an integral part of everyday work and view lean as a job resource as opposed to something that takes time away from their routine activities. Therefore, the culture must be open and willing to change to adopt the new mentality fully. All stakeholders are committed to change and invest the necessary time to adapt to the approach.

	An **open, no-blame culture** exists in the hospital to foster an environment where people feel safe and free to report errors or issues.
	The hospital is both patient-centred and process-driven: The focus is oriented to the patients and their needs, as well as to the integrated and dynamic management of processes.
	A bottom-up approach is adopted where ideas and proposals generated by professionals at all levels of the organisation are fed into improvement initiatives. Decisions are taken in consensus, not top-down, allowing people more freedom to generate new ideas for improvement and discuss them to decide the best for the organisation.
	Rewards and recognition: Improvements are recognised by celebrating successes and rewarding employees based on improvement ideas implemented or performance goals achieved. This can be done by implementing a structured incentive system correlated to the performance achieved with respect to the overall objectives pursued and supported by accurate measurement mechanisms.
	Teamwork: There is a culture of shared understanding, awareness, support for co-workers, and accountability that builds teamwork at all levels to provide a clear vision to guide the program. There is interaction and collaboration within the multidisciplinary teams.
Lean team	**Clarity of roles and responsibilities:** A team dedicated to supporting and facilitating the implementation of lean and continuous improvement activities is appointed. The team is responsible for guiding the transformation process, managing the dynamics of continuous improvements, and providing support for bottom-up project development. The various figures and roles in this team are made clear, and the responsibility and ownership of each role are specified, giving power and authority to the necessary roles (such as the power to allocate resources).
	Utilisation of internal resources: A lean team can make use of external consultants, but it is vital that once staff has developed the necessary knowledge and skills to manage the lean process, the lean team employs staff from within the organisation to make up the lean team, thus making use of internal human resources to run the change.
	A **lean champion** (preferably someone from within the organisation) is appointed to promote the change, act as a catalyst, and motivate the employees in order to keep their attention and involvement high. They train colleagues to make sure employees understand lean and support them in developing projects. They additionally act as the link between employees and leadership and must work in synergy with top management.
	Teams are multi-professional and multidisciplinary: Team members span across departments and are responsible for cross-functional tasks.

Change management	**Strategic planning:** There is a transformation or improvement plan that has been customised to the hospital's context. The plan has a clear change vision that communicates explicit, clear, and measurable goals and contains the set of steps to be followed to achieve them (action plan). The link between the organisational goals, key objectives, and lean project activities is clear.
	Improvement program and organisational strategy integration: There is integration between the improvement program and organisational strategy. The change program must be incorporated and developed within the organisation's strategy. Lean is integrated into the organisational strategic planning (e.g., into the annual budget), and similarly, the change/ improvement program is aligned with the organisation's strategy.
	Paced hospital-wide implementation: Along with lean implementation being organisation-wide and continuing, it is paced and systematic. Each step is adequately completed, and the implementation is not rushed or done too quickly before the previous stage has been fully integrated into the organisation. This change is driven and supported across the entire hospital and all workplace levels.
	Gain stakeholder commitment and buy-in: Prepare staff and ensure that they understand the expectations and reasons for change, accept the reasons for implementing change, and understand how the change will benefit them and the patients.
	Contextual influence is understood: There is an understanding of how and why context complexity influences lean's implementation and its normalisation process.
Organisation structure	**There are no functional and professional silos.** There is collaboration between different departments and units and flexibility to adapt procedures, processes, behaviours, and skills to changes. Additionally, there is alignment from senior leadership to frontline staff so plans, visions, resources, actions, and results to support system-wide gaols are consistent.

4.3 DISCUSSION

The meta-analysis found 29 practices that aid sustainable lean implementation and grouped them into ten overarching areas. This section discusses each of the ten areas and how their practices contribute to lean's sustainability.

4.3.1 MEASUREMENT SYSTEM

A measurement system that continuously monitors metrics and performance measures of the hospital needs to be put in place to track progress throughout lean implementation and provide the necessary data to manage it (Lindskog *et al.*, 2016). Gathering accurate and valid measurements allows the current hospital state to continuously be assessed so that improvements can be recognised and quantified, feedback can be provided to stakeholders, and further opportunities for improvements can be identified (Sobek II, 2011; Breuer, 2013; Abuhejleh, Dulaimi and Ellahham, 2016; Henrique *et al.*, 2020). Executing these follow-ups and continuously providing feedback to participants helps guide them in their activities and allows them to respond to changes and opportunities more quickly, reducing the likelihood of performance regressions (Sobek II, 2011; Lindskog *et al.*, 2016; Leggat *et al.*, 2018).

Further, the data gathered from the measurement system is something that leaders can use to motivate and explain to employees why lean is necessary (Breuer, 2013). For staff to become truly engaged in the process, they need to understand the reasons for change (Sobek II, 2011; Breuer, 2013). To support the argument, leadership may use financial and non-financial performance measures as an example. It is additionally something that leaders themselves can reflect on to ensure their continued buy-in and support. Abuhejleh, Dulami and Ellahham (2016) found that top management's support and continued commitment to implementing it will diminish without such evidence.

It is important to note, however, that some staff might find having to monitor and track additional metrics a cumbersome task, adding to their already heavy workload (Sobek II, 2011; Stelson *et al.*, 2017). The extra monitoring could thus have a negative effect on the practices such as participation and ownership or stakeholder commitment and buy-in. The impact could be mitigated to some extent by automating measurements, and the increase in work could be alleviated by ensuring that adequate resources are available (Sobek II, 2011).

4.3.2 LEAN TOOLS AND PRINCIPLES

"Lean emphasises the use of an array of tools and methods to aid workers in improvements, each designed to address certain types of problems and methods to illuminate and remove sources of waste through systems design" (Sobek II, 2011). It would therefore be expected that to implement the practices inherent to the lean philosophy and realise improvements, the use of these tools would be necessary (Steed, 2012;

Centauri *et al.*, 2018). While not all studies explicitly state the application of lean tools as necessary to sustain lean, various specific tools were often identified as essential to lean's sustainability. Examples include value stream mapping, Kanban and pull, demand levelling, A3, kaizen events, 5S or 6S, standard work/standardising, Gemba walks, and more (Barnas, 2011; Sobek II, 2011; Steed, 2012; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2018; Udod *et al.*, 2020). The use of Kaizen, for example, gains greater adherence from workers and thus increases the chance of lean improvements being sustained (van Aken *et al.*, 2010). VSM, on the other hand, can be used to help identify opportunities to eliminate process waste (Abuhejleh, Dulaimi and Ellahham, 2016).

However, when using the tools to implement lean, it is critical for hospitals to also be conscious of the principles inherent to the philosophy (Dickson *et al.*, 2009). Because lean offers a number of tools that can be used for its implementation, all too often, lean leaders tend to see lean as a collection of stand-alone operational tools rather than a broader system-wide improvement philosophy based on fundamental principles and underlying assumptions (Radnor, Holweg and Waring, 2012). Without fully comprehending its core ideas and underlying principles, some of the more deep-rooted ways of thinking and doing that are critical to realising a shift in how the hospital operates in the long run are often ignored (Radnor and Boaden, 2008; Breuer, 2013).

Assessment tools to measure the degree to which the lean philosophy is being practised in the organisation can be used to ensure adherence to its principles. This type of assessment is referred to as a leanness assessment, where leanness is the degree to which an organisation adheres to the principles of lean (Saleeshya and Binu, 2019). Leanness assessment is distinctly different to the more common lean assessment, also referred to as lean evaluations or lean performance assessments, where the impact lean's implementation has had on hospital operations is evaluated. A leanness assessment is intended to evaluate the implementation of the lean philosophy itself by measuring the implementation of its practices. It is therefore a helpful tool when it comes to ensuring this aspect of lean's sustainability is adhered to (Henrique *et al.*, 2020). Essential for such a tool, however, is the customisation to context (Steed, 2012). Leanness assessments are more common in manufacturing, and there is a significant lack of assessments focusing on leanness in healthcare. Thus, the practices necessary for a holistic implementation of the lean philosophy in hospitals specifically are explored in Chapter 5.

4.3.3 KNOWLEDGE AND COMPETENCY

The significant role that the workers at the hospital have when it comes to lean practice means having them be knowledgeable about lean and possess the competencies required to fully integrate it into everyday practices is imperative (Breuer, 2013). Not training them on these aspects makes it challenging to create a foundation to initiate and drive forward improvement work (Udod *et al.*, 2020).

When it comes to understanding the lean philosophy, having knowledge of its principles, methods, and tools is fundamental to an appropriate and long-lasting adoption of the philosophy (Sobek II, 2011; Steed, 2012; Centauri *et al.*, 2016; Stelson *et al.*, 2017; Flynn *et al.*, 2019; Kahm and Ingelsson, 2019; Henrique *et al.*, 2020). To derive the full benefit from lean, there simply is no shortcut to understanding these underlying assumptions (Radnor, Holweg and Waring, 2012). Understanding lean not only drives the correct application of its tools but it highlights all aspects of the philosophy needed to realise a holistic application of its principles, the importance of which was discussed in Section 4.3.2 (Breuer, 2013; Kahm and Ingelsson, 2019; Udod *et al.*, 2020). It is also a significant driver of buy-in and participation for both management and staff (Flynn *et al.*, 2019). Those with knowledge of lean are more likely to see potential value in it and support its use for improvement (Centauri *et al.*, 2016; Goodridge *et al.*, 2018; Flynn *et al.*, 2019). Additionally, communication with and between staff could be hindered if there is not adequate knowledge of lean and its language. It therefore also increases their ability to interact with leadership and collaborate within multidisciplinary teams (Centauri *et al.*, 2016, 2018). Furthermore, for leadership specifically, an understanding and knowledge of the purpose and value of lean drives management's ability to provide value-creating opportunities, makes them more capable of communicating the reasons for which change is needed to employees, and enables them to teach other managers and staff about lean (Kaplan and Patterson, 2008; Breuer, 2013; Kahm and Ingelsson, 2019).

In addition to being knowledgeable about lean, staff and managers also need skills to make them capable of correctly implementing and continuously improving it. Staff, for example, must have the skills to use the data provided to them to guide activities (Leggat *et al.*, 2018). If they do not understand or know how to interpret the provided information, it hinders the learning process and prevents further improvement. Additionally, managers must be trained with the skills necessary to lead change and a knowledge of processes and operational dynamics (Boaden, R., Harvey, G., Moxham, C., Proudlove, 2008; Centauri *et al.*, 2016; Leggat *et al.*, 2018). Executives are often perceived to not sufficiently understand and support improvement work (Kahm and Ingelsson, 2019). Increased management engagement requires understanding which conditions need to be created to realise improvement work (Ericsson and Augustinsson, 2015). The acquisition of skills and knowledge on managing expectations and interests helps managers understand the validity of the logic underlying the improvement program, enabling them to motivate workers to actively engage with lean's implementation (Centauri *et al.*, 2016; Kumah, Ankomah and Antwi, 2016). As such, the approach to organisational learning of the lean system strategy is one of the most significant factors in the widespread adoption and success of lean (Steed, 2012).

To disseminate the necessary knowledge for sustainable lean implementation, professionals involved must constantly be trained. Training is used as part of the learning process to equip staff with the necessary skills and knowledge to implement, understand, and maintain changes (Udod *et al.*, 2020). It ensures everyone in the organisation is gradually immersed in the lean philosophy and prepares them with the necessary competencies, thus facilitating the integration of lean work practices (Centauri *et al.*, 2016). Organisations that invest in constantly training their employees in lean techniques have a greater chance of sustaining lean implementations (de Souza and Pidd, 2011; Bhasin, 2012b; Steed, 2012; Udod *et al.*, 2020).

It is important to note, however, that simply receiving training is not sufficient for sustainability. The nature and type of training have implications for the extent to which lean is normalised. There are various ways staff can be educated in lean concepts, namely through theoretical training programs, on-the-job training such as investing in and including staff members to lead change initiatives, or bringing in outside expertise (Sobek II, 2011; Henrique *et al.*, 2020). While mass education can be a cost-effective way to disseminate knowledge and develop a common vocabulary, Delphi panellists in a study by Sobek II (2011) were sceptical of how effective mass education could be. The overall expression is that traditional education models are not always effective in changing workplace behaviours. On the other hand, the use of outside expertise, such as consulting companies, usually hindered learning because of the complex language sometimes used or the over-focus on senior leadership, making frontline staff not feel involved (Flynn *et al.*, 2019). Research also identified instructor disposition and experience as determinants of training success (Towler and Dipboye, 2001). While the training approach does affect the normalisation of lean, there is not necessarily one best approach to use. Rather, the hospital should be aware of the shortcomings of each when considering the different options and should use feedback from staff to tailor its delivery (Flynn *et al.*, 2019). What is critical to sustainability, however, is the nature of training, or in other words, the messaging and language that is used (Flynn *et al.*, 2019).

Misunderstandings could result from the complex terminology sometimes used during training due to the "Japanese" terms that form part of lean language (Stelson *et al.*, 2017; Flynn *et al.*, 2019). The overuse of these terms does not resonate well with healthcare professionals and thus results in their disengagement (Flynn *et al.*, 2019). Furthermore, in a study focusing on factors that affect continuous improvement project success in hospitals, Stelson *et al.* (2017) found that respondents expressed the need for detailed explanations and relevant examples to be used. Not only pointing to using language that is easier to understand, but to the importance of training to be adapted to context and audience (Wiseman, Eseonu and Doolen, 2014; Flynn *et al.*, 2019). Since each level of the organisation would interact with lean in a different way, there are different knowledge requirements for each of them. It is therefore important to identify the specific training needs for each level. Senior management certainly does not need the same kind of training as frontline staff, and the same is true for middle management and medical staff (Sobek II, 2011).

In addition to training being adapted to the different organisational levels, at an even higher level, it needs to be adequately adapted to healthcare. Failure to connect lean to the specific healthcare context it is being applied in triggers resistance and a failure to understand lean, hindering lean sustainability (Flynn *et al.*, 2019). It is therefore important that the gap between lean manufacturing and lean in healthcare be accounted for, and that the learning system established is relevant and practical from a healthcare context (Steed, 2012). It is critical for leadership to make the personal commitment, backed by the allocation of sufficient resources, to give employees the training that will allow them to succeed in implementing lean projects (McCreery, Mazur and Rothenberg, 2011).

4.3.4 COMMUNICATION AND FEEDBACK

Various authors point to the importance of communication for the sustainability of lean (Sobek II, 2011; Steed, 2012; Centauri *et al.*, 2016). It is thus important to highlight what needs to be communicated and how it should be done. Firstly, to align and engage people in change, leadership must communicate all aspects of the change vision (Steed, 2012; Breuer, 2013; Rotteau *et al.*, 2015; Leggat *et al.*, 2018). These aspects include the clear and explicit goals for lean's implementation, as well as the strategies to achieve them (Dixon-Wood et al., 2014). Transparency of how lean is being implemented reduces fear and anxiety about the changes that will happen and ensures staff understand their specific role in continuous improvement. Additionally, communicating how this change vision fits in with the organisational strategy shows them that lean is not just another improvement program with little impact, but rather long-term a change towards a new way of operating. It makes it clear to them that it focuses on efficient operations and quality of care, helping them understand that it does indeed benefit both them and patients in the long run, thus facilitating their buy-in and participation (Sobek II, 2011; Breuer, 2013; Stelson *et al.*, 2017).

Additionally, information on the results and changes due to lean and other metrics needed to manage it must be provided to the entire hospital (Centauri *et al.*, 2016; Henrique *et al.*, 2020). The measurement system highlighted in Section 4.3.1 needs to be accompanied by a well-functioning communication system so that it can be used to provide feedback to everyone involved (Sobek II, 2011; Leggat *et al.*, 2018; Kahm and Ingelsson, 2019). Ongoing and frequent communication with those involved with and affected by the change is an essential component of a lean implementation effort (Sobek II, 2011; Abuhejleh, Dulaimi and Ellahham, 2016). Recognising successes and communicating them throughout the hospital helps motivate and engage employees (Sobek II, 2011; Breuer, 2013; Rotteau *et al.*, 2015; Stelson *et al.*, 2017). In fact, effective communication and information sharing in general support the involvement of people (Centauri *et al.*, 2016). It is thus vital for all communication to be widespread, transparent, and visible (Steed, 2012; Breuer, 2013). Ways to visibly communicate successes, process changes, and their facilitators include display boards, newsletters, or other visual tools (Breuer, 2013; Henrique *et al.*, 2020). Verbal communication tools include communication huddles, daily leadership debriefings, face-to-face meetings, standard work meetings, and organisation-reporting out (Sobek II, 2011; Steed, 2012).

4.3.5 LEADERSHIP

The transformation to a lean hospital is a task that requires considerable change to occur throughout the organisation (Reinerstsen, 2004). For this change to be realised, there needs to be a strong driving force behind it. Thus, numerous studies report that a strong leadership function established at all levels of the organisation is fundamental for an effective change to take place (McCreery, Mazur and Rothenberg, 2011; Sobek II, 2011; Abuhejleh, Dulaimi and Ellahham, 2016; van Rossum *et al.*, 2016; Kahm and Ingelsson, 2019; Udod *et al.*, 2020). However, while leadership is instrumental in initiating change, it alone is not what results in the sustainability of lean (Wood, 2014). If it is not accompanied by engaged stakeholders and a change in culture, long-term impact will never be realised (Wood, 2014). It is therefore the behaviours and attitudes of this leadership specifically that are important for change, even more so than their presence (Sobek II, 2011; Steed, 2012). Due to the influence leaders have on staff, how they view and promote lean has a significant impact on the extent to which they are engaged, and an organisational change is realised (Udod *et al.*, 2020). This section thus aims to highlight specific leadership practices necessary for lean's sustainability.

Firstly, top management commitment, engagement, and support of the lean implementation are essential for integrating the lean philosophy into the organisation (Barnas, 2011; McCreery, Mazur and Rothenberg, 2011; Sobek II, 2011; Steed, 2012; White and Waldron, 2014; Abuhejleh, Dulaimi and Ellahham, 2016; van Rossum *et al.*, 2016; Centauri *et al.*, 2016, 2018; Stelson *et al.*, 2017; Leggat *et al.*, 2018; Kahm and Ingelsson, 2019; Henrique *et al.*, 2020). They can show their commitment by using their time to work with and prioritise lean in their daily work, making lean a standard agenda topic, being vocal about its importance, and being visible in its support (Zidel and Hacker, 2006; Sobek II, 2011; Steed, 2012; White and Waldron, 2014; Centauri *et al.*, 2016; Henrique *et al.*, 2020). Visible support requires leaders to actively be involved with lean by participating in day-to-day improvement projects and personally working with staff to identify and resolve problems, in addition to being present and not far away from workplaces where improvements are being implemented (Kaplan and Patterson, 2008; Steed, 2012; Centauri *et al.*, 2016; Henrique *et al.*, 2020). While they should be engaged in the decision-making process, they must be careful not to force specific solutions (Sobek II, 2011; Steed, 2012). Rather, they must provide a strong presence and use their expertise to guide and oversee problem-solving activities (Sobek II, 2011). Visibly showing their commitment to and support of lean by interacting with it increases its credibility, which then, in turn, influences the degree to which the staff then also support it (Stelson *et al.*, 2017; Kahm and Ingelsson, 2019).

Secondly, besides being visible, top management's guidance and support of lean must also be continuous and stable over time (Dickson *et al.*, 2009; Centauri *et al.*, 2016, 2018; Leggat *et al.*, 2018). If lean has not been adequately integrated into the organisational culture, it can be vulnerable to key personnel changes (Pedersen and Huniche, 2011). Therefore, when the leaders guiding the transformation change, the staff revert to operating in the same manner as before lean was introduced. Although personnel changes are inevitable in any organisation and not something that can necessarily be prevented, it does not change the fact that it has an impact on lean's sustainability. Therefore, to maintain lean's principles, where possible, personnel must remain in leadership until lean thinking has successfully been embedded in the organisational culture (Spagnol, Min and Newbold, 2013).

Lastly, there needs to be buy-in from senior leadership (Steed, 2012). The level of leadership engagement is driven by the degree to which they are assured of lean's effectiveness (Steed, 2012; Kahm and Ingelsson, 2017). Thus, if management views lean in a positive light, as something that is needed, and something that will drive long-term change, they are more likely to engage with its implementation, which is necessary for a sustainable lean transformation (Leggat *et al.*, 2018). Leadership with a positive perception of lean will also be better at promoting it to staff, thus getting their buy-in and greater engagement. Without which, lean would not function in the requisite way.

4.3.6 WORKFORCE EMPOWERMENT

One of the key tenets of the lean philosophy is the respect for people, which means that including employees in the improvement process and empowering them to identify and solve problems is key to making the philosophy work (Abuhejleh, Dulaimi and Ellahham, 2016). Several authors thus reported on the importance of engagement and empowerment of all stakeholders as key to the maintenance of best practices (Brandao de Souza, 2009; Dickson *et al.*, 2009; Steed, 2012; Breuer, 2013; White and Waldron, 2014; Wood, 2014; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016; Leggat *et al.*, 2018; Bartram *et al.*, 2020).

Engaging stakeholders mean real-time, active participation, cooperation, and responsibility in various aspects of the process, such as lean analysis, planning, and implementation (Sobek II, 2011; Leggat *et al.*, 2018). Involving employees in this way leads to improved buy-in and support for its continuation and is thus critical for integrating lean into the hospital culture (Stelson *et al.*, 2017; Flynn *et al.*, 2019). For staff to become engaged, the implemented improvements must be meaningful to them. If they value the changes being pursued, they are more likely to become involved with their implementation (Kim *et al.*, 2006). In a hospital, this means focusing on patient safety and quality of care or making day-to-day work more manageable and less frustrating, instead of focusing on cost reduction, efficiency, or waste elimination for their own sakes (Sobek II, 2011). Along with taking a patient-centred approach, practices such as training, which will help them gain an understanding of what lean aims to do, and communication of the change vision also support engagement (Leggat *et al.*, 2018; Flynn *et al.*, 2019; Udod *et al.*, 2020).

For true participation, however, people must be provided with the opportunities to influence the redesign of their work (Leggat *et al.*, 2015). Thus, encouraging ownership and accountability among workers is critical for lean's uptake (Scott *et al.*, 2011; Steed, 2012; Breuer, 2013; Sirsly and Sur, 2013; Bartram *et al.*, 2020). Such empowerment is especially in line with lean's focus on creating a "thinking people system", where every person is encouraged to improve their work environment, every day (Centauri *et al.*, 2017).

Ownership means being aware that you are responsible for the quality of your work and for improving processes in your workplace (Leggat *et al.*, 2018). By taking ownership over the improvement of their own workplace, workers can create change that benefits their day-to-day work and supports their view of improved care (Bartram *et al.*, 2020). It not only makes them more optimistic about lean, but gives them a level of control over their own work, helping them maintain their professional power and thus becoming more invested in the process (Leggat *et al.*, 2018; Bartram *et al.*, 2020). This relationship also demonstrates how ownership and participation drive one another. When workers gain ownership of their work, they become empowered to participate. On the other hand, participation increases the chances of workers taking ownership of the work because they are directly involved with it (Sobek II, 2011; Lindskog *et al.*, 2016). Engaging and empowering internal professionals to manage and develop improvement projects makes the whole change initiative self-sustaining (Centauri *et al.*, 2018).

While ownership is important, such accountability cannot rely on a few enthusiastic staff members; the organisation as a whole must adopt a culture of long-term accountability (Steed, 2012; Rotteau *et al.*, 2015). Making all staff responsible for identifying value is critical, and is equally true for engagement (Centauri *et al.*, 2016). Thus, effective involvement requires every level of the organisation to be committed to change, including frontline staff, management, and physicians (Dickson *et al.*, 2009; Lindskog *et al.*, 2016; Leggat *et al.*, 2018; Bartram *et al.*, 2020; Henrique *et al.*, 2020). Management involvement has been explored in Section 4.3.5 as part of the leadership area. This discussion, therefore, focuses on the involvement of frontline staff and physicians (Leggat *et al.*, 2018).

Due to their in-depth understanding of the process and areas they work in, frontline staff are in the best position to identify and generate improvements (Sobek II, 2011). They are the system operators who make the operation happen (Henrique *et al.*, 2020). Their involvement is thus incredibly valuable for solving problems (Brandao de Souza, 2009; Sobek II, 2011). On the other hand, physicians have a lot of positional and political power in the industry, organisation, and all workplace levels (Bartram *et al.*, 2020). Very little happens in healthcare without an order from them (Sobek II, 2011). Their involvement shows that they support the implementation of lean and, because of the influence they have, legitimise the change for the rest of the employees (Henrique *et al.*, 2020). They can also influence many other aspects of lean's implementation. For example, in their study, Bartram *et a*l. (2020) found that doctors assisted management in securing more resources. Therefore, if leadership support and adequate resources are lacking, doctor engagement could help alleviate the problem because of their influence on resource designation (Bartram *et al.*, 2020). Leggat *et al.* (2015) also reported that lean is unlikely to be successful where doctors do not participate. On the whole, managers can improve project success by involving employees directly affected by the proposed changes (Stelson *et al.*, 2017).

There are several ways in which employee engagement and ownership can be encouraged and supported. For example, staff participation is largely influenced by the time available to participate (Lindskog *et al.*, 2016; Leggat *et al.*, 2018). Staff could be interested in making improvements and getting involved, but unwilling to invest in the additional time that may be required (Stelson *et al.*, 2017). It is therefore essential that shifts are managed and work is organised in a way to ensure the workforce is available for involvement in training and improvement activities (Centauri *et al.*, 2016; Leggat *et al.*, 2018). Being provided adequate time and ensuring an understanding of lean thus both impact the willingness of workers to participate in lean (Udod *et al.*, 2020). Additionally, the involvement and empowerment of employees must be supported by the power to influence processes and set goals. Thus, assigning lean roles and being clear about the authority of these roles gives staff the power they feel they need to do this (Lindskog *et al.*, 2016). A high-quality relationship between employees and managers also positively influences employees' commitment to change (Pfeffer, 1994). When staff have a good, trusting relationship with their manager, where they feel they can suggest improvements that are valued, it makes them more willing to participate. Hospital managers must thus also trust staff to have control over the improvement of their own work and embrace a bottom-up approach in the hospital (Berwick, 2003).

4.3.7 CULTURE

An organisation's culture is the collection of values, expectations, and practices that guide and inform the actions of all team members. Thus, to completely integrate lean into a hospital where it has become the norm, there needs to be a change in culture (Sobek II, 2011; Spagnol, Min and Newbold, 2013; Wood, 2014; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016, 2018). Anchoring a new way of thinking and acting into a hospital's culture is arguably the most critical step in ensuring the hospital's culture does not fall back into the old way of doing things (Breuer, 2013). There thus needs to be a change in the mentality, expectations, behaviours, and beliefs of all staff (Mazur, McCreery and Chen, 2012; Spagnol, Min and Newbold, 2013; Wood, 2014; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016). Changing expectations creates a "fertile ground for the full internalisation of the new logic" and makes the organisation ready to change (Centauri *et al.*, 2016). This section thus aims to highlight different cultural characteristics that are important for the hospital to foster long-term and continuous change.

Firstly, because lean projects have a beginning and an end and can be accomplished relatively quickly, many hospitals see lean as a quick-fix project (Sobek II, 2011; Spagnol, Min and Newbold, 2013; Leggat *et al.*, 2018). Hospitals, however, have to recognise and communicate that lean is a long-term transformation aimed at creating the capability to continuously improve (Radnor, 2011; Sobek II, 2011; Breuer, 2013; Spagnol, Min and Newbold, 2013; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016; Henrique *et al.*, 2020). It is important for senior managers to thus structure and promote these projects as components of a continuing, well-designed and resource change-management plan designed to meet strategic organisational goals (Sobek II, 2011; Rotteau *et al.*, 2015; Leggat *et al.*, 2018). Communicating this long-term view helps the hospital establish a culture of continuous improvement, as employees understand that lean is not just an improvement program with little impact, but rather a change towards a long-term journey of improvement (Abuhejleh, Dulaimi and Ellahham, 2016; Leggat *et al.*, 2018). This continuous improvement capability means lean is practised every day, decisions are made based on long-term thinking instead of short-term gains, and the commitment to improvement continues even when results are not immediately shown (Sobek II, 2011; Henrique *et al.*, 2020). It also means that actions are frequently reassessed for further improvement opportunities. Once goals are met, they have to be set higher to pursue the idea of perfection (Breuer, 2013).

Secondly, for lean to be sustained, lean needs to be wholly integrated into the culture to the point where it is part of daily work (Sobek II, 2011). Thus, instead of seeing lean as something that takes time away from their routine activities and adds to their workload, it should be viewed as part of their routine work. Staff often express frustration towards the increased workload resulting from participation in lean and not enough time being allocated to perform lean tasks (Sobek II, 2011; Stelson *et al.*, 2017). However, the entire premise of lean is that it eliminates waste and thus frees up more time for more meaningful, value-adding work. The solutions that come from integrating lean into routine activities may very well mitigate some of the extra workload and time that is initially invested (Sobek II, 2011). If staff realise that lean is valuable to their daily operations, they are more likely to dedicate time towards its practice and adapt their workload to their new responsibilities (Spagnol, Min and Newbold, 2013; Flynn *et al.*, 2019). Thus, this can be achieved by communicating how lean values such as efficiency, patient safety, and waste reduction align with their own values through effective training that is correctly adapted to the healthcare context (Flynn *et al.*, 2019).

A third crucial cultural element is thus for staff to be open and flexible to change (Dickson *et al.*, 2009; Abuhejleh, Dulaimi and Ellahham, 2016). Adopting lean into a positive environment that is willing to change aids the diffusion of lean into the hospital's culture (Abuhejleh, Dulaimi and Ellahham, 2016). Dickson *et al.* (2009) state that the Toyota Production System transformed Toyota by motivating its workers and managers to be flexible to change.

Furthermore, creating a "thinking people" system, where every person is encouraged to improve their work environment, every day, is an integral part of lean (Centauri *et al.*, 2017). Aspects of such a system were addressed in Section 4.3.6, where the importance of workforce engagement and empowerment was discussed. Encouraging every person to improve their own work environment means it is essential to feed ideas and proposals generated by professionals at all levels of the organisation (Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016). Thus, promoting individual initiative is a critical element of lean culture (Centauri *et al.*, 2016). The method of harnessing employee suggestions is called the "bottom-up" approach. With this approach, people are given more freedom to generate new ideas for improvement, as well as opportunities to discuss the ideas and decide what is best for the organisation. Having decisions made from the bottom when appropriate helps build a culture supportive of each other and quality improvement (Abuhejleh, Dulaimi and Ellahham, 2016). Support from co-workers is important for leadership and staff in gaining the ability to drive improvement work (Abuhejleh, Dulaimi and Ellahham, 2016; van Rossum *et al.*, 2016; Kahm and Ingelsson, 2019). Braithwaite (2018) pointed out that people resist change imposed by others and that mandated change is never given the same weight as clinically driven change. This sentiment was echoed by Scott (2009), who concluded from a systematic review that clinician-driven improvements are more effective than management-driven improvements. Managers must acknowledge that frontline staff members have greater insight into the process and are therefore more likely to find ways of improving it (Dickson *et al.*, 2009). Making decisions in consensus by those involved in the operation and not by unilateral top-down mandates puts the staff at the forefront of change, encouraging and supporting involvement (Centauri *et al.*, 2017; Henrique *et al.*, 2020).

Given the importance of adopting a bottom-up approach, another essential part of the culture created in the hospital that will support this is to foster an open, no-blame environment. Not only must leaders listen to the issues that frontline staff raise, but they must make it clear that they do not need to fear reprimand (Tonkin and Bremer, 2009). Staff must additionally be assured that any improvements made to the areas they work in may result in redirection of job description and duties, but they will not lose their employment (Kim *et al.*, 2006). If staff feel free and safe to report errors or issues, they will be more encouraged to recognise problems, thus resulting in more solutions being developed (Sobek II, 2011).

To encourage bottom-up involvement and motivate employees to generate improvements in their own areas, there needs to be a structured incentive system in the hospital supported by accurate measurement systems (Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016). Thus, employee teams are assessed and rewarded through competition programs based on implemented improvement ideas or performance goals achieved (Henrique *et al.*, 2020). Therefore, leadership needs to support resources for the recognition and rewards for improvements made (Sobek II, 2011; Abuhejleh, Dulaimi and Ellahham, 2016). Organisations that celebrate successes and recognise the work done by employees tend to maintain these improvements in the long term more efficiently and support the internalisation of lean as a work tool, as it makes employees feel more motivated to sustain the new procedures and continue to improve (Wood, 2014; Centauri *et al.*, 2016).

Additionally, the hospital as a whole needs to take on a patient-centred and process-based approach, so that lean is combined with clinical pathways to streamline primary care processes (Centauri *et al.*, 2016, 2018). Patient-centredness orients the hospital's focus to the user and his needs when identifying problems and developing solutions (Wood, 2014; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016). The patient's perspective needs to be taken into account, as without them, there is no need for healthcare. Their need drives the system (Hellström, Lifvergren and Quist, 2010). Focusing operations on their satisfaction creates a culture that is continuously focused on improving the patient healthcare experience (Spagnol, Min and Newbold, 2013; Wood, 2014).

Furthermore, the organisation needs to be viewed as an integrated and dynamic system of processes. If a process vision is not acquired, there is a risk that the intrinsic dynamics of the system may eliminate any improvements that may have been realised (Centauri *et al.*, 2016). Without considering how other departments are affected by the change, an improvement in one area could create additional bottlenecks further down the line. Therefore, not taking on a process-based organisational model makes it almost impossible to optimise hospital processes (Centauri *et al.*, 2016).

The final element that is important in fostering a culture that will sustain lean is a focus on teamwork (Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016). Creating a shared understanding, awareness, and accountability culture that builds teamwork at all levels is necessary to provide a clear vision to guide the program (Sobek II, 2011).

Various other practices aid and support the cultural aspects discussed above. For example, an essential element of an effective, lean-driven culture is lean leadership. Culture change is affected by the presence of someone with the specific role of supporting the implementation of any new approach or concept in the organisation (Dickson *et al.*, 2009; Amar, 2012). Therefore, practices in the leadership area and the presence of a champion, which is part of the lean team area, support this. Breuer (2013) stated that champions are responsible for emphasising that lean is a journey with a long-term perspective. Additionally, for staff to view lean as a job resource, they need to understand change. Not only does communication and knowledge thus aid this practice, but the achievement of a culture where lean is viewed in this way means that there will be more buy-in. Engaging frontline staff in all problem-solving process stages motivates, gives ownership, and a sense of making a difference, thereby making quality an integral part of everyday work. Therefore, staff involvement is essential for normalising lean into daily practice. Furthermore, viewing lean as something that leads to an overburdened workload can have a negative effect on employee engagement (Stelson *et al.*, 2017). Therefore, ingraining this culture where lean is viewed as something that aids day-to-day work and ultimately benefits both staff and patients can improve staff engagement.

4.3.8 LEAN TEAM

When undergoing a large organisational transformation such as lean, management can't oversee every aspect of its implementation (Breuer, 2013). Therefore, it can be helpful to introduce new lean roles and appoint a specific lean team to support and facilitate the implementation process (Breuer, 2013; Rotteau *et al.*, 2015; Lindskog *et al.*, 2016; Centauri *et al.*, 2017, 2018; Henrique *et al.*, 2020). The lean team is tasked with guiding the transformation process in the intended direction and managing the dynamics of continuous improvement to gradually disseminate the use of lean tools and methods into the organisation (Centauri *et al.*, 2016, 2018). Various authors referred to the importance of role clarity in lean's sustainability (Lindskog *et al.*, 2016; Centauri *et al.*, 2018). Therefore, by intentionally assigning these roles and discussing the boundary location and authority of each role, the staff is clear on their responsibilities, avoiding any potential role conflict amongst employees. Unclear roles result in frustration and a lack of ownership, consequently inhibiting unit-level participation (Lindskog *et al.*, 2016).

The lean team also acts as an intermediate level between top management and staff. The bidirectional communication created between these two groups helps overcome the gap between strategic and operative levels within the hospital, which is often experienced, improving the alignment between the improvement efforts and organisational goals (Centauri *et al.*, 2018).

While the importance of having a lean team of specific roles dedicated to facilitating lean's implementation was frequently mentioned, the composition of such a team was less commonly discussed. Only some authors indicated that internal staff members specifically need to take on this role (Scott *et al.*, 2011; Centauri *et al.*, 2018; Henrique *et al.*, 2020). However, external lean teams are often used by hospitals to guide them in the transformation process due to their knowledge and experience with lean. While they offer value in this regard, they can sometimes lack insight into the particular hospital's history, organisational structure, and politics, which can result in a disconnect between lean and hospital staff (Rotteau *et al.*, 2015). Furthermore, it has been found that externally led hospital redesign can lead to a withdrawal of resources, managerial focus, and staff returning to the old way of doing things once this team leaves (Scott *et al.*, 2011). Despite these drawbacks, implementing lean is a large undertaking, so without external help, it can be overwhelming. Therefore, external consultants do offer value, but this is generally more so the case in the beginning stages of implementation (Centauri *et al.*, 2016). Once staff has developed the awareness and skills to manage lean, their involvement is no longer necessary, allowing space for the hospital to invest in internal company resources instead, which is imperative for engagement and empowerment (Centauri *et al.*, 2016). Using internal resources to guide sustainability engages professionals, thus increasing their involvement, strengthening the organisation's bottom-up dynamics, and creating a culture of waste identification (van Rossum *et al.*, 2016; Centauri *et al.*, 2018). Scott *et al.* (2011) concluded that when compared to externally led redesign, internally led redesign resulted in superior and sustained improvements due to the changes driven by committed and involved staff. So while an external lean team is helpful in lean's implementation, it is the use of an internal lean team specifically that is critical to sustainability.

Furthermore, in addition to the team needing to be built with employees, they should also have appointed leaders (Breuer, 2013). The most frequently discussed form that this takes, and one that plays a pivotal role in a successful lean implementation, is that of a lean champion (Dickson *et al.*, 2009; Breuer, 2013; Centauri *et al.*, 2016). A lean champion is someone who is very well-versed in lean by either having studied it or attained substantial practical experience with its implementation. They serve as mentors to project teams and act as a bridge between these teams and management (Breuer, 2013; Rotteau *et al.*, 2015). Champions are also responsible for making sure employees understand lean. They therefore train colleagues and support them in the development of projects (Breuer, 2013; Rotteau *et al.*, 2015; Centauri *et al.*, 2017). They must thus have a deep understanding of both lean the challenges faced by the hospital, and have proficient skills in facilitation, collaboration, and conflict resolution. Generally, a lean champion will focus and lead teams on some or all of the following areas: facilitating integrated action among interdepended units and service departments, motivating employees to keep participating in lean after initial implementation, leading workshops, and coordinating Kaizen or rapid improvement events (Dickson *et al.*, 2009; Breuer, 2013; Centauri *et al.*, 2016). To ensure these activities align with core business objectives, champions must always work in synergy with top management (Centauri *et al.*, 2016).

Additionally, multi-professional and cross-functional teams were considered critical to program success (Rotteau *et al.*, 2015; Centauri *et al.*, 2016; van Rossum *et al.*, 2016). Teams that consist of staff who span across departments enable flexibility of the workforce, therefore supporting interaction and collaboration between units and strengthening the change capacity of the hospital (van Rossum *et al.*, 2016). It further drives hospital-wide improvement by encouraging the utilisation of a system view instead of only improving locally (Breuer, 2013). Lean champions can be used to facilitate this integrated action among interdependent units and service departments (Leggat *et al.*, 2018).

4.3.9 CHANGE MANAGEMENT

The hospital must have a transformation or improvement plan specific to the hospital's context that is communicated to everyone (Breuer, 2013; Leggat *et al.*, 2018; Henrique *et al.*, 2020). This plan must have a change vision that communicates explicit, clear, and measurable goals; and the set of steps to be followed to achieve them (Steed, 2012; Spagnol, Min and Newbold, 2013; Centauri *et al.*, 2016, 2018;

Stelson *et al.*, 2017; Leggat *et al.*, 2018; Kahm and Ingelsson, 2019). Developing a long-term vision and strategy helps establish the expectation and goals of the lean implementation and guides the transformation, while the strategy outlines the steps to achieving this vision in more detail, outlining not only which processes will be changed and when, but also how and why they will be changed (Sobek II, 2011; Breuer, 2013).

The goals included in the transformation plan need to be broken down all the way to unit-level so that all levels have goal clarity (Steed, 2012; Lindskog *et al.*, 2016; Centauri *et al.*, 2018). If goals are not fully realised in every unit and aligned across the hospital, it results in numerous competing objectives and changes with unintended consequences (Peltokorpi *et al.*, 2008; Sobek II, 2011). Additionally, fuzzy goals result in vague purposes and a lack of guidance, leading to indecisiveness on how to proceed and confusion amongst staff (Lindskog *et al.*, 2016). Employees thus hesitate to become part of the program, resulting in lean not being prioritised and a lack of participation, ownership, and buy-in from staff (Breuer, 2013; Lindskog *et al.*, 2016). Furthermore, not setting clear goals at the onset of lean makes it difficult to follow up on progress, inhibiting learning and resulting in late responses to further improvement opportunities (Lindskog *et al.*, 2016). By then translating these goals to clear and coherent action plans for the different levels of the organisation, it prevents the implementation team from neglecting any steps that could undermine sustainability in the future (Centauri *et al.*, 2016; Henrique *et al.*, 2020).

In developing the implementation plan for lean, it is vital to consider the strategic objectives already established in the hospital and its overall vision. At the same time, lean also needs to be integrated into the hospital's strategic planning from the beginning to ensure integration between lean and the hospital (Steed, 2012; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2018; Leggat *et al.*, 2018; Flynn *et al.*, 2019; Henrique *et al.*, 2020). If the improvement plan is not coupled with the hospital's strategy, sustaining and replicating any improvements can be challenging (Centauri *et al.*, 2016). Aligning the lean initiative goals and strategic objectives for the hospital ensures they are moving towards achieving the same thing. Thus, the results will have more of a global impact (Bhasin, 2012b; Henrique *et al.*, 2020). Therefore, fully aligning the goals results in lean's integration into organisational activities, an important aspect of sustainability (Steed, 2012; Centauri *et al.*, 2016; Flynn *et al.*, 2019).

Communication and training are fundamental to ensuring that improvement actions that arise within the individual departments align with the strategic vision. Thus, senior managers need to provide a visible link between goals, measures, and targets related to efficient operation and quality of care (Leggat *et al.*, 2018). Furthermore, aligning and sharing organisation goals throughout the organisation visibly aids accountability and makes staff more willing to accept the change and be involved (Centauri *et al.*, 2017, 2018). All staff need to understand how lean and quality improvement fit the organisation's strategy and understand their specific role in continuous improvement (Leggat *et al.*, 2018). Introduction and maintenance of lean as a strategic pillar is essential to continually foster and address the hospital staff towards the change.

Leadership plays a vital role in the development of the transformation plan, as it is their responsibility to set the vision and project guidelines and ensure a link between this vision and efficient operations and quality of care (Sobek II, 2011; Centauri *et al.*, 2018). There may be a need to develop forums where managers meet so goals can be translated into daily practice and an agreement on what they want to change, why, and how can be reached (Kahm and Ingelsson, 2019). Furthermore, the conviction of this plan is essential, and part of the management's sponsorship function must be to communicate it to everyone (Kotter, 2007; Stelson *et al.*, 2017; Leggat *et al.*, 2018).

An important part of change management that has a significant effect on how well lean is integrated into the organisation is the level of stakeholder commitment and buy-in (Sobek II, 2011; Steed, 2012; Centauri *et al.*, 2016; Kahm and Ingelsson, 2017; Stelson *et al.*, 2017; Bartram *et al.*, 2020). Gaining employee buy-in is critical for achieving engagement, as without being assured that it is needed, there will be a reluctance to participate in its implementation. Without an agreement to participate, lean initiatives will not be embedded or sustained (Bartram *et al.*, 2020). Critical to achieving buy-in and assuredness is establishing a sense of urgency (Breuer, 2013). Establishing urgency means employees understand that change is needed (Breuer, 2013). A sense of urgency is expressed as an assuredness that change is necessary (Kahm and Ingelsson, 2017). To support the argument, leadership may use financial and non-financial performance measures as well as competing hospitals as examples (Breuer, 2013).

While several authors mentioned stakeholder buy-in as something that aids sustainability (Steed, 2012; Kahm and Ingelsson, 2017; Bartram *et al.*, 2020), it is a practice that is difficult to implement directly. Overcoming cultural barriers is one of the main aspects of securing buy-in (Centauri *et al.*, 2016). The implementation of several other practices, however, can help ensure that this is achieved. For one, an awareness of the urgency and need for change helps achieve buy-in (Sobek II, 2011; Stelson *et al.*, 2017).

Therefore, the "communicate reasons for change" aspect of Communication and Feedback is critical (Steed, 2012). It ensures that employees understand and accept the reasons for implementing lean (Sobek II, 2011). Additionally, by integrating the improvement plan with the strategic vision, as discussed above, how lean and quality improvement fit the organisational strategy is shown in a more tangible way, fostering a positive view of lean and willingness to change (Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016). It additionally helps them understand the benefits that improvements will bring them and patients, another aspect that supports buy-in (Sobek II, 2011; Udod *et al.*, 2020). If they have the perception that the changes being pursued are needed, they are more likely to commit to change (Stelson *et al.*, 2017). A lack of understanding of the benefits of change contributes to the tendency of staff to revert to the old way of doing things. Furthermore, a closed culture that is unwilling to change and does not see lean as a job resource can preclude the acceptance of lean (Centauri *et al.*, 2016). Therefore, the culture practices "view lean as a job resource" and ensuring an "open and willing to change" can support this. Lastly, a recent study on the implementation process of lean by Goodridge *et al.* (2018) found that those with lean training were more likely to see potential in the value of lean and support the use of lean for their work. It is part of the leadership's role to secure buy-in from key stakeholders (Sobek II, 2011).

What makes lean different from other improvement processes is its focus on the flow through the entire system (Breuer, 2013). Lean requires a holistic, system-wide approach to be adopted, where change is driven across the whole hospital and all workplace levels (Brandao de Souza, 2009; Scott *et al.*, 2011; Steed, 2012; Breuer, 2013; Rotteau *et al.*, 2015; Leggat *et al.*, 2018; Bartram *et al.*, 2020; Udod *et al.*, 2020). This approach prevents narrowed implementation where smaller, local improvements are made that do not have more significant organisation-wide results and may even have sub-optimal effects on other units or departments (Breuer, 2013). For example, suppose the emergency department attempts to expedite their patient discharge without considering the larger system. In that case, the adjacent critical clinics may not be able to accommodate the amplified demand, thus negating any improvements made in that department when it comes to the hospital overall (Breuer, 2013). In practice, however, hospitals often neglect this aspect of lean (Burgess and Radnor, 2013). They tend to focus on lean tools and small-scale activities without attempting to bring these together into a more comprehensive program for change (Radnor, Holweg and Waring, 2012; Breuer, 2013; Centauri *et al.*, 2018). Radnor and Boaden (2008) indicate that many public managers primarily use a set of tools and techniques to attempt to apply lean without fully understanding its principles. The research often criticises the focus on lean as a toolbox approach rather than a broader system-wide improvement philosophy (Brandao de Souza, 2009; Radnor, Holweg and Waring, 2012). Of course, with healthcare being a highly political and complex organisational setting characterised by professional groups and regulatory systems, achieving this systems view is not an easy task (Breuer, 2013). Resource constraints often mean lean is approached at a micro-level and not as the organisation-wide holistic approach intended (Bhasin, 2012a; Breuer, 2013). Consequently, there is conflicting evidence in literature about whether lean should be applied to the whole hospital, honouring the principles of lean, or more sequentially to aid change management. It is more common for a selective, step-by-step approach, but several authors push for a large-scale change focused on a holistic implementation of lean (Breuer, 2013). Whichever way the hospital chooses to do it, what is clear is that they must follow through until the entire system is operating in a lean way (Breuer, 2013).

Another aspect of change management important for lean sustainability is understanding the context of the hospital and how it influences lean (Rotteau *et al.*, 2015; Cummings *et al.*, 2017; Braithwaite *et al.*, 2018; Flynn *et al.*, 2019). An aspect of this was addressed in the knowledge and training area (Section 4.3.3), where the importance of training being adapted to context was addressed. It was found that failing to translate lean concepts, principles, and their meanings from a manufacturing perspective to a healthcare perspective when training staff hindered the sense-making process, thus negatively impacting the degree of support for lean's continuation and, ultimately, precluding sustainability (Flynn *et al.*, 2019). In addition to this, failure to understand the implications a complex hospital system has on lean's implementation and normalisation negatively impacts its success. It cannot be assumed that the transition of lean from healthcare without consideration for context will offer the same benefits as found in manufacturing, where lean originated (Mazzocato *et al.*, 2014; Braithwaite *et al.*, 2018). It is also important to note differences in macro-level (system) contexts, such as differences in funding models between different provincial governments or insurance models, etc., when implementing lean (Flynn *et al.*, 2019). A lack of fit between lean and healthcare and a lack of customisation to context can lead to unsuccessful implementation, creating the perception that healthcare is not congruent with lean and triggering some inhibitors for its sustainability, such as resistance to change and a lack of buy-in (Øvretveit, 2011; Flynn *et al.*, 2019). The hospital thus needs to identify its services and core competencies as well as define patient values relevant and unique to its business environment (Breuer, 2013).

Another critical aspect of lean's implementation, and any organisational change, which authors did not frequently address, was to allow time for its uptake (Scott *et al.*, 2011). When implementing lean, enough time needs to be given to staff to internalise a new concept or way of working before introducing the next one. Overwhelming staff with too much at once can lead to change fatigue, resulting in them reverting to the old way of doing things (Wright and McSherry, 2013; Flynn *et al.*, 2019). The organisation's structure must prepare itself to maintain the new management culture by being aware of the time needed to implement new logic and the effects these could have on the organisation and staff's workloads (Steed, 2012). And rather, gradually introduce and involve everyone in the hospital in lean (Centauri *et al.*, 2016; Stelson *et al.*, 2017). A common mistake is not to devote the necessary time for the uptake of lean activities. Just because lean needs to be applied to the whole hospital, does not mean all aspects need to be done at once, but simply that those aspects that are done, be done everywhere. Therefore, lean should be deployed in a paced and systematic fashion and should not be rushed (Steed, 2012). Actual change takes time; it does not happen overnight.

Furthermore, adequate human, fiscal, material, and technical resources are needed to support the uptake of lean (McCreery, Mazur and Rothenberg, 2011; Steed, 2012; Spagnol, Min and Newbold, 2013; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016; Stelson *et al.*, 2017; Udod *et al.*, 2020). The most important being adequate funding, as additional finances allow for the provision of all the other resources. Additional funding can be used to provide staff more time to participate in lean and attend workshops, extra resources for data analysis, rewards for improvements made, training and education, or external consultants for support in the initial phases of implementation (Kundu and Murali Manohar, 2012; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016; Stelson *et al.*, 2017).

However, additional resources cannot always be afforded. This position is one of the most significant areas where public and private sector hospitals differ. There is more potential for greater investment in lean in the private sector than in the public sector, where, without additional government support, there are rarely additional resources available. Even if additional funding is provided, it is usually insufficient for a system-wide implementation (Leggat *et al.*, 2018). Financial capability is, however, an important factor for the success of any project (Abuhejleh, Dulaimi and Ellahham, 2016). Where additional funding cannot be provided, it can be managed in a different way. For example, providing human resources with the time and availability to engage with lean is what additional human resources allows. Instead, leaders can manage shifts and organise work in such a way to ensure an appropriate the necessary involvement of employees in training and operational activities related to implementation of the lean model (Steed, 2012; Centauri *et al.*, 2016). Additionally, rewards for improvements made are given to make employees feel their contributions are valued, thus keeping them motivated and engaged. The hospital can still recognise these achievements without financial rewards and celebrate them by communicating successes and acknowledging their accomplishments instead. It is thus not to say lean cannot be sustainable without additional resources, but that it will create challenges and certainly impede it. The hospital still needs to ensure that staff is adequately trained, lean is appropriately implemented, and that there is enough time available for resources to participate (Barnas, 2011; Steed, 2012; Spagnol, Min and Newbold, 2013; Centauri *et al.*, 2016; Stelson *et al.*, 2017; Udod *et al.*, 2020).

4.3.10 ORGANISATIONAL STRUCTURE

For lean to be successful the entire workforce must be flexible in responding to changing environmental conditions and be able to collaborate with different departments or units (Walley, 2003; van Rossum *et al.*, 2016; Leggat *et al.*, 2018). Having the knowledge and skills to do this ensures that voices from other departments or functions indirectly affected by the change are heard. Thus, allowing teams to consider how their proposals might affect activities beyond the current task being improved and aiding optimisation of the entire process flow (van Rossum *et al.*, 2016; Stelson *et al.*, 2017). Moreover, the right degree of workforce flexibility will determine the extent to which organisational elements such as behaviour, procedures, systems, and structures can be adjusted (van Rossum *et al.*, 2016). Employees must be able to respond to changes in demand and adapt their approach to different types of patients entering the system (Walley, 2003).

However, the professional and functional silos found in traditional hierarchical structures of hospitals have been found to impede such flexibility (de Souza and Pidd, 2011; Stelson *et al.*, 2017; Flynn *et al.*, 2019). Hospitals thus need to focus on their organisation structure to remove such barriers and have less rigidity in hospital structures and systems (Sobek II, 2011; van Rossum *et al.*, 2016). It can be done by creating multidisciplinary teams without hierarchy, where decisions are made together (de Souza and Pidd, 2011). Lean healthcare teaches that optimising the performance of an individual unit or "silo" is insufficient for creating long-lasting change (Kim *et al.*, 2006). The entire flow must be improved if meaningful and sustained performance is to be achieved (van Rossum *et al.*, 2016). Autonomous working in hierarchies reinforces institutionalism and reduces the flexibility of the workforce and, in effect, the capacity of the hospital to change (Thakur, Hsu and Fontenot, 2011; van Rossum *et al.*, 2016). Therefore, the ideal hospital should have all the specialities with a uniform layout and structures not bound to specific uses, making it easily mouldable for any future changes at a strategic level or in organisational care activities (Centauri *et al.*, 2016). Decisions on the physical configuration of spaces are critical for the correct functioning of the internal dynamics of hospitals (Centauri *et al.*, 2016). Such an organisational structure also aids alignment from senior leadership to frontline staff, which means there is a consistency of plans, visions, resources, actions, and results to support system-wide goals (Baldrige National Quality Program, 2006; Lukas *et al.*, 2007). Hierarchical structures can result in incongruence between leadership and frontline staff and the perspective that lean is not currently part of their daily work (Flynn *et al.*, 2019).

4.4 CHAPTER 4: CONCLUSION

This chapter executed a systematic review of literature to obtain factors that have been found to aid or inhibit lean sustainability in hospitals. This review was done as a starting point to the development process, gathering information for what the tool needs to assess. The data analysis process resulted in the development of 29 sustainability practices grouped into ten main areas. This chapter ended with a discussion on how each identified practice contributes toward improved lean sustainability in hospitals.

Amongst the identified practices for lean's sustainability was the need for a holistic implementation of lean. Leanness assessments aim to measure the extent to which such a practice has been implemented. Thus, investigating what such assessments measure to determine leanness would reveal further information regarding how it can be implemented. Therefore, as a continuation of the tool development, Chapter 5 reviews existing approaches to leanness assessments. Such a review uncovers practices needed for a holistic implementation of lean and explores possible ways to structure such a tool.

Chapter 5 Existing leanness assessment tools and methodologies

The need for a holistic implementation of lean being identified for effective uptake and long-term change meant what constitutes such an implementation needs to be investigated. Additionally, how to approach an assessment of these elements needs to be determined. Therefore, a systematic review of existing leanness assessment tools and methodologies was executed. This review served two purposes: 1) to uncover the parameters used in literature to determine leanness and 2) to investigate the characteristics and methodologies adopted to assess them. Given the lack of tools for assessing sustainable lean practices, approaches focusing on assessing leanness were studied so the findings could be adapted to the overarching sustainability assessment. The review thus aims to answer the following research questions:

1. Which parameters are used to determine leanness?
2. What are the different types of methodologies adopted to assess the leanness level of an organisation?
3. What data is required for a leanness assessment and how is it generated?
4. What information is generated from these assessments and how is the output presented?

Two similar reviews on the assessment of leanness were found in exploring the literature available on this topic, namely Doolen and Hacker (2005), and Narayanamurthy and Gurumurthy (2016a). Neither of these, however, has been executed from the perspective of the healthcare industry.

This chapter begins by conceptualising leanness assessments in Section 5.1 which is followed by an overview of the methodology used to execute the review (Section 5.2). The results are then presented and critically analysed in Sections 5.3 - 5.5. The analysis of these results is explored in the subsequent chapter (Chapter 6), which details the development of the SLAT. Lastly, the chapter is concluded in Section 5.6.

5.1 LEANNESS ASSESSMENT

As previously discussed, leanness is the degree to which organisations adhere to the principles of lean, a practice which was identified in Chapter 4 as necessary for leanness. However, as lean practices are the activities used to implement these principles, by measuring the implementation of lean practices, the degree of leanness of an organisation can be determined (Figure 5.1). Therefore, the focus of this review is on leanness assessments. Identifying the practices that are used to assess leanness will provide further insight into what is required to realise the “Holistic implementation of lean philosophy” sustainability practice.

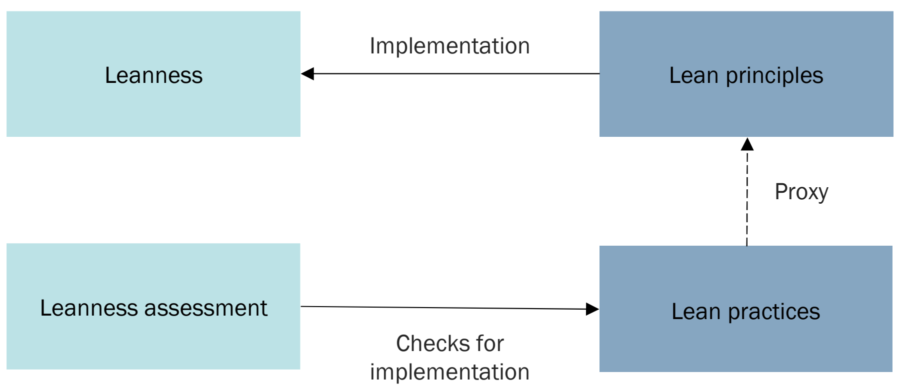


Figure 5.1 Leanness assessment

5.2 METHODOLOGY

To again ensure the review is executed with rigour and without bias, the methodology outlined in Chapter 2 was used. The steps are shown in Figure 5.2. and their execution is discussed in this section.

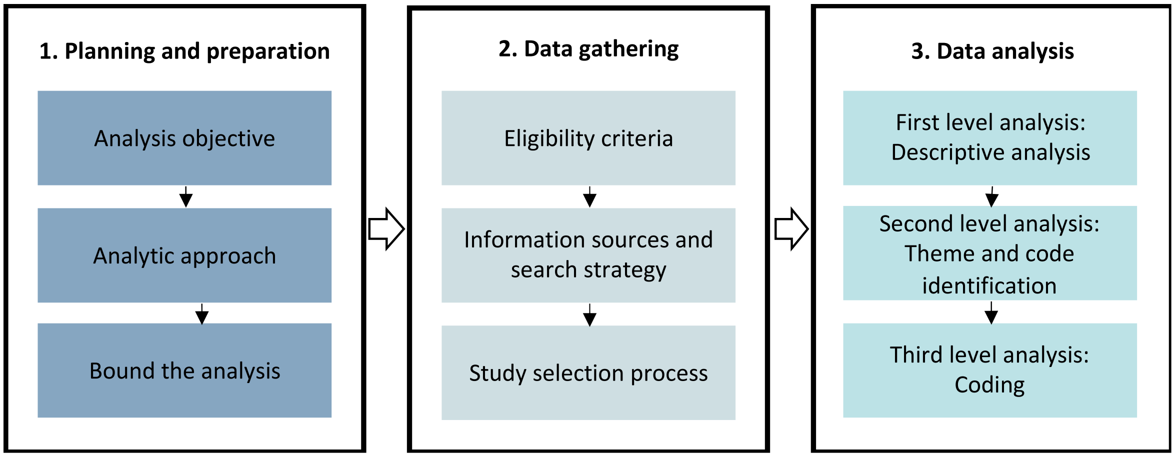


Figure 5.2 Process of systematic review on leanness assessment tools and methodologies

5.2.1 PLANNING AND PREPARATION

The analysis plan begins by establishing the analytic objectives (Section 5.2.1.1). Once the analysis objective has been identified and briefly described, the primary analytical approach that will be followed to achieve it must be chosen (Section 5.2.1.2). Next, the data to be used for the analysis and the reason behind the decision must be detailed as part of "bounding the view" (Section 5.2.1.3). Once the boundaries of the analysis have been defined, the last step involves establishing how the text will be coded. This process can be decided while planning the analysis, generating the data, or after it has been collected, processed, and cleaned (Guest, MacQueen and Namey, 2012). In the case of this review, the specifics of the coding process were only decided after the data collection took place, and thus is described in Section 5.2.3, where the data analysis procedure is explained.

5.2.1.1 Analytic objectives

As was the case in the review executed in Chapter 4, the objective of this analysis is to answer a research question, specifically those presented in the introduction of this chapter. It is thus intended to uncover how existing tools and methods approach leanness assessment in terms of the data used, how it is collected, which assessment parameters are used, how leanness is determined, and the output presented.

5.2.1.2 Analytic approach

The three broad approaches to analysis within qualitative research include exploratory, explanatory, and confirmatory analysis. Exploratory analysis is used to explore data and find relationships between variables, and explanatory analysis is done to discover more about what was found. The output of such an analysis is information that can then be used to guide decision-making. In the case of this research, the exploratory analyses executed in Chapter 3 uncovered the problems with the practical implementation of lean in hospitals. These problems highlighted the need for a leanness assessment tool. This review now seeks to understand the existing leanness assessment tools and how they are structured to inform the decisions in developing such a tool for hospitals. Therefore, for this review, an explanatory analytic approach was adopted.

5.2.1.3 Bounding the analytic view

Bounding the analytic view involved establishing the sources of data and what domains will be considered when analysing them. Essentially, what data will be used to answer the research questions, the type of inquiry, and the questions that will be asked are specified. These decisions are all driven by the objectives of the analysis. Broadly, the data sources considered in this analysis were published literature detailing an approach to assessing leanness in an organisation. A detailed explanation of the data collection process in Section 5.2.2 outlines more specific criteria for the data sources used. As few leanness assessments were explicitly developed for hospitals, the data was not limited to approaches developed for such an application. The leanness of any industry was considered to ensure a thorough consideration of lean in all its instantiations. The findings would then be adapted to healthcare.

5.2.2 DATA COLLECTION

The data collection process included firstly ascertaining the inclusion and exclusion criteria for the studies to be considered. The eligibility criteria are detailed in Section 5.2.2.1. Secondly, the search strategy employed to collect relevant articles and the information sources used for this search must be decided. These decisions are outlined in Section 5.2.2.2. Once the search has been executed, the study selection process using the previously defined eligibility criteria must be outlined. This process, showing how the final studies used for this review were identified, is shown in Section 5.2.2.3.

5.2.2.1 Eligibility criteria

Clearly defining the eligibility criteria for articles being considered for this review ensures that only those relevant to the study's aims are included (Shinyi Wu, Liu and Belson, 2010).

The inclusion criteria were:

- The study is published in English
- The paper develops or presents an assessment methodology, tool, technique, or procedure to evaluate the extent of lean implementation in an organisation
- The methodology focuses on leanness, level of leanness, leanness assessment, leanness evaluation, leanness measurement, or leanness quantification

The exclusion criteria were:

- The full paper is not accessible
- Lean implementation in an organisation is broadly discussed without attempting to assess the level of leanness
- The tool focuses on lean deployment or other parts of the lean process that does not involve assessing leanness

Due to the lack of literature focusing on assessing leanness in the healthcare sector, the inclusion of assessment methodologies was not limited only to those developed for this field. Methodologies from all sectors and industries were included to comprehensively consider the methods available to assess the level of lean in an organisation. Additionally, leanness assessment did not have to be the main focus of the study. Papers presenting a framework focusing on lean implementation, but still including a method for assessing it, were also considered. However, only the practices relating to the assessment aspect of the paper were included.

5.2.2.2 Information sources and search strategy

The electronic platform Scopus was chosen to search and retrieve literature for this study for the same reasons shown in Section 4.1.2.2. The keywords used to perform the literature review were based on terms most commonly used in publications on the subject. The selected keywords of the search defined to retrieve the most relevant literature were, therefore, "lean assessment" OR "leanness assessment". These were applied to titles, abstracts, and keywords. The search was executed in May 2019.

Although lean assessment considers the organisational effect on lean and the extent to which it has been implemented, all authors do not use this same categorisation. Some present leanness assessment as a lean assessment or as part thereof. Thus, to prevent excluding articles dealing with the correct subject matter, "lean assessment" was also used as a search term. However, the focus of this review was only on the leanness aspect (i.e. the extent of its application). Therefore, any tools presenting the incorrect focus or not including a leanness aspect would have been excluded during the study selection process.

5.2.2.3 Study selection process

A total of 96 articles were initially retrieved from searching Scopus. After excluding those in languages other than English (1) and cases where the full article was not accessible (25), 70 remained. The titles and abstracts were then reviewed against the eligibility criteria, resulting in another two being eliminated. The remaining 68 full papers were then considered against the same criteria, and any with an incorrect focus was removed. The final result is a total of 48 articles presenting a leanness assessment tool or methodology included in this review. The study selection process can be seen Figure 5.3, where the number of included and excluded studies are shown in each step.

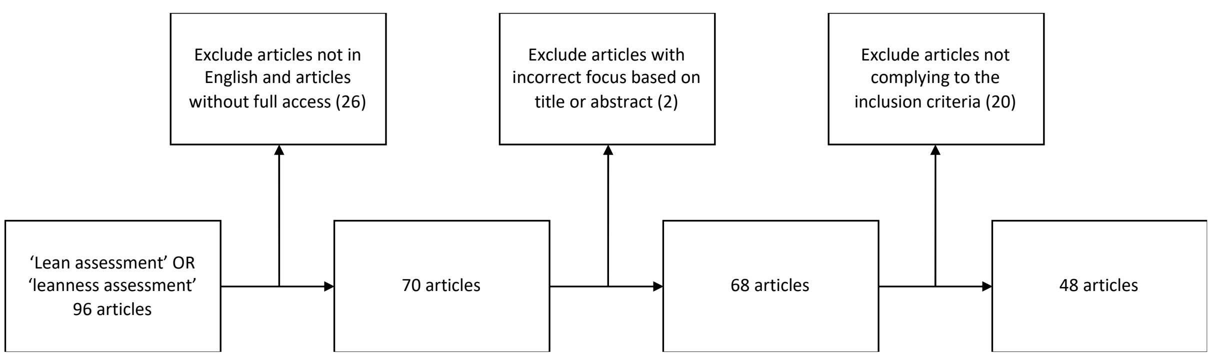


Figure 5.3 Systematic literature review selection process

A limiting factor to this review was not having full access to some of the articles obtained from the search. All available platforms were utilised to find a fully accessible version. Still, of the original 96 articles retrieved, 25 were excluded for this reason. Thus, a significant number of articles that could have contributed to this analysis were eliminated. However, because saturation was reached during the data analysis, the number of papers considered was deemed adequate to provide valuable insights. Reaching data saturation meant that no new information emerged from the data after some time. The point at which saturation was achieved is discussed in Section 5.2.3, where the data analysis process is detailed.

5.2.3 DATA ANALYSIS

Like the data analysis executed in Chapter 4, themes and codes are again used to categorise the different tools and methodologies and explain how they approach the assessment. This process involved considering: 1) the tools are going to be used for the coding process, 2) the codebook development process, and 3) the steps that must be taken to ensure that there is an agreement on when to use each code if more than one coder is working through the data. Once again, only one coder was used to code the data; therefore, the third component was not explored. With regards to the tools used for the coding process, Atlas.ti was used for coding, while Excel spreadsheets were used to record the text associated with the different codes and to track the analysis process. The codebook was developed iteratively, using the three stages shown in Figure 5.2.

Unlike the previous review, this review was not trying to uncover the reasons or causes behind a particular phenomenon. Thus, before commencing with the data analysis, there was already an idea of which themes would comprise it. However, to not limit the analytic view, all the data was still read for the first time without collecting any categorical information so that any additional themes or codes that may be necessary or of interest are realised. The first level of analysis thus included an initial read-through of all the articles while extracting the following *descriptive* data:

1. **Industry:** Papers were classified according to the industry the tool was developed for, such as manufacturing, service, or construction.
2. **Year:** Year the study was published.
3. **Country:** The country where the research was done.
4. **Research methodology:** The methodologies employed to develop the tool were broadly categorised as conceptual or empirical.

It was decided to execute a descriptive and categorical analysis to comprehensively investigate the research trends and different assessment approaches. The descriptive analysis focused on the research domain to give insight into the various trends in the research itself, such as geographical location, research methodology used, and the different industries it is being done in. Alternatively, the categorical analysis creates an understanding of the trends in the assessment methodologies presented in the research, such as how leanness is calculated, the type of data used, and how it is collected. The categorical analysis, therefore, gathered information about the approach to assessing leanness. Additionally, the parameters used to determine leanness were collected to satisfy the first purpose of this review.

Therefore, following the first level of analysis, the different types of measurements, in addition to specific tool characteristics that may be of value to note, were added to the already determined themes of data type, the methodology adopted, and the output provided as part of the categorical analysis. The second level of analysis thus involved reading through all the data and determining the specific codes that would be used for each theme. The list of *categorical parameters* extracted related to the assessment approach are listed below:

1. **Type of measure:** Whether the study was practice- or performance-based.
2. **Type of data:** The data that the tool or methodology used to assess leanness is classified into two categories: whether it uses qualitative or quantitative data and if it is subjective or objective.
3. **Methodology adopted:** Both the methods used to collect data and those used to determine leanness from this data are represented by this attribute.
4. **Tool characteristics:** Specific attributes of interest that the tool possesses, such as: if it uses a numerical index, weighs the parameters according to their importance, considers the relationships or interdependence between parameters, or provides decision support.
5. **Output:** This captures the type of output generated by the assessment and how the assessment results are presented.

Lastly, the *assessment parameters* analysis highlighted the parameters used to test leanness and, thus, what the tool considered to be a factor contributing to leanness. Figure 5.4 provides a summary and the hierarchy of the structural attributes defined. The final level of analysis involved reading all the text again and using this codebook to codify the data.

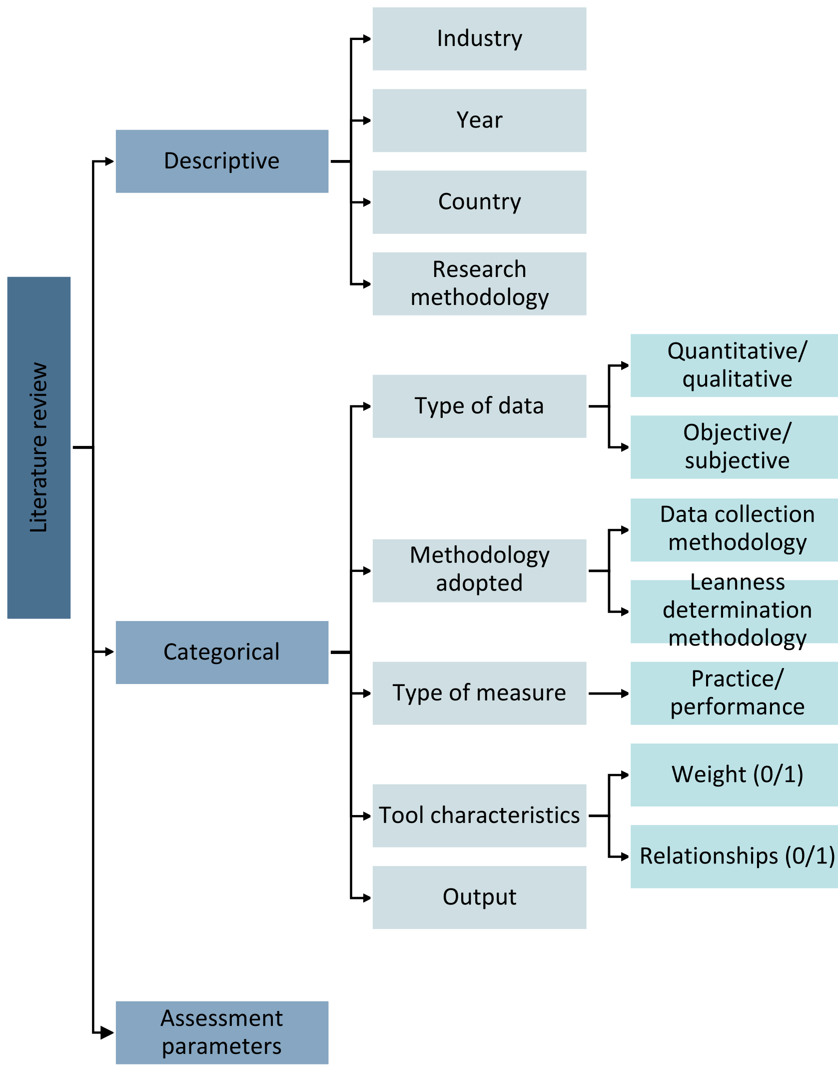


Figure 5.4 Hierarchy of attributes defined for data extraction

A codebook was used to analyse the data systematically. The final codebook developed is shown inTable 5.1 below.

Table 5.1 Codes used for the analysis of existing leanness tools and methodologies

Theme	Code name	Code definition
Type of data	Qualitative	**Definition:** Qualitative data is used to determine leanness. **When to use:** Open-ended questions, interviews, or hospital observations are used to determine the extent to which lean practices have been implemented. **When not to use:** (1) Subjective opinion is given quantitatively, or practice implementation is measured quantitatively. (2) Qualitative data is used to build the assessment tool, not to assess leanness.
	Quantitative	**Definition:** Quantitative data is used to assess leanness. **When to use:** Ratings, performance measures, or close-ended questions providing data that can be put into categories, ranked, or measured are used to determine the extent to which lean practices have been implemented. **When not to use:** Quantitative data is used to build the assessment tool, not to assess leanness.
	Objective	**Definition:** Objective data is used to assess leanness. **When to use:** Data that can be tracked directly with numbers and that does not vary between information

		sources is used to determine the extent to which lean practices have been implemented. **When not to use:** Objective data is used to build the assessment tool, not used to assess leanness.
	Subjective	**Definition:** Subjective data is used to assess leanness. **When to use:** Information from personal perspectives, feelings, or opinions is used to determine the extent to which certain lean practices have been implemented. **When not to use:** Subjective data is used to build the assessment tool, not used to assess leanness.
Methodology adopted	Data collection methodology	**Definition:** Methodology that the tool uses to collect the data used to determine leanness. **When to use:** The study mentions how data used for calculating leanness was generated. **When not to use:** The method for collecting data used for building the tool is mentioned.
	Leanness determination methodology	**Definition:** The methodology used by the tool to either calculate or determine the reported leanness is mentioned. **When to use:** (1) The methodology or approach used to convert data into a leanness score is mentioned; (2) The methodology or approach used to determine any output used to assess leanness is mentioned. **When not to use:** When the study discusses the methodology used to collect the data used to

		determine leanness or when the method for building the tool presented is discussed.
Type of measure	Practice	**Definition:** The degree to which certain practices have been implemented is used to measure leanness. **When to use:** The adoption of any lean principle, practice, or tool is used to represent the degree to which lean has been implemented in the hospital. **When not to use:** Lean practices necessary for successful lean implementation are discussed but are not used to determine leanness or do not form part of the tool.
	Performance	**Brief definition:** Performance measures are used to determine leanness. **When to use:** The improvement in hospital performance or outcome measures are used to determine the degree to which certain lean practices have been implemented. **When not to use:** An improvement in performance or outcome measures are reported when discussing lean's implementation but do not form part of lean's evaluation or contribute to leanness.
Tool characteristics	Numerical computation	**Brief definition:** Numerical computation is used to determine leanness. **When to use:** Numerical data is used to calculate the results of the leanness assessment or the leanness score.

		When not to use: Quantitative data is referred to in the study but is not used to determine leanness in any way or does not form part of the leanness assessment.
	Weight	**Definition:** The leanness score is weighted **When to use:** When numerical computations are used to determine leanness, the different elements determining this score are weighted differently according to their importance. These weights can be determined subjectively or by considering the effect the various parameters have on each other and the overall score. **When not to use:** (1) All parameters being used to determine leanness are assigned the same weight, or (2) there is no differentiation between elements with regards to their importance or the impact their improvement may have on leanness.
	Relationships	**Definition:** The tool considers how assessment parameters interact and influence each other to determine leanness. **When to use:** Inter-relationships between leanness parameters factor into the leanness score calculations or are used to structure the assessment. The inter-relationships do not necessarily have to form part of the leanness score but must be considered in the assessment.

		When not to use: Inter-relationships are discussed or evaluated as part of the study but do not form part of the assessment methodology.
Output	Output	**Definition:** Results of the leanness assessment reported. **When to use:** Any form of output used to report the organisational leanness determined from the assessment. **When not to use:** Any results reported reflecting on the experiences with adopting lean but not forming part of its evaluation or relating to leanness.
Assessment parameter	**Definition:** Parameter used to test leanness. **When to use:** To note any practices determining the degree to which lean has been implemented in the organisation **When not to use:** For any metrics relating to lean performance or lean effectiveness measurement instead of leanness.	

When analysing the 48 articles that formed the base for this review, no new methods for determining leanness were found after the 33rd study. Similarly, no new forms of outputs were uncovered after the 23rd study, showing data saturation had been reached. Thus, it was decided that a sufficient number of studies had been analysed to draw meaningful conclusions regarding the existing approaches to leanness assessment.

5.3 DESCRIPTIVE RESULTS

The results and findings from the descriptive data extraction process outlined in Section 5.2.3 are presented in this section. These aspects were extracted to understand the trends in this research domain over time.

5.3.1 PUBLICATION YEAR

The number of articles published each year for the studies included in the review is shown in Figure 5.5 below. From this, the publication trend for papers published in leanness assessment can be observed. The fact that the earliest one was published in 2005 shows that this is a relatively recent field of research, with a general trend of increasing interest being shown as time progressed. The increasing trend in the number of publications and the fact that it is a more recent field of research indicates a growing interest in this field.

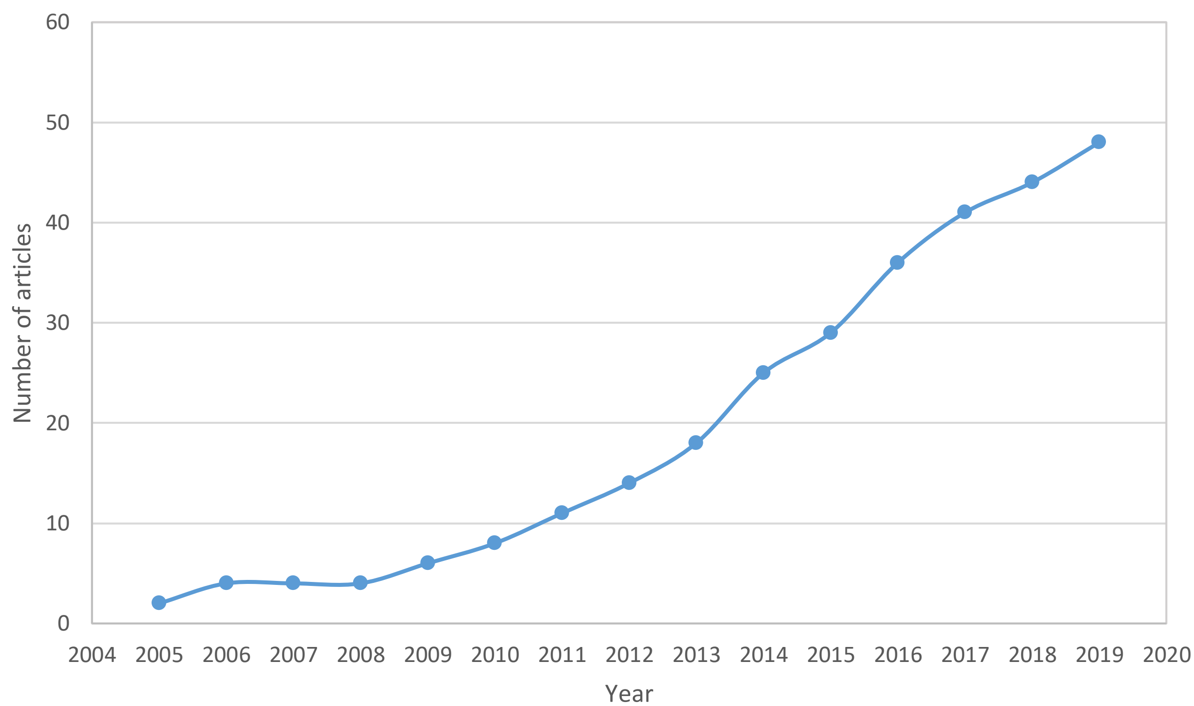


Figure 5.5 Cumulative number of articles on leanness published over time

5.3.2 COUNTRY

By categorising the studies according to where they were executed, an indication is given as to where the research may be more widespread and which countries focus mainly on this assessment form. Figure 5.6 shows the identified countries and how many studies originated from each. India and the USA are the most notable countries, with 9 and 6 studies coming from each, respectively. Together this makes up over 30% of all the studies.

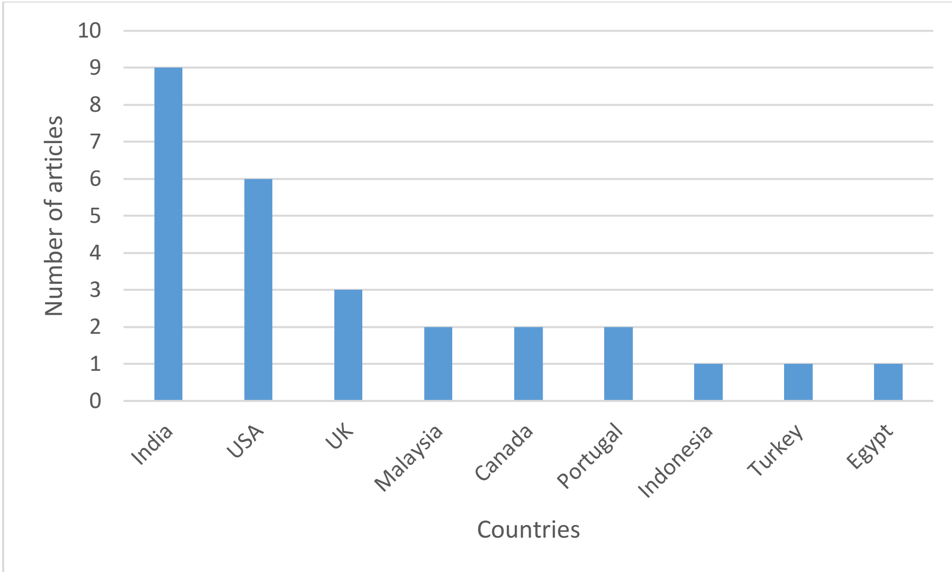


Figure 5.6 Number of articles published on leanness in each country identified

5.3.3 INDUSTRY

The industries for which the various leanness assessment tools were developed are shown in Figure 5.7. The four industries were manufacturing, services (such as banking and healthcare), construction, and product design and development (D&D). It is interesting to note how few studies there were for services despite the popularity of lean's application in healthcare and the abundant research on its implementation.

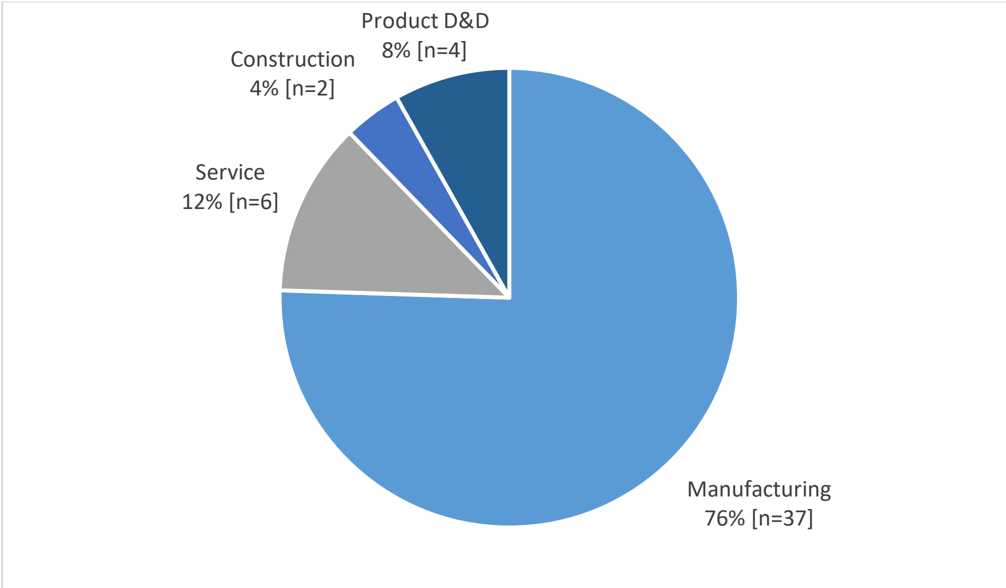


Figure 5.7 Proportion of studies published in each industry

5.3.4 RESEARCH METHODOLOGY

The research methodology employed by a study was categorised as either conceptual or empirical. Conceptual studies included those that simply offer a discussion on the concept of leanness assessment or develop the tool with no practical or real-life consideration, commonly done using literature to develop the tool (Sangwa and Sangwan, 2018). Alternatively, empirical studies include those where the theory used or the tool itself is developed from, or verified with, the help of case studies or expert interaction (Sangwa and Sangwan, 2018). A case study involves applying a tool developed in a real-life situation to validate it and the concepts or thinking behind it (Seuring, 2005). Expert opinion, alternatively, can be incorporated using data gathered via interviews, ratings, or surveys. Data for empirical verification can also be collected using an organisation's historical data. In summary, studies with research inputs grounded in practice were classified as empirical, whereas those that explained the model through hypothetical and example data were classified as conceptual (Narayanamurthy and Gurumurthy, 2016a).

The strength of an empirical study is that by considering practice, the applicability of the research is improved. The problem with this, however, is there are often issues with the practical application of research, with the oversights of theoretical concepts being observed. The advantage of a conceptual approach is that it investigates concepts and finds what might be lacking in practice. In this review, most empirical studies included or started with an element of conceptual research. They then took these findings further by testing and adopting them in practice or incorporating opinions and thinking from real-life approaches. Only 6% of the articles in this review did not include some form of empirical research, showing that practical application and verification are essential in this research field.

5.4 CATEGORICAL RESULTS

The results and findings from the categorical data extraction process outlined in Section 5.2.3 are presented and discussed in this section. The different approaches to leanness assessment are categorised according to various considerations for the tool development. Organising the studies this way allows for a systematic decision-making process.

5.4.1 TYPE OF MEASURE

Following the review of all included studies, it was found that the elements being assessed (i.e leanness parameters) could broadly be categorised as either practice or performance measurements. Classifying assessment parameters in this way was similarly done in the review by Narayanamurthy and Gurumurthy (2016a).

Studies classified as practice-based assess the level and extent to which certain lean practices have been adopted or implemented by the organisation to determine leanness (Narayanamurthy and Gurumurthy, 2016a). On the other hand, performance-based studies used the degree of improvement in operational outcomes or performance indicators to determine leanness (Maasouman and Demirli, 2016; Narayanamurthy and Gurumurthy, 2016a). It is important to note that assessments using performance-based measures are not necessarily lean effectiveness assessments, but rather use performance measures to represent lean practice implementation indirectly. Performance-based leanness assessments specifically attributed these measurements to leanness or used them in combination with practice-based measures. The various cases of performance-based studies are discussed in more detail in Chapter 6 where the tool is developed, and the different measurement approaches are considered.

Practice-based assessments used measures such as the presence of managerial support and extent of tool implementation to evaluate leanness. The specific measures used varied depending on the industry or organisation being assessed, but there were many similarities due to the transferability of lean practices between sectors. Performance measures used varied more significantly due to the different types outputs in each type of organisation.

The number of assessments based on practices far outweighed those using performance measures, with 88% of studies using practice to determine leanness and only 25% using performance measures (12.5% used both). The advantage of performance measures is that they provide immediate feedback and are easily measured. However, looking at performance data in isolation can lead to incorrect conclusions on the success of lean's implementation. Measures of this type are impacted by a range of other organisational factors and only really reflect the impact of lean and does not indicate the true extent to which lean is being practiced in the organisation. Thus, this study only focused on approaches that used practice-based measures. Those that incorporating performance- and practice-based measures were also considered.

5.4.2 TYPE OF DATA

The type of data used to perform an assessment is essential to any assessment process, as it determines the assessment methods that can be used and the type of output that can be provided. It is important to note that the data being classified specifically refers to what is used to determine leanness and does not include or refer to the data used in executing the research (i.e. the data used to build the tool or methodology).

One of the most fundamental ways of classifying data is by stating whether it is quantitative or qualitative. In other reviews of a similar nature, the way studies are classified as qualitative or quantitative varies. Authors commonly refer to a tool as qualitative or quantitative based on the measurement type. For example, studies using practice-based measures were often classified as qualitative assessments despite them being quantitatively assessed. Thus, in this study, the data type refers to the form of data used to determine leanness, not the type of measure used.

Additionally, whether the data is subjective, or objective was also indicated for when the data collection methodology is considered. The data used in an assessment was thus categorised according to two parameters: whether the tool used qualitative or quantitative data and whether the data was subjective or objective.

There were few cases of qualitative data being used across all studies. Due to the computational ease and simplicity in representing leanness numerically, all studies reviewed included some form of quantitative data. Of the 48 studies reviewed, 92% used only quantitative measures, and 8% used it in combination with qualitative ones. There were thus no cases where the assessment used only qualitative data.

Quantitative data is a practical decision in terms of developing a tool that can be used for self-assessment. Using quantitative data allows the tool to calculate results based on the input provided, eliminating the need for inferences needing to be made from data. A trained evaluator is thus not necessary, and any manager who wishes to understand leanness in an organisation would be able to use the tool.

Quantitative data were obtained by either subjectively rating the degree to which practices have been implemented or by using objective surrogate metrics. A surrogate metric is when a quantitative metric is used to represent a naturally qualitative variable that cannot be expressly measured (Oleghe and Salonitis, 2016). Examples include 'number of kaizen events undertaken' to measure the practice of continuous improvement or 'percentage of personnel who are active members of work teams, qualitative teams, or problem-solving teams' to represent the practice of involving the workforce with improvement activities. Specific examples of the different cases are explored in more detail in Section 6.2.1 where the LAT data type was considered.

Subjective data was the primary data type, occurring in 85% of the studies. The high proportion of studies using subjective data is most likely due to the preference practice-based measures, which are generally difficult to measure objectively. Showing a relationship between the type of measure that makes up the assessment and the data used. All performance-based studies used objective based data, and 93% of practice-based studies used subjective data. Generally, practice-based assessments that do not use subjective data use surrogate metrics to eliminate potential bias from subjective data. The advantage objective data is that it is not susceptible to such bias and it does not vary between information sources or situations, something that subjective data, on the other hand, can be subject to (Oleghe and Salonitis, 2016). However, it can be challenging to find objective data measurements to represent the implementation of lean practices accurately.

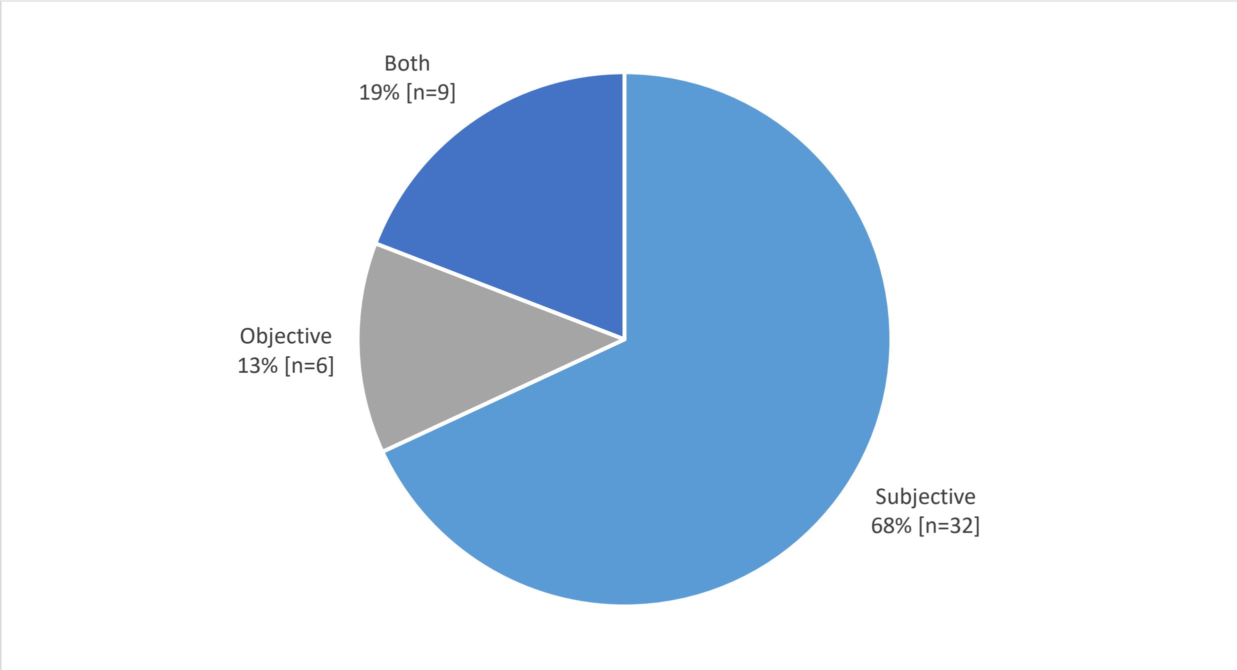


Figure 5.8 Distribution of subjectivity and objectivity in collected data

5.4.3 METHODOLOGY ADOPTED

Once the type of measures being assessed and the data used to represent them was considered, the methods used to collect this data and turn it into a degree of leanness were analysed. This section, therefore, explores the data collection methodology and the method used to determine leanness.

5.4.3.1 Data collection methodology

The data collection methodology discussed in this section refers to the method used by the leanness tool itself to collect or gather the data required to ascertain the degree of leanness, and not how the information used to build the tool was collected. This was discussed in Section 5.3.4. The different forms of data collection found in the review included surveys or questionnaires, performance metrics, historical data, direct observation, and interviews. The proportion of observations for each of the methodologies is shown in Figure 5.9.

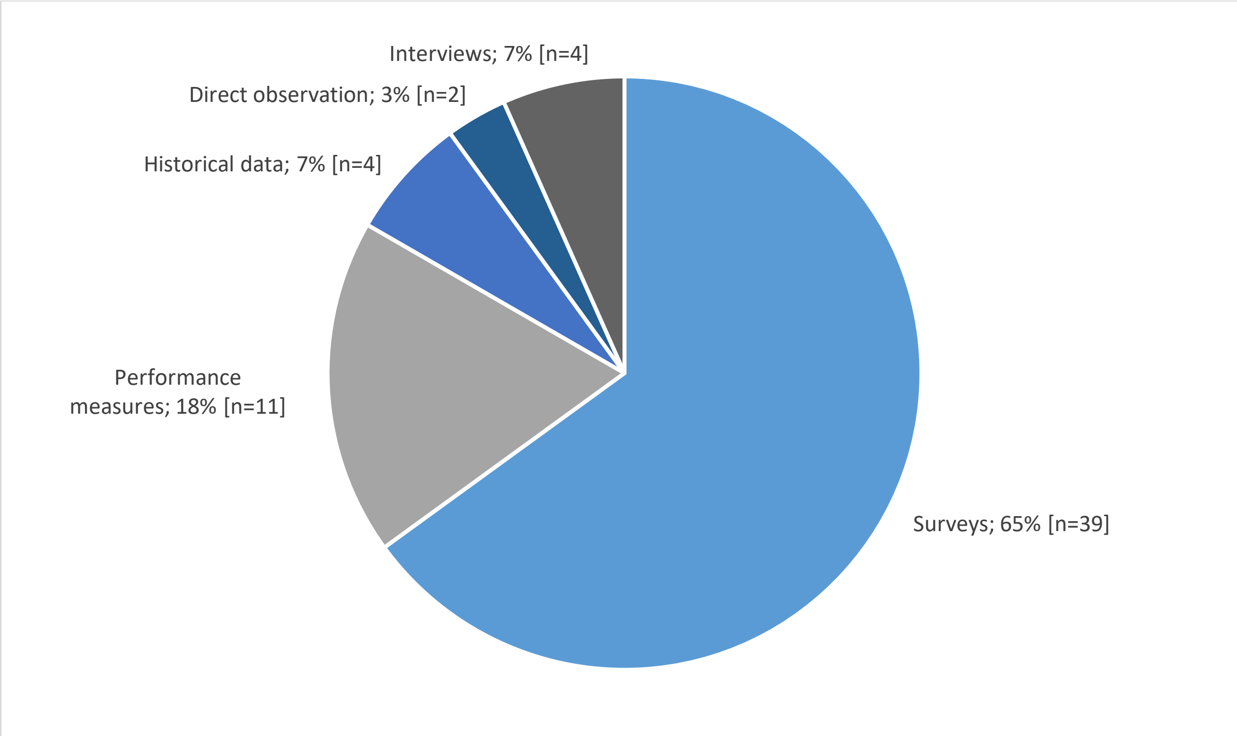


Figure 5.9 Distribution of the use of different data collection methodologies

Surveys comprise the largest portion of data collection approaches used. It was the method most commonly used for assessing practice measures and the main source of subjective data. The survey category included open- or closed-ended questionnaires, spreadsheets, checklists or other templates for any form of rating or scoring. The primary method data collection method used by performance-based approaches was performance measures such as systems factors, levels, and various other types of performance data.

Other data collection methods included direct observation, interviews, and historical data. The most common type of interview included semi-structured interviews, which allow for the information necessary for the assessment to be obtained together with any supplementary data on the present situation that may not necessarily be anticipated (Lemieux, Pellerin and Lamouri, 2013). Historical data included archival or specialised company, industry, or financial reports.

5.4.3.2 Assessment methodology

There are various methodologies available for determining an organisation's leanness. The method used influences the tool's capabilities, analytical rigour and, type of output that can be provided. While a relatively wide range of methodologies was identified in the literature sample, some to note included:

- Rating averages or weighted averages;
- Fuzzy logic computation methods;
- Maturity models;
- Descriptive statistical analysis of performance data (such as variation modelling, hierarchical cluster analysis, or the use of Mahalanobis distance);
- Simulation modelling; and
- Multi-criteria decision-making processes (such as analytic hierarchy process (AHP), analytic network process (ANP), graph-theoretic approach (GTA), interpretive structural modelling (ISM), data envelopment analysis (DEA)).

Many studies (23%) used an average or weighted average of assessment parameter ratings to determine leanness. Surveys or questionnaires comprising fixed questions or leanness criteria were typically used to obtain the data used. A five-level Likert scare was the most common form of data. The ratings given were then divided by the maximum possible value to get a percentage or averaged to get an overall score (Doolen and Hacker, 2005; Weloa, Tonninga and Rølvåga, 2013; Guimarães and de Carvalho, 2014; Al-Aomar and Hussain, 2018; Galankashi *et al.*, 2018; Martinez, 2018). In these cases, the current and desired state was often indicated to determine the gap between current and target performance and prioritise the areas or practices with the most significant gaps for improvement (Weloa, Tonninga and Rølvåga, 2013).

In their study, Doolen and Hacker (2005) reviewed numerous lean assessment tools and identified factors contributing to the degree of leanness in an organisation. They then developed a survey instrument to measure the degree of implementation of these practices. The survey averaged the points given by respondents to determine the leanness level. The number of lean practices adopted and to which level were assessed in this survey (Narayanamurthy and Gurumurthy, 2016a). Taj (2005) similarly used the average rating given by respondents to evaluate nine identified key areas of manufacturing. A spreadsheet-based assessment tool was developed to obtain the responses, with the totals for each of the nine areas displayed in the score worksheet. The totals were additionally displayed on a lean profile chart to identify the gaps in each area from their specific lean targets (Taj, 2005; Narayanamurthy and Gurumurthy, 2016a; Sangwa and Sangwan, 2018).

Other assessment types, such as checklists, were also used when a Likert scale or rating was not. Salem *et al.* (2006) developed a lean assessment tool that uses a checklist to evaluate the implementation of different lean construction techniques. Each technique was split into different elements and then defined by some criteria. The champion then completes the checklist, indicating the level of implementation for each technique on a linguistic scale for the initial state, desired state, and current state. The linguistic scale was then converted to numbers, and an average score was calculated for each technique to gauge its implementation. This approach provides management with a simplified way to assess the implementation progress. Gonçalves and Salonitis (2017) similarly used a checklist-type survey questionnaire which assessed various best practices for Workstation Design of assembly lines. Their questionnaire was excel-based, similar to that of Taj (2005). Rather than classifying each category on a determined scale, each practice corresponds to a different question assessed through the checklist. The type of response selected was the alternative response ("True", "Partially true", "False", or "Not Applicable"). This strategy is easy to construct and simple for respondents to mark. The scores were then converted to a scale between 0 and 5, each described by a different level, and subsequently averaged.

Using numerical ratings retrieved through surveys and applying an average or weighted average to the data to obtain overall leanness is advantageous in its simplicity and straightforwardness. It is a convenient way to retrieve the data used for calculation. This approach does, however, have its limitations. Ratings given by expert opinion can often be arbitrary or imprecise (Oleghe and Salonitis, 2016). In cases such as the assessment of practices, where the criteria being evaluated are challenging to measure explicitly, it is recommended to use linguistic instead of numerical values to quantitatively collect data (Doolen and Hacker, 2005; Matawale, Datta and Mahapatra, 2015; Sharma and Shah, 2016).

Fuzzy logic is a typical example of an assessment approach that does this. It uses linguistic variables to measure qualitative attributes and matches them with fuzzy set numbers. This approach allows the results to be acquired quantitatively, mitigating the disadvantages associated with numerical scoring methods while still allowing a quantitative analysis (Vinodh and Vimal, 2012).

The use of fuzzy logic was the most popular approach for determining leanness, with 31% of studies employing fuzzy concepts in their assessment. It is a powerful and effective decision-making tool when dealing with the impreciseness and vagueness often associated with practice-based measures (Lin and Chiu, 2006). Because a fixed numerical value often cannot express the assessed elements, the fuzzy approach uses linguistic variables to assess these identified lean capabilities. It then matches the linguistic variables with a set of fuzzy numbers (Matawale, Datta and Mahapatra, 2015). Therefore, the bias in the expert's decision is overcome and allows a quantitative analysis of elements that do not come in such a form (Vinodh and Balaji, 2011; Madhan and Suresh, 2017).

Due to the nature of fuzzy logic tools, they are primarily used to assess practice-based measures. Of the studies using fuzzy logic, 87% used it for assessing practices, while 37% of practice-based assessments use fuzzy logic. Even though it is predominantly used for assessing practice measures, the concepts used in the fuzzy logic methodology can also be used for performance-based studies. An advantage of the fuzzy approach is thus that it applies to both practice- and performance-based criteria, making it a convenient assessment methodology if both are being integrated into the same assessment tool (Oleghe and Salonitis, 2015). Therefore, fuzzy logic-based leanness assessment has gained attention in both fields. Like numerical survey ratings, fuzzy models are straightforward in their approach, use simple calculations, and allow for loose imprecise input (Almutairi, Salonitis and Al-Ashaab, 2019). They use expert judgement to weigh the relative importance of the different elements, and using a linguistic scale eliminates the possibly vague and imprecise output data (Madhan and Suresh, 2017). The use of fuzzy logic to assess practices is well established and has been empirically validated in the literature. However, the same is not true for its use in more quantitative cases (Oleghe and Salonitis, 2016).

Maturity models was also frequently used way to assess leanness. This approach links an organisation's leanness level to a certain degree of maturity. Like fuzzy logic, maturity models use surveys to obtain the data for determining this leanness. A maturity model is a conceptual model that assumes a particular path of evolution in an organisation and outlines this path in logical and anticipated stages towards maturity. Reaching maturity involves progressing step-by-step along these stages with a growth in the organisation's capabilities. The next stage cannot be achieved without fully reaching maturity in the current stage. A set of descriptors or benchmarking variables are generally used to outline each stage and assess when a certain level of maturity has been reached. These stages can then be used as a roadmap for improvement. As lean is a gradual process of change in an organisation's culture, a maturity model can be used to derive and prioritise improvement initiatives (Maasouman and Demirli, 2016). The idea is that the progression to a higher maturity level will thus lead to a higher, more sustainable level of Leanness (Guimarães and de Carvalho, 2014). Literature suggests that there is, in fact, an increasing interest in the application of maturity models in research.

Soliman and Gadalla (2014) developed a Lean Maturity Tracker (LMT) in their study, which describes levels of lean capability measurement and tracking. This approach was used because it is suggested that for sustainable lean implementation, a focus on performance improvement, capability development and maturity tracking is needed (Soliman and Gadalla, 2014). In their methodology, various elements, each with different categories of lean goals, are given a score from zero to five. Each weight is achieved when an element's goal is completed and validated. The scores are, therefore, indicative of the achieved level. The results are recorded in the Lean assessment table and finally plotted on a radar chart called the Lean maturity tracker (Soliman and Gadalla, 2014). Maasouman and Demirli (2016) alternatively developed a visual, data-driven operational level lean maturity model to assess the level of Lean maturity in the organisation. In their framework, Lemieux, Pellerin and Lamouri (2013) include a maturity-based causal/relations matrix that links product development process objectives and potential improvement enablers according to the organisation's current lean maturity level. Sorli *et al.* (2010) proposed a "SMART readiness maturity assessment" tool to assess the current maturity of the product development industry in applying lean practices in their processes. Welo and Ringen (2017) use a hierarchical capability maturity model (CMM) to analyse the extent to which an organisation is engaged with Lean practices. The model assesses the degree to which identified lean capabilities are implemented, utilised, and followed up to identify gaps and possible improvements (Welo and Ringen, 2017). Like Soliman and Gadalla (2014), the capabilities are linked to a descriptive text associated with a capability scale. The output from Welo and Ringen's (2017) study is a list of areas that must be prioritised for a leaner organisation.

Where the use of averages and weighted averages of ratings was a common approach to determining leanness, less common was more in-depth statistical analysis going beyond the use of averages. This was only found in 4% of studies. It was sometimes performed on ratings, but more commonly applied to performance data. In one case, such as the study by Oleghe and Salonitis (2016), this included variation modelling in addition to averages. Here, performance data was analysed monthly to monitor the progression over time. More complex methodologies, such as that by Srinivasaraghavan and Allada (2006), were also employed. They proposed a new method to evaluate leanness based on Mahalanobis distance (MD), called the Mahalanobis Taguchi Gram Schmidt System (MTGS), to better identify the direction of abnormality. This method provides a numerical measure and allows for benchmarking with other organisations (Thanki and Thakkar, 2014; Azadeh *et al.*, 2015). Thanki and Thakkar's (2014) approach used descriptive statistical analysis, hierarchical cluster analysis, and ANOVA to analyse the data retrieved from their survey with SPSS statistical software (Thanki and Thakkar, 2014).

In terms of either its use for the analysis of input data or how leanness performs over time, the benefit of using statistical parameters such as mean and standard deviation to model leanness is that the inputs and outputs can be defined by their probability density function (Oleghe and Salonitis, 2016). Defining them this way enables their use in simulation and modelling, such as Monte Carlo-type simulation, making scenario analysis, probability analysis, correlation analysis etc., possible (Oleghe and Salonitis, 2016). The statistical analysis input in the form of performance measures is valuable but leads to the problems previously discussed with having a purely performance-based assessment. Statistical analysis would benefit the assessment most by being combined with other assessment methodologies. Simulation and modelling, additionally, are powerful tools for analysis. However, its applicability mainly extends to performance-based studies.

Simulation or modelling was used in 8% of the studies and often integrated to study a system and its parameters. Simulation allows the impact that specific changes may have to be investigated without actual implementation. Thus allowing for a risk-free investigation into different system alternatives. Therefore, simulation's advantage lies in not only enabling the development of future-state maps, but when combined with optimisation tools, can inform decisions for selecting the system settings needed to improve the current lean status (Mahfouz, Shea and Arisha, 2011; Narayanamurthy and Gurumurthy, 2016a).

System Dynamics (SD) is a modelling technique used to map the variables and structure of the system under consideration, allowing the relationships between elements and the causal influences between them to be explored (Ali and Deif, 2014; Omogbai and Salonitis, 2016). It uses simulation to investigate the current functioning of a system and how it dynamically responds to changes, allowing the identification of improvements and optimal settings for various system alternatives, resulting in more sustainable performance metrics to be identified (Zhang, Calvo-Amodio and Haapala, 2013; Omogbai and Salonitis, 2016).

Mahfouz, Shea and Arisha (2011) developed a simulation-based optimisation model to optimise a set of parameters concerning three performance measures: cycle time, work in process (WIP) and workforce utilisation in a packaging manufacturer. Ali and Deif (2014) use a model based on systems dynamics to assess the degree of leanness in manufacturing firms and present a leanness score to represent this. In their study, they used the SD approach to analyse and compare two scenarios of producing at the original cycle time versus at takt time to determine which would result in an improved leanness score and, thus, a more lean organisation (Ali and Deif, 2014). This study uses SD to model the system and decide between two production alternatives that would promote a lean environment. Therefore, the result is an optimised setting instead of identifying areas that need improvement or a list of possible improvements to be implemented. Further work done by Omogbai and Salonitis (2016) also used SD to objectively investigate the interaction between lean practices, their performance outcomes, and other variables to study the impact various lean practices and their improvements may have on the organisation. Their tool incorporated both tangible and behavioural aspects of lean and resulted in the determination of an optimised setting of Lean improvements needed to minimised manufacturing lead-time (Omogbai and Salonitis, 2016).

It can be observed that simulation is predominantly used to analyse the effects different settings have on operational outcomes and optimises the system by choosing the alternative that would lead to leaner operations. SD on its own therefore does not provide a leanness score. While a leanness score is not necessary to execute a successful and insightful lean assessment, if such a score is desired, simulation can be used alongside, or in combination with, other methodologies.

Multiple methods were often integrated to assess leanness. An example of this is the study by Mahfouz and Arisha (2016), which uses modelling and simulation along with value stream mapping (VSM) and Data Envelopment Analysis (DEA) to assess the leanness of a distribution business. These methods were employed to evaluate the effect two different lean distribution practices have on the company's performance and leanness (Mahfouz and Arisha, 2016). VSM is first used to map the current and future state of the system, allowing for visual comparison and identification of wastes. Thereafter simulation models are developed for both these states and the proposed lean practices (Mahfouz and Arisha, 2016). Integrating VSM with simulation allows the system to be modelled while various performance metrics are evaluated. The additional integration with the DEA model facilitates the calculation of a leanness score that decision-makers can use to assess the current leanness level against the ideal system state, as well as for benchmarking with other companies in the same industry (Mahfouz and Arisha, 2016).

The DEA can be helpful if the evaluation of leanness is based on optimisation algorithms, such as in simulation or modelling (Azadeh *et al.*, 2015). DEA is an optimisation linear programming model that can be used to maximise the efficiency of comparable units, called Decision Making Units (DMUs), described by various inputs and outputs (Charnes, 1994). Therefore, this methodology is useful when optimisation algorithms are used to compare different operational settings that would maximise leanness in an organisation (Azadeh *et al.*, 2015). Azadeh *et al.* (2015) also used DEA in their study to rank leanness factors according to their impact degree on lean manufacturing policies. While the traditional DEA method can only be used with crisp input or output data sets, which contrasts the typical data representing leanness, Azadeh *et al.* (2015) extended the traditional DEA model with fuzzy logic (FDEA) in their approach to accommodate this.

One advantage of the DEA model over ordinary optimisation procedures is that the weights of input and output variables need not be assumed beforehand (Azadeh *et al.*, 2011). The aggregation weights result from solving the optimisation problem, thus making DEA solely dependent on the empirical observations involved (Lee *et al.*, 2011; Azadeh *et al.*, 2015).

The interpretive structural model (ISM) helps structure the complex relationships between elements of a large-scale system and can therefore be used in a leanness assessment to consider the inter-relationships between the parameters and how they work together to influence leanness (Warfield, 1974). If there is a lack of understanding and literature to identify the parameters for leanness and how they interact, ISM is a useful tool. It structures and manages these complex relationships by using expert opinion to determine whether or not given elements are interrelated, and from this, an overall structure is extracted (Gupta, Acharya and Patwardhan, 2013; Yadav *et al.*, 2019). The ISM thus uses the interdependency and inter-relationships established to identify the most significant factors for improving organisational leanness (Gupta, Acharya and Patwardhan, 2013; Yadav *et al.*, 2019).

Similarly, the graph-theoretic approach (GTA) can be used to consider the interaction between parameters. This methodology evaluates the relationships between the elements and sub-elements used for assessing systemic leanness, but unlike ISM, it also computes leanness. The GTA considers how the elements interact and the impact these interactions have on leanness to calculate an overall score (Narayanamurthy and Gurumurthy, 2016b).

AHP is a multi-criteria decision-making method that can be used to determine and rank the impact various elements have on the leanness level (Seyedi *et al.*, 2013; Azadeh *et al.*, 2015). Like DEA, it determines the impact each factor has. However, where DEA is a mathematical model, AHP is based on expert opinion. Decision makers assign weights for the different criteria from personal opinions on the current state of the enterprise. The ranking of alternatives will then be done based on the score resulting from the AHP (Seyedi *et al.*, 2013; Almomani *et al.*, 2014; Azadeh *et al.*, 2015). AHP is widely used in management sciences due to its reliability and ability to deal with problems quickly and efficiently (Seyedi *et al.*, 2013; Almomani *et al.*, 2014).

The AHP method uses pairwise comparisons to perform this ranking of elements. It uses the idea that the subject can be effectively tested if it is hierarchically decomposed into its parts. It begins by developing a hierarchical tree to link the competing alternatives and factors. At each level, these elements are compared to attain a ratio scale of measurement, which can be used to compare the different alternatives and rank their relative priority (Bodin and Gass, 2003; Seyedi *et al.*, 2013; Azadeh *et al.*, 2015).

While AHP is efficient in finding a solution to suit individual goals, it fails to consider the relationships between elements and assumes they are independent of each other. Therefore, an advanced form of the AHP was developed to overcome this, called the Analytic Network Process (ANP) (Narayanamurthy and Gurumurthy, 2016b; Yadav *et al.*, 2019). ANP is a structured model that can be used for complex decision-making and is a generalisation of the AHP approach (Shams Bidhendi, Goh and Wandel, 2019; Yadav *et al.*, 2019). It generates relative importance weightings among decision elements while considering their interrelationships (Lesmes, Castillo and Zarama, 2009). Where the AHP approach uses hierarchical relationships to assess leanness, ANP uses a dynamic multi-directional relationship between elements (Shams Bidhendi, Goh and Wandel, 2019). As significant interaction exists between organisational components, the ANP is more effective in leanness assessment situations. The ANP similarly uses ratio scale measurements based on pairwise comparisons.

ANP is often used with other methodologies such as ISM or RTD. Shams Bidhendi, Goh and Wandel (2019) used ISM to uncover the relationships being considered in the model and then used the ANP methodology to calculate the weights for the different elements to assign their relative importance weightings. Sharma and Shah (2016) similarly identified the need to combine ANP with other survey-based methods and thus proposed a combined RTD-ANP model for lean assessment. A fuzzy-ANP approach is often used when the input criteria are vague (Sharma and Shah, 2016).

5.4.4 ASSESSMENT PARAMETER IMPACT

This aspect of the analysis intends to capture different ways studies consider assessment parameter data in their approach to determining leanness, such as if they weight them according to their importance or study their interrelationships. Figure 5.10 shows the proportion of studies including such considerations.

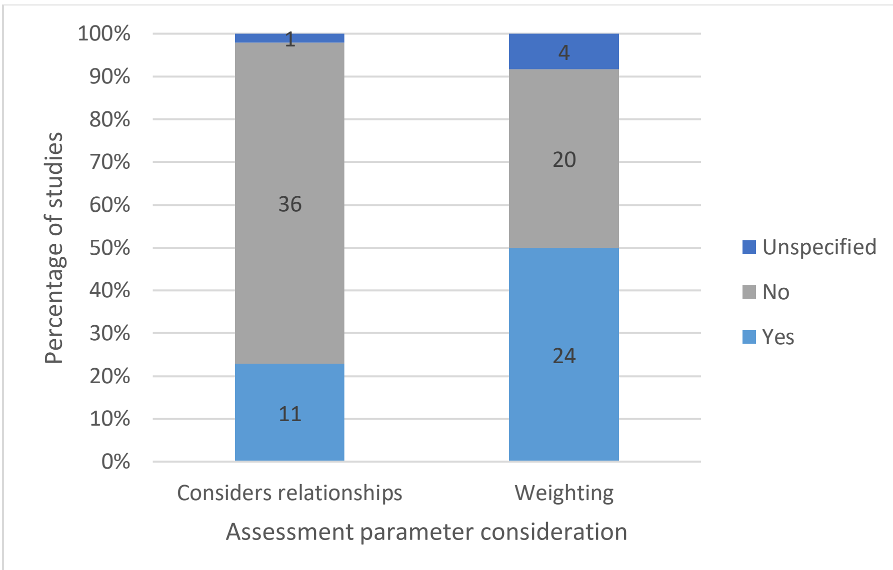


Figure 5.10 Frequency of observed tool characteristics

5.4.4.1 Considers relative importance

When assessing leanness, various measures are used to arrive at the determined result. This tool characteristic captures whether the parameters used were weighted according to their importance or impact level when determining these results. Of the cases reviewed, 50% weighted parameters, 42% did not, and it was unclear in 8% of cases. This shows that a significant portion of studies considered all elements as equally contributing to attained leanness. However, in reality, certain items may have a more significant impact on leanness or be of greater focus to the organisation being considered and thus have more importance (Gonçalves and Salonitis, 2017a).

Typically, if elements were treated differently, this was done by multiplying implementation measured with an importance weight to arrive at an adjusted leanness index. A weighted index will provide a score closer to reality and fairer in its assessment, leading to a more accurate improvement prioritisation (Shetty, Ali and Cummings, 2010; Cil and Turkan, 2013)

Approaches used to determine these relative weights included either using the subjective expert opinion or deriving these weights from their interrelationships. Subjective weights were either obtained directly from the tool user by requesting them to indicate a parameter's importance when scoring its degree of implementation, or by consulting experts to determine the weight separately. Alternatively, more rigorous methods such as DEA, AHP, or ANP can be used. Deriving the weights from interrelationships between elements means assigning weights based on the degree of impact on other parameters and overall leanness. Methods for establishing these interrelationships are discussed in Section 5.4.4 that follows.

5.4.4.2 Considers interrelationships

When so many aspects are considered for a single system, there will naturally be relationships that form between them. It is clear that the parameters for leanness are not independent. For an accurate assessment, is essential to consider how these elements affect one another and the impact these interactions may have on leanness (Yadav *et al.*, 2019). This parameter, therefore, investigates the studies that explored these interactions and incorporated them into the determined leanness.

The majority of studies (75%) did not consider the inter-relationships between the elements determining leanness; only 23% did. Due to a lack of methodology details presented, it was unclear in one study (2%). The methods adopted to account for the inter-relationships are shown in Table 5.2. These approaches are all considered and discussed when the tool development takes place in Chapter 6.

Table 5.2 Assessment methodologies considering the interrelationships between elements

Assessment methodology	**Study**
Mahalanobis distance (MD)	(Srinivasaraghavan and Allada, 2006)
Analytic hierarchy process (AHP)	(Azadeh *et al.*, 2015)
Interpretive structural model (ISM)	(Gupta, Acharya and Patwardhan, 2013; Yadav *et al.*, 2019)
Graph-theoretic approach (GTA)	(Narayanamurthy and Gurumurthy, 2016b)
Simulations	(Mahfouz, Shea and Arisha, 2011; Ali and Deif, 2014; Omogbai and Salonitis, 2016)
Analytic network process (ANP)	(Sharma and Shah, 2016; Shams Bidhendi, Goh and Wandel, 2019; Yadav *et al.*, 2019)
Fuzzy cognitive map (FCM)	(Azadeh *et al.*, 2015)

The effect a change in one metric may have on others has a significant impact on the overall leanness of an organisation (Krishnamurthy and Chan, 2013; Narayanamurthy and Gurumurthy, 2016b; Shams Bidhendi, Goh and Wandel, 2019). A leanness assessment that considers the relationships between elements thus more accurately reflects the current system state (Omogbai and Salonitis, 2016). Not considering these relationships could lead to an inaccurate leanness calculation, and incorrect conclusions about where to improve leanness (Krishnamurthy and Chan, 2013).

The interrelationships between metrics and their effect on leanness can be incorporated into the assessment by assigning a higher weighting to those parameters that impact leanness more significantly and a lower weighting to those that do not have as significant an impact. In their study, Shams Bidhendi, Goh and Wandel (2019) compared two leanness assessment results where one considered the relationships between metrics and the other did not. The study showed that the determined leanness index is significantly different when considering the interdependent relationships between metrics by multiplying them by their relative importance weightings. Additionally, the results highlighted other areas of improvement as the highest priority. Their findings showed that weighting measures by their importance provide a more accurate result, and not considering this may drastically change the conclusion. Even if the overall score is not significantly different, the identified focus for improvement efforts could be entirely misdirected. In the case presented by Shams Bidhendi, Goh and Wandel (2019), the overall optimum leanness index considering equal relationships was 0.6158, while this same index is 0.6305 when different importance weights are assigned. The overall score has not changed significantly, but the performance metrics demonstrating the lowest leanness score among other metrics were entirely different for the two considerations, which would have led to misdirected improvement initiatives.

The lack of consideration for the interactions between lean indicators in literature may be due to the complexity it adds to a methodology. An approach like this is more difficult and time-consuming to develop and, depending on how it is implemented, could result in decreased ease of use. Thus, the added complexity may be undesired if a quicker, more straightforward evaluation is required. However, in some instances, to ensure the correct obstacles are being identified, this trade-off may be worth the more realistic and accurate assessment this would result in (Wong, Ignatius and Soh, 2012).

5.4.5 OUTPUT

In this section, the various forms of assessment outputs encountered are considered. The output generated by the assessment is critical because it communicates the assessment results and is, thus, ultimately, what informs the lean improvement decisions. The common forms of output identified include: (1) the report of leanness level, which was either linguistic or numerical; (2) some form of visual results (such as graphs); (3) a form of decision support, this included the identification of weak gaps or areas, a prioritisation or implementation strategy, or an optimised setting or design (such as considering different manufacturing setups to result in the leanest operations and reporting the best one); and (4) a display of how the leanness elements are interrelated. Figure 5.11 shows the frequency with which these different forms of outputs were found, and a more detailed discussion on these types is offered below.

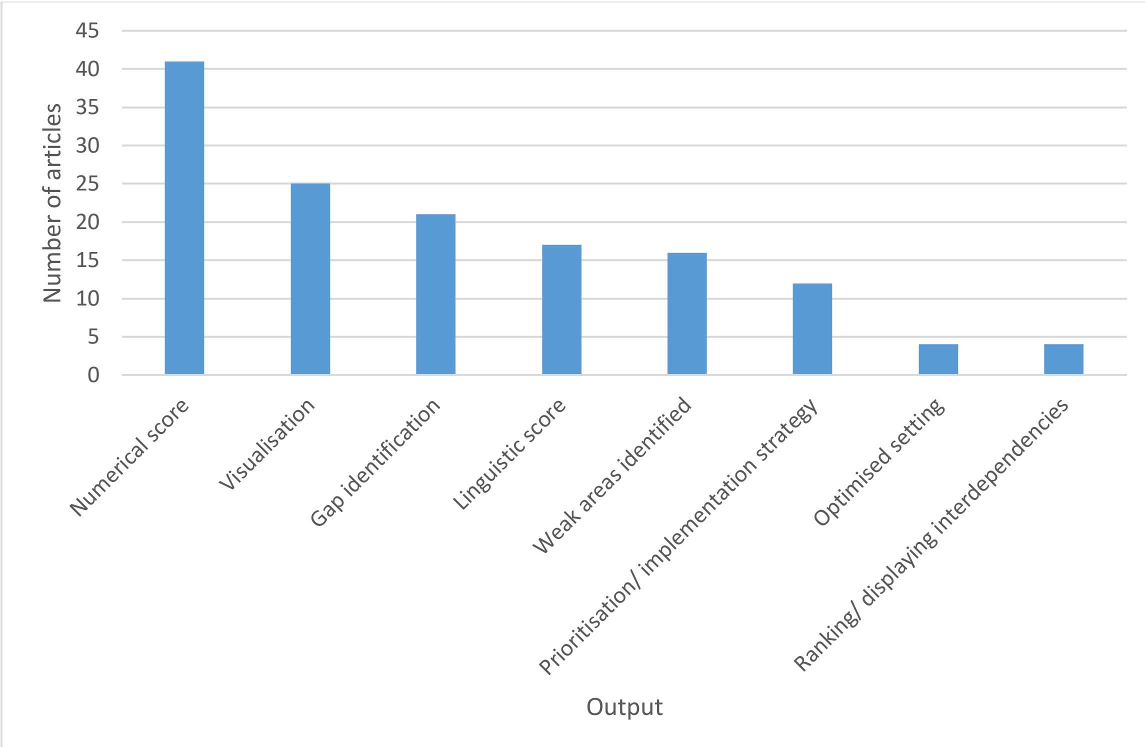


Figure 5.11 Percentage of articles making use of different forms of output

The first category, leanness level, refers to studies where a linguistic or numeric degree of leanness is reported. This score can be given overall or separately for the various areas or practices considered. The use of an overall score refers to studies where one final score is provided as a measure of the whole organisation's leanness. It was found that of the studies quantitatively computing leanness, 85% reported a numerical score, but only 69% reported it as an overall score. Although a smaller portion of studies report one composite score, the use of an overall score to communicate leanness is still relatively high. Most of the studies that did not report an overall score reported findings separately for different areas or practices being considered.

Narayanamurthy and Gurumurthy (2016b) define a systemic leanness index in their study as one representing the true measure of leanness attained by the entire value stream and not a particular sub-unit of the value stream after incorporating the inheritance of lean elements and interaction between the lean elements (Narayanamurthy and Gurumurthy, 2016b). The finding that lean application in hospitals is often limited to a particular area or done for a single lean initiative makes an overall leanness index appear necessary. It additionally allows for easy comparison over time and can be used for benchmarking.

Narayanamurthy and Gurumurthy (2016a) found that the provision of an overall leanness index demonstrated a higher ability to benchmark leanness than studies without one. However, the most purpose of a leanness assessment is to identify areas of lean implementation that need to be improved. It is thus not imperative to develop an overall index to represent these findings.

Examples of how a numerical leanness level could be reported includes a score out of 10, a percentage, or a ranking out of 5. For any quantitative analysis, it is relatively easy to calculate a numerical score and is thus a convenient form of output. In some quantitative cases, the numerical index used was converted to a linguistic level to report leanness. Linguistic scores were often done on a scale such as “Not lean”, “Lean”, and “Very lean”.

The visualisation category refers to any outputs visually representing the leanness assessment result, such as with a lean radar or spider chart. The radar chart is used to visualise the scores for different departments and to see which areas may be lacking in lean implementation or practices that have not been adequately implemented. It can also display the gap between the current performance and the ideal or target situation. Other visual presentations include graphs showing statistical parameters such as mean and standard deviation or a visual depiction of how mature various lean principles are in their implementation, which Maasouman and Demirli (2016) employed to communicate their findings. A graphical display of the result allows for quick visualisation of the situation.

The third form of output, decision support, refers to studies that went beyond simply providing a leanness score or identifying underperforming areas. It included anything from providing potential solutions, a prioritisation or implementation plan, or ranking priorities based on the assessment; to a framework that incorporates various factors such as time and cost required for alternative solutions into deciding where to focus improvement efforts.

Beyond providing scope for improvement and identifying weaker areas for improvement, Vinodh and Vimal (2012) highlighted improvement methods and suggested possible solutions for improving the identified weak attributes. Srinivasaraghavan and Allada (2006) not only identified the ideas where improvement methods must be directed but considered additional elements such as the cost of a project and the time it would take to execute it, inter alia, in the possible solutions suggested. The three common types of decision support included a) identifying weak areas, b) gap identification, c) a prioritisation or implementation strategy, and d) an optimised setting. Each of these types and their occurrence in the studies is represented in Figure 5.11.

Identifying weak areas refers to tools that compare the numerical score or leanness level of the different parameters being assessed and identify those with the lowest scores for future improvement. The difference between this parameter and gap identification is that gap identification goes further and compares the score of the current state to an ideal or target one. The suggestion will generally be to improve the areas with the biggest gaps. The gap identification parameter, therefore, inherently also represents the identification of weak areas. Thus, if gaps were identified in the tool, it was not additionally classified as identifying weak attributes. “Improvement/weaker areas identified” refers to those who do not use gaps to infer where the areas must be improved, but simply the areas that are lower than others. The gap identification also identifies the improvement areas by identifying the biggest gaps, but the improvement area does not.

Studies that went beyond providing a leanness score or identifying underperforming areas are represented in “prioritisation or implementation strategy” category. Such output could include suggesting possible solutions, ranking priorities, providing a prioritisation or implementation strategy, improvement proposals or an optimum lean implementation route. However, this type of output was not commonly used—only 25% of studies proposed tools that guide selecting the lean initiative required to achieve improved leanness. Additionally, even studies including decision support often simply rank priorities. Very few offered a more robust implementation strategy. There are further factors to consider when deciding where to implement and improve lean applications in an organisation, such as the cost of such an improvement or the time it might take. Offering a ranking of the worst performing leanness areas is, therefore, only one aspect to consider (although it may be an important one).

The least occurring output (equal to ranking or displaying of interdependencies) is an optimised setting or design. This feature was only found in performance-based studies, as the solution often came from a simulation of the system resulting in the optimum settings of given parameters to achieve the best performance and leanness level.

The final form of output includes a report of the interrelationships and interdependencies between elements. As only 23% of studies considered how elements are interrelated in the first place, a low percentage of studies using this form of output (8%). Of the 11 studies considering these relationships, only four included this analysis in the output. Consideration of interrelationships was more commonly used to determine a leanness score, and not reported as a result. The studies that did report the relationship findings, however, did this by either displaying a hierarchical interaction, relationship network, or a ranking of the interdependencies of which elements have the most significant impact on leanness.

Different outputs were often integrated, and studies frequently used more than one way to communicate their findings. For example, a tool that is shown to have a numerical score, radar chart and gap identification as an output likely means that the numerical score for each evaluated area is displayed on the radar chart together with the ideal or desired case for each area to give a more comprehensive view of the overall lean situation. Some radar charts simply plotted the score without showing the expected case. This type of assessment would include a numerical score, visualisation, and identification of the weak areas.

5.5 ASSESSMENT PARAMETER RESULTS

The last study aspect considered was the parameters used to determine leanness. These findings will be used to ascertain what is needed for a holistic implementation of the lean philosophy and obtain a list of leanness indicators. Therefore, the assessment parameters used in the existing tools were extracted and synthesised as they exist in the context for which they were developed. In the tool development process detailed in Chapter 6, these are further adapted to the healthcare context and transformed into assessment parameters for the overarching tool being developed.

Through the analysis of all the studies, 783 different indicators were extracted. Each of these was then considered for relevancy and eliminated if it did not apply or could not be adapted to healthcare. The remaining parameters showed significant overlap in their considerations. Thus, they were combined to realise a more concise list of unique concepts, resulting in a final list of 161 leanness indicators. The initial parameters identified and how they were combined into the final 161 indicators are shown in Table C.1 in Appendix C. The further development of these indicators into leanness assessment parameters included in the tool is detailed in the tool development chapter that follows.

5.6 CHAPTER 5: CONCLUSION

In this chapter, a systematic review of existing leanness assessment tools and methodologies was executed to uncover leanness indicators and investigate the approaches and necessary considerations to assess them. The measurement types, data, assessment methodologies used, and the capabilities of these existing tools were all analysed. This chapter concludes the information-gathering phase of the preliminary tool development. Chapter 6 that follows analyses the information obtained in Chapter 4 and Chapter 5 to build the preliminary tool and form its assessment parameters.

Chapter 6 Tool development

Once the practices needed for a sustainable and holistic implementation of lean had been identified, the tool to support their practical implementation needed to be developed. Chapter 5 investigated ways such tools have been approached, and this chapter draws on these findings to develop a sustainable lean assessment tool (SLAT). The development process focused on the following aspects: (1) Identifying the key assessment parameters and organise them into logical categories, (2) Proposing an appropriate method to assess the parameters, and (3) Determining and structure the output that will be generated from performing the assessment.

This chapter begins by synthesising the practices found in Chapters 4 and 5 to contribute to sustainable and holistic lean implementations into a structured set of assessment parameters that would be used by the SLAT to determine the hospital's capability to sustain lean and its leanness level in Section 6.1. Next, Section 6.2 considers how the SLAT evaluates these parameters. The chosen method was then explored, and the assessment methodology was outlined in Section 6.3. Finally, how the assessment findings would be provided was determined in Section 6.4.2. The chapter then summarises the overarching assessment methodology process in Section 6.6 and presents the preliminary SLAT in Section 6.7. An overview of the development process presented in this chapter is illustrated in Figure *6.1*, which summarises the steps executed. Lastly, the chapter is concluded in Section 6.8.

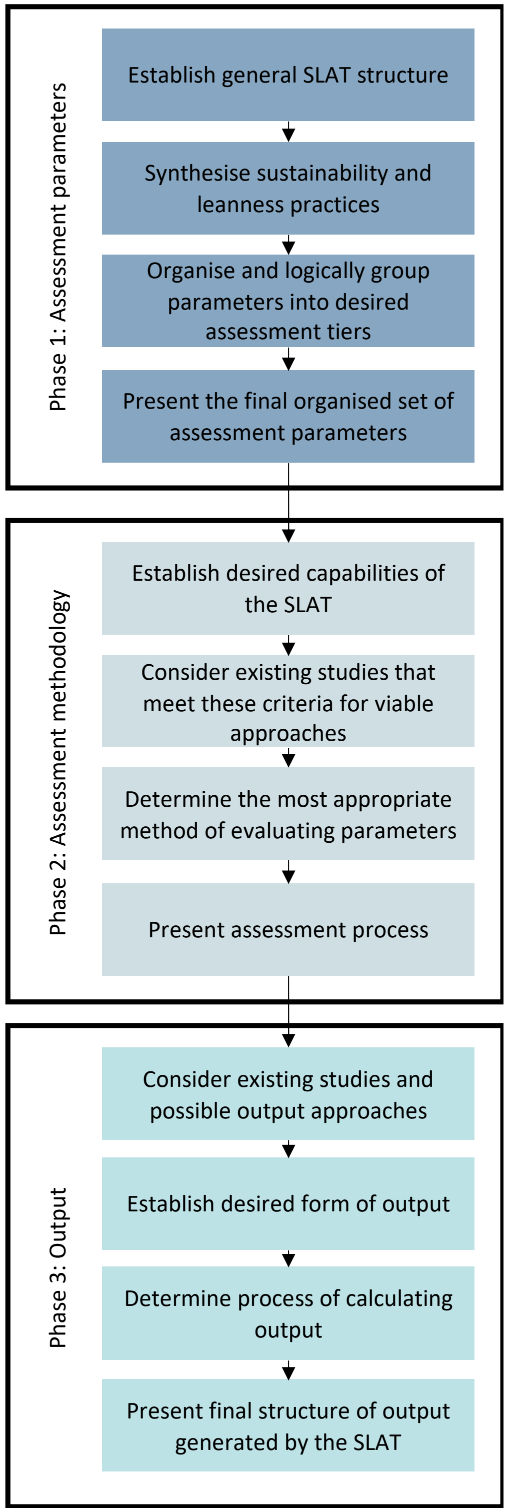


Figure 6.1 SLAT development process

6.1 ASSESSMENT PARAMETER IDENTIFICATION

The development process began by structuring the assessment parameters, which are the measurable factors used by the tool to determine the sustainability level of the hospital. The assessment parameters are derived from the practices and indicators found through executing the SLRs. The significant overlap between Chapter 5 indicators and the practices identified in Chapter 4 meant the overall tool context and existing sustainability practices needed to be considered before the leanness indicators could be organised into assessment groups and levels.

Because holistic lean implementation was identified as a sustainability practice, the leanness indicators form a lower level of abstraction for that practice. Once formed into assessment parameters, they serve as additional indicators of the "holistic lean implementation" sustainability practice, so its adoption can more accurately be determined. Thus, the set of sustainability practices and leanness indicators needed to be considered together in structuring the tool's assessment parameters. How they were integrated is shown in Figure *6.2*. The supplementary assessment for leanness is referred to as the leanness assessment tool (LAT).

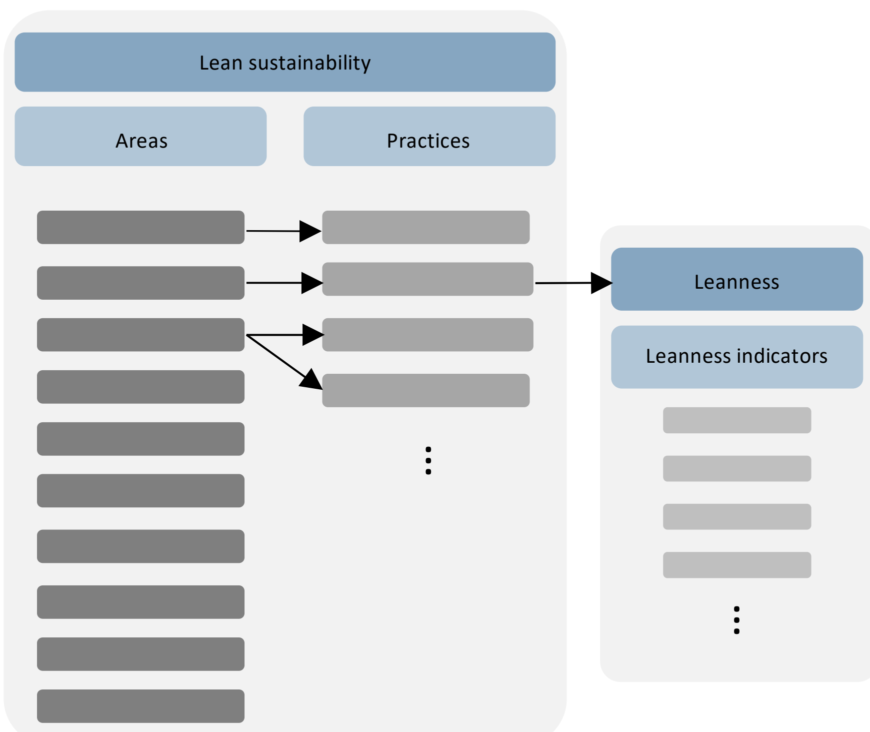


Figure 6.2 SLAT general structure

The first step involved isolating the practices that apply to leanness by eliminating those already represented by any lean sustainability practice. For example, the leanness indicators "Job enrichment used", "Employees lead improvement efforts", and "Strong employee spirit, cooperation, and engagement" were already addressed in the sustainability practices through "Workforce empowerment" area and "Bottom-up approach". Similarly, the leanness indicator "rewards and recognition system" was already represented by the "Rewards and recognition" sustainability practice. Thus, these were removed. The process of synthesising the two collections resulted in 26 leanness indicators remaining.

Thereafter, the leanness indicators needed to be structured into assessment tiers. Given that these parameters aimed to ensure a holistic implementation of the lean philosophy, it was decided to structure the remaining practices into five overarching areas representing each lean principle. Structuring them in this way ensured that each aspect of the lean was philosophy represented and, in effect, implemented by the hospital. Thus, each of the 26 remaining indicators was grouped into the lean principles to which they best related. The indicators were then grouped into similar concepts to form the leanness practices and the intermediate parameter level. The overall general structure of the leanness assessment parameters is shown in Figure *6.3*, while the complete collection is shown in Table 6.1.

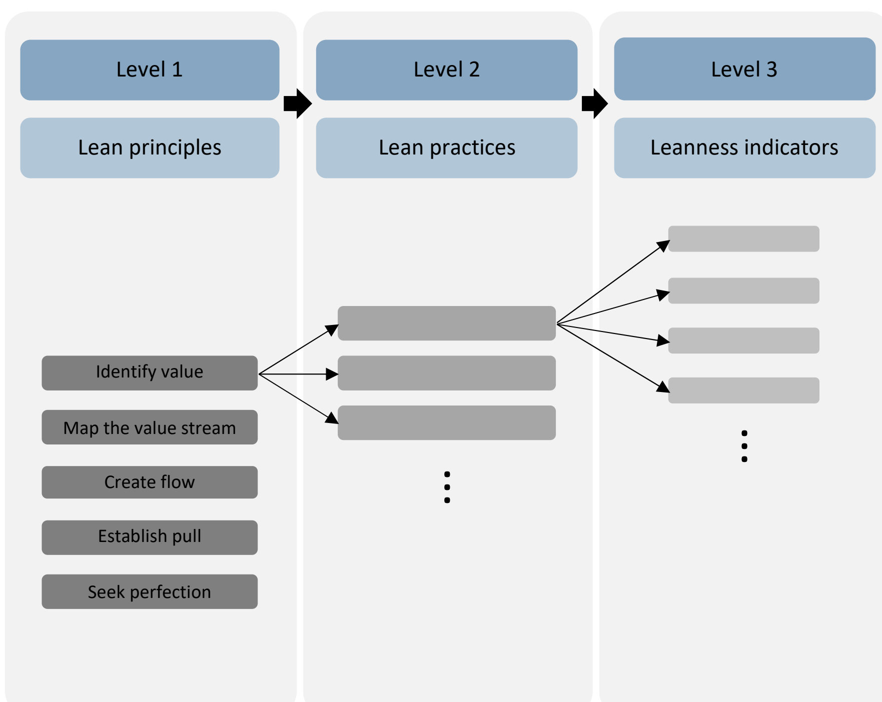


Figure 6.3 Leanness assessment parameter structure

Table 6.1 Leanness assessment parameters

Lean principles	Lean practices	Leanness indicators
Identify value	Define customer expectations	A formal and informal "voice of customer" system is in place for close cooperation, collaboration, and information sharing with the customer, allowing their requirements, needs, and preferences to be adopted and prioritised.
Map the value stream	Identify and eliminate wastes	Process and value streams are mapped and analysed to classify activities as value-added (VA), non-value added (NVA), or necessary but non-value added (NNVA). These activities identify wastes so that they can be minimised or eliminated where possible. Tools such as value stream mapping (VSM), 5 Whys, plan-do-check-act (PDCA) cycle, A3 report, DMAIC, and root cause analysis are used to map the value stream and identify and eliminate wastes.
Create flow	Workload levelling (Heijunka)	The processing sequence is optimised, and its variation is reduced to level workload for smooth flow without interruptions, delays, or bottlenecks.
		Plans for resource management are drawn up for the short- and long-term, including worker, workstation, and equipment schedules. In these plans task precedence is organised to maximise concurrency. Physicians are engaged in forecasting the planning process.
	Process time improvement	Streamline processes to improve patient throughout. Cycle or lead time reduction techniques such as layout optimisation, quick changeover, set-up time reduction, etc., can be used.
		Usage of automated tools to enhance processing time
		Productivity is measured, and optimisation tools are used to improve resource productivity. Quality is not infused at the cost of productivity.
	Reduce delays and interruptions	Maintenance techniques such as TPM are employed to reduce disruptions caused by tool and equipment downtime. Staff are also trained to maintain competency in providing uninterrupted care without error.
	Workplace organisation	Workplaces are organised and standardised with an activity policy (such as 5S) to help keep work areas clean, tidy, and uncluttered.
	Quality	The hospital has a formal quality system and program that ensures the provided service exceeds customer expectations. Measurable quality objectives are set regularly to monitor quality status, and quality issues are tracked, reported, and communicated.

		Implementation of Total Quality Management (TQM) practices.
		Quality is built-in by preventing errors (implementing poka-yoke methods) and having visual controls (such as signs, pictures, or procedures) to identify errors.
		The Jidoka principle (autonomation) is implemented.
		The quality of materials received from suppliers is ensured through supplier selection and development activities, such as providing technical and financial assistance and training in quality issues.
	Flexibility	To quickly adapt to changes, there is flexibility and adaptability in the service provided, as well as flexibility in the workforce, layout, and set-up.
	Visual management	Visual management (such as Kanban) is used to manage inventory levels and patients as they move through the system so that inventory levels and overproduction waste is minimised for better material, patient, and workflow.
Establish pull	Pull system	A pull system is used to determine the supply of sundries and jobs. The hospital thus executes healthcare demand analysis and forecasting. It has a capacity management system/ programme to ensure new work is started only when there is demand for it and the staff has spare capacity.
	Minimise inventory and patients waiting	Inventory and work-in-process (WIP) items must be limited while ensuring that the requisite materials and information are available for a smooth workflow. Therefore, inventory and material logistics are managed to monitor and reduce inventory and lot sizes, and just-in-time (JIT) techniques are employed.
		Techniques are employed to minimise the number of patients waiting in the system.
	Supplier delivery and responsiveness	A strategic network is utilised to exercise a zero inventory system. Suppliers must thus have minimum delivery lead time and on-time delivery to ensure hospital consumables are delivered when needed or in emergencies.
		Hospital-supplier integration. There is a proactive and long-term relationship established with suppliers. They are included in planning, goal-setting, continuous improvement, quality, and problem-solving activities.
		There are transparent communication systems between the hospital and supplier, where feedback is provided, and information is shared.
Seek perfection	Continuous improvement	Tools such as kaizen and Gemba walks are used to engage with employees and explore opportunities for continuous improvement. Employee suggestions are utilised when identifying possible improvements.

		Process and improvements are monitored, evaluated, and controlled to identify opportunities for improvement and allow data-based decision-making.
		Customers are involved in continuous improvement efforts to adapt the services to changing demands.
	Standardisation, systematisation, and simplification	Processes are continuously standardised, systematised, and simplified.

6.2 EXISTING APPROACHES TO ASSESSMENT

Once the assessment parameters had been structured and all relevant indicators included, the assessment methodology needed to be determined. Therefore, how these parameters would be assessed (i.e., data collection methodology) and turned into a result (i.e., output calculation methodology) was defined. Because leanness assessments already exist (which was not the case for sustainability assessments), their approaches to determining leanness were considered. The methodology found to be the most applicable would be adopted for the larger overarching tool.

6.2.1 DATA COLLECTION METHODOLOGY

The self-assessment and ease-of-use objectives for the tool meant information requiring deduction (and therefore advanced knowledge) was not ideal. Due to the ease with which a tool that executes an assessment based on input can be built from quantitative data, it was the preferred form of input data. Objectively obtaining such data would increase input accuracy and avoid bias. However, it is challenging to measure lean practices in this way. Studies that use objective data either a) assessed performance measures as opposed to practices or b) used surrogate metrics to measure their implementation. As this research sets out to measure practices, only the second case could be considered. Of the 15 quantitative studies that use objective measures, only 8 used them to measure practices. These studies, with examples of metrics used, can be found in Table *6.2*.

This approach, however, has limited applicability. Using objective measures to represent practices only indirectly measures their implementation level. Many of the metrics shown measure the possible effect of practice implementation, which could have resulted from several other factors not relating to the practice itself. For example, using the defect rate to measure the adoption of quality improvement practices does not consider whether total quality management (TQM) has been implemented or if a formal quality system and program exist. It merely shows if quality may have improved since lean's deployment. Similarly, using customer complaint rate as a measure of the transition to a customer-focused organisation could lead to incorrect conclusions about the implementation of such a practice. Improved customer satisfaction could result from various factors but does not reflect whether essential practices such as involving the customer in continuous improvement efforts or stabilising demand have been implemented.

Furthermore, finding unique performance measures for each of the identified leanness parameters would be difficult. The inability to accurately and practically measure the assessment parameters objectively resulted in it not being deemed a viable option for this study. Consequently, studies that used subjective quantitative data were deemed more appropriate. Of the studies that used quantitative data, 85% measured it subjectively. While there are drawbacks to this type of measurement, it was determined to be the most effective way to measure the types of parameters being considered. In deciding how to assess leanness, only studies using subjective data collection methods were thus considered.

Table 6.2 Examples of quantitative data used to measure lean practices

Author	Example metrics used	
Pakdil and Leonard (2014)	Human resources	Labour turnover rate Absenteeism rate Sales per employee Number of hierarchical levels
	Delivery	Order processing time/ total orders Average total number of days from orders received to delivery
	Customer	Customer satisfaction index Customer retention rate
	Inventory	Total inventory/ total sales Stock turnover rate
Srinivasaraghavan and Allada (2006)	# of kaizen events undertaken	
Taj (2005)	Percentage of personnel who are active members of work teams, quality teams, or problem-solving teams Percentage of personnel receiving teambuilding training Job security Annual personnel turnover	

Shetty, Ali and Cummings (2010)	Employee empowerment	The number of suggestions implemented per employee per year
	Quality function	Scrap rate Percentage of time product(s) passes quality checks the first time through
	Supplier management	Percentage on-time delivery from major suppliers
	Production control	Number of times inventory turns over per year Percentage of product lines set up to manufacture product with minimal WIP between steps
	Reward and recognition	Frequency of the reward system
	Lean implementation	Dedicated continuous improvement (kaizen) events held per year Percentage of product families for which the value stream has been mapped
Maasouman and Demirli (2016)	People	Absenteeism rate
	Facilities	Uptime Mean time between failures (MTBF)
	Working conditions	Safety risk factor
	Production processes	Value-added rate
	Quality	Scrap rate Rework
	JIT	On-time delivery Inventory turnover rate
	Leadership	Average percentage of meeting target value of each performance measure
Oleghe and Salonitis (2016)	Training	Change in factory efficiency
	Cleanliness	Number of machine cleaning activities as a percentage of total number of machines
	Standard operating procedure (SOP)	Number of defects that could have been avoided if an SOP was used
	Kaizen	Number of improvement suggestions per employee
	Single-minute exchange of dies (SMED)	Total set-up time/total number of set-ups

	Quality management WIP reduction	Process-related defect rate in % Total closing process inventory as a percentage of total current workload
Lemieux, Pellerin and Lamouri (2013)	Responsiveness	Time-to-market (TTM)
Rakhamanhuda and Karningish (2018)	Time effectiveness Quality Process Human resources Delivery Customer Inventory Safety	Set-up times Machine downtime Defect rate Rework % of the units that need to be sent to rework Overall equipment effectiveness (OEE) Absenteeism rate Total of suggestions per employee Total of hierarchical levels Order lead time Ratio order processing time / total order Customer complain rate Customer retention rate Finished good inventory/ total inventory Raw material inventory/ total inventory Incident rate Lost time case rate

6.2.2 METHOD OF DETERMINING LEANNESS

This section discusses how the subjective data gathered can be used to determine leanness. The review in Chapter 5 showed that the number of studies considering the relationships between lean elements and criteria is low. Although the number of tools that take interdependency into account has increased, it remains mainly unaddressed (Cil and Turkan, 2013). Thus, to improve the accuracy of the leanness assessment, the relevant methodologies that use quantitative data, apply weighting to the parameters, and consider their relationships were considered. The studies which exhibit these characteristics are shown in Table *6.3*. How each author approached leanness assessment is discussed and summarised below.

Table 6.3 Studies using quantitative data, weighted parameters, and consider interrelationships

Author	**Title**	**Score calculation methodology**
Azadeh *et al.* (2015)	Leanness assessment and optimization by fuzzy cognitive map and multivariate analysis	Fuzzy cognitive map (FCM), DEA, and AHP
Gupta, Acharya and Patwardhan (2013)	A strategic and operational approach to assess the lean performance in radial tyre manufacturing in India: A case based study	ISM
Narayanamurthy and Gurumurthy (2016)	Systemic leanness: An index for facilitating continuous improvement of lean implementation	GTA
Sharma and Shah (2016)	Towards lean warehouse: transformation and assessment using RTD and ANP	RTD and ANP
Shams Bidhendi, Goh and Wandel (2019)	Development of a weighted leanness measurement method in modular construction companies	Fuzzy-based ANP
Yadav *et al. (*2019)	Development of leanness index for SMEs	ISM and ANP

Azadeh *et al.* (2015) used a combination of the fuzzy cognitive map (FCM), DEA, and AHP to assess leanness. In addition to determining an overall leanness score, the approach evaluates not only the impact the various leanness factors have on each other but also the impact these factors have on this overall score. DEMATEL (decision-making trial and evaluation laboratory) was used to assess the degree to which each leanness factor influences other factors. This approach utilises the opinion of experts to provide judgement on the various pairwise comparisons. After the factors' degree of interaction is determined with DEMATEL, AHP and DEA are used to rank leanness factors according to the impact they have on the overall leanness of the organisation. DEA is used to determine the impact of each factor on overall leanness, and AHP is used then to rank the impact level of the various factors. This methodology requires three different questionnaires, one scoring the factors, a second the interactions, and a third the factors' effects on leanness. This approach becomes cumbersome when considering the size of the SLAT developed thus far.

Gupta, Acharya and Patwardhan (2013) use ISM in their approach. ISM is a methodology that aids in structuring and managing the complex relationships among elements that make up a system. Their leanness assessment tool is thus used to determine the structural hierarchy of the lean critical success factors. Like Azadeh *et al.* (2015), expert judgement is used to determine the relationships. In this approach, however, the expert decides whether given elements are interrelated by specifying if one helps achieve the other or vice versa. While Gupta, Acharya and Patwardhan (2013) use ISM to determine a structural hierarchy of the success factors, these relationships are not incorporated into the overall score. The leanness score itself simply uses ratings that have been gathered from experts for each element. As the SLAT's goal is to have one system accounting for the relationships in determining the result, separating these two activities eliminates this approach as a possibility.

Narayanamurthy and Gurumurthy (2016) use the GTA to compute a "systemic leanness" score similar to the one desired for the SLAT. This leanness score captures both the degree to which lean elements have been implemented (inheritance) and the degree of their relationship (interaction). The GTA 1) develops graphs that identify the system, sub-system, and components and 2) delivers a single index at the end of the approach. Firstly, diagraphs showing the directional relationships are constructed between sub-elements within an element. These diagraphs are then developed for each element and are used to identify the system. In its application to this study, this would translate to five diagraphs showing the relationships between the practices of each lean principle. Secondly, to deliver a single systemic leanness index, the GTA uses matrices where the diagonal elements are made up of the inheritances, and the interactions fill the off-diagonal elements. In cases where no relationship was indicated, the off-diagonal for those elements would be populated with a zero. The GTA steps thus involve 1) developing the diagraphs, 2) constructing matrices representing these diagraphs, 3) quantifying the matrix elements, and 4) computing the permanent of these matrices. Like the previous two approaches, expert opinion is used to determine the interaction and scores that would be used to populate the matrices.

A 5-point Likert scale is used to rate the interaction between elements and sub-elements, and a Saaty scale is used to rate the degree of inheritance of each sub-element. While this approach seems attractive due to aligning well with the goals of this LAT, it is developed for a system with only two levels of indices. As is the case where ANP was used by Azadeh *et al.* (2015), these matrices become immensely large when extended to three indicator levels, which is the case for the LAT. It was considered to only account for parameter interaction at the highest two levels, so this methodology could feasibly be adopted. Executing the GAT would then be done as in the case by Gupta, Acharya and Patwardhan (2013). The level two scores would be an average of the leanness indicators scores representing that practice, effectively treating each leanness indicator as equal and not considering the relationship between parameters at this level. Doing this brought into question the accuracy of the final score, as the assumption that each leanness indicator is equally important takes liberties that might result in a score not representative of the true leanness, thus negating the point of considering the interrelationships in the first place.

Alternatively, the tool developed by Sharma and Shah (2016) uses RTD (real-time Delphi) and ANP. The ANP is used to uncover the relationships and interdependency between the elements. At the same time, the RTD supports the continuous assessment and improvement in team building, modelling, developing, implementing, and validating the procedure. The RTD allows for real-time input and tracking, thus continuously mapping the progress and providing real-time suggestions that aid quick decision-making and collaboration with experts. This approach facilitates leaders to identify exact problems and the possible tools for improvement, helping with the preparation of action plans. The application of ANP then provides practical validation and enhancement to the results of the RTD. However, the application of the RTD and ANP in this methodology focused on warehouse operations within the organisation. Therefore, the resulting method is more suited for individual areas, answering day-to-day operational questions and informing departmental decisions instead of providing a more systemic evaluation.

Shams Bidhendi, Goh and Wandel (2019) also used the ANP; however, in their approach, it was combined with fuzzy logic to employ a fuzzy-based ANP to allocate relative importance weighting to the various assessment metrics. A supermatrix with pairwise comparisons is used to evaluate the relationships between metrics and calculate overall priorities based on these relationships. The supermatrix represents each metric's cumulative influence on every metric it interacts with (Saaty and Takizawa, 1986). The input to construct the required pairwise comparison matrices included linguistic data, and respondents rated each sub-element's interaction relative to another for a given area.

The last approach to consider is Yadav *et al.* (2019), which combines ISM and ANP. The ISM is used to identify the inter-relationships between elements, and the ANP derives the weights of the parameters. The construction of the ANP is based on the interrelationships uncovered by the ISM and follows the same methodology as previously discussed in studies using this process.

It became clear after considering all the existing approaches that taking the relationships into account for the leanness score in the desired way would require some pairwise comparison that becomes unpractical when given the number of leanness indicators developed for the LAT in this study. Thus, given the context of the LAT, it was deemed infeasible to incorporate the relationships between the various leanness parameters. A different approach, therefore, needed to be considered, which does not require extensive amounts of pairwise comparison. The remaining studies that weighted parameters and quantitatively determined leanness were considered next. Figure *6.4* shows the filtering process executed, which resulted in the further consideration of 18 studies. Table D.1 in Appendix D further lists the 18 assessment approaches considered and summarises their approach.

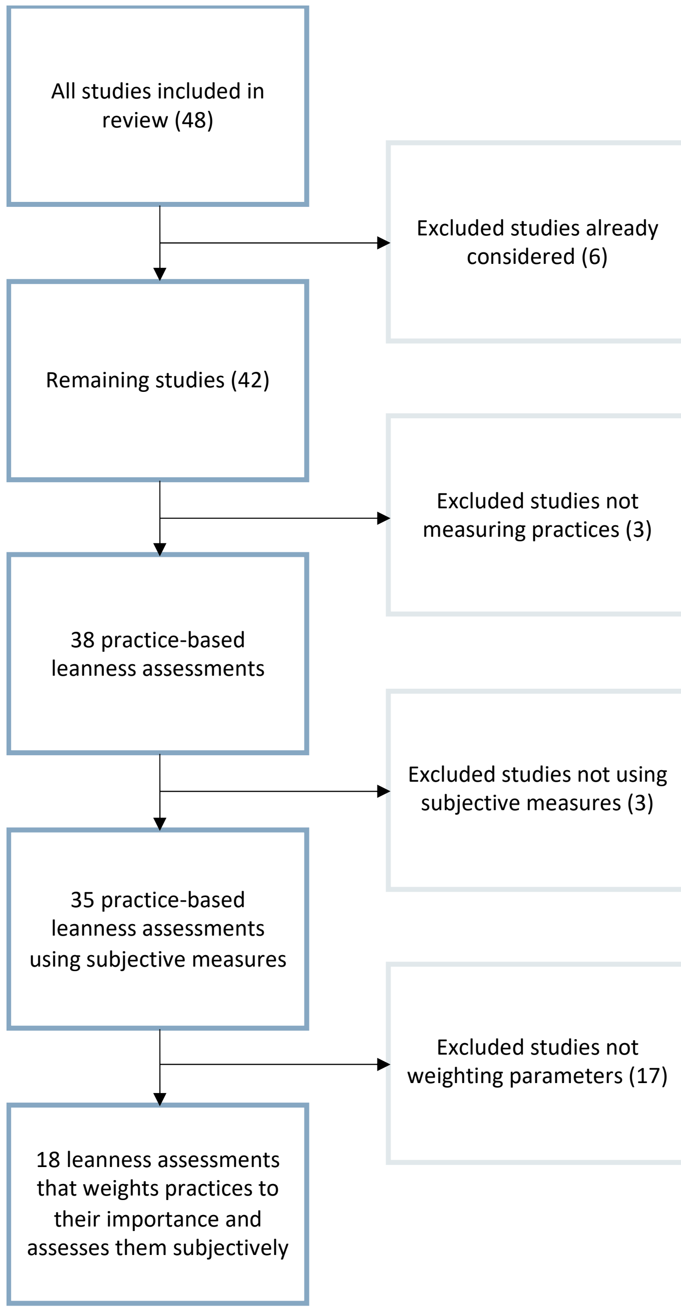


Figure 6.4 Process of filtering studies for leanness computation methodology

Of the cases considered for their assessment procedure, two were vague in their description of the computation method and did now show how leanness was calculated. The lack of a transparent process means it would be difficult to implement into the SLAT accurately and consequently could not be considered. These studies included an adaptive assessment approach by Wan and Chen (2009) and Lean Excellence Assessment Framework Driver (LEAF-D) by Gomez (2009).

The remaining studies used either a fuzzy-based leanness assessment (11 studies) or calculated the scores by averaging ratings given in a survey (5 studies). A preference for fuzzy logic is shown, being more than double the number of studies using survey ratings. Beyond the evident popularity of the fuzzy approach, it also offers additional benefits to the method of averaging ratings given in the form of a survey. Fuzzy models are straightforward, use simple calculations, and allow for loose imprecise input (Almutairi, Salonitis and Al-Ashaab, 2019). Linguistic variables measure qualitative attributes and match them with fuzzy set numbers. It will enable the results to be acquired quantitatively and, in effect, mitigates the disadvantages associated with numerical scoring methods while still allowing a quantitative analysis (Vinodh and Vimal, 2012). Fuzzy logic's approach of converting human perception with a mathematical base mitigates the expert's bias (Matawale, Datta and Mahapatra, 2015; Madhan and Suresh, 2017; Balaji and Senthil Kumar, 2018). While there is no ideal methodology for estimating systemic leanness, its apparent popularity and ability to deal with the types of attributes considered in this study made the fuzzy approach suitable.

6.3 PROCEDURE FOR LEANNESS ESTIMATION

The procedure used to estimate the leanness of a hospital was primarily based on the methodology presented by Yang and Li (2002). In their application of the approach, they used it to assess the level of agility of an organisation. However, according to the authors, multi-grade fuzzy logic can similarly be used to calculate leanness (Almutairi, Salonitis and Al-Ashaab, 2019). The procedure presented here is additionally based on the work by Vinodh and Chintha (2011), Madhan and Suresh (2017), and Saleeshya and Binu (2019), some of who similarly based their work on Yang and Li (2002).

6.3.1 SELECTION OF VARIABLE SCALE

The fuzzy approach to assessment uses a set of fuzzy numbers that have been linked to a linguistic scale so that the responses from the data collection process can be collected numerically (Saleeshya and Binu, 2019). The first step in this fuzzy modelling approach thus requires the selection of the linguistic variables that will be used and the fuzzy numbers to approximate them (Madhan and Suresh, 2017). The linguistic terms chosen will be used to score the importance weights of the various lean attributes and the degree to which each has been implemented. Using fuzzy numbers to represent qualitative responses aids in overcoming the inherent vagueness and impreciseness typically encountered with this type of data (Madhan and Suresh, 2017).

Trapezoidal and triangular are among the possible membership functions that can transform linguistic variables into fuzzy numbers (Singh *et al.*, 2006). Most of the available studies used the triangular membership functions and were thus similarly adopted for this SLAT.

Following the examples of Vinodh and Vimal (2012) and Saleeshya and Binu (2019), seven possible responses were selected to describe both the level of implementation of the various leanness indicators, called the implementation rating, and how important an indicator is for leanness in a hospital, termed importance weighting. These different responses were then linked to fuzzy triangular numbers, as shown in Table *6.4*. Additionally, the membership function plot of implementation rating and importance weight can be found in Figure *6.5* and Figure *6.6*, respectively.

Table 6.4 Fuzzy numbers for approximating linguistic variables

Implementation rating		Importance weighting	
Linguistic variable	Fuzzy number	Linguistic variable	Fuzzy number
Worst (W)	(0, 0.5, 1.5)	Very low (VL)	(0, 0.05, 0.15)
Very poor (VP)	(1, 2, 3)	Low (L)	(0.1, 0.2, 0.3)
Poor (P)	(2, 3.5, 5)	Fairly low (FL)	(0.2, 0.35, 0.5)
Fair (F)	(3, 5, 7)	Medium (M)	(0.3, 0.5, 0.7)
Good (G)	(5, 6.5, 8)	Fairly high (FH)	(0.5, 0.65, 0.8)
Very good (VG)	(7, 8, 9)	High (H)	(0.7, 0.8, 0.9)
Excellent (E)	(8.5, 9.5, 10)	Very high (VH)	(0.85, 0.95, 1.0)

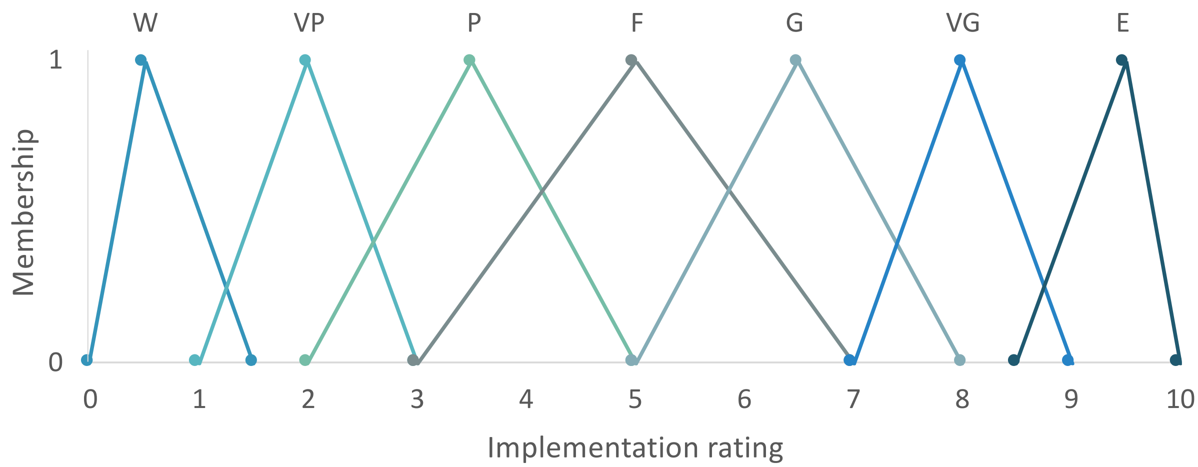


Figure 6.5 Implementation rating membership function

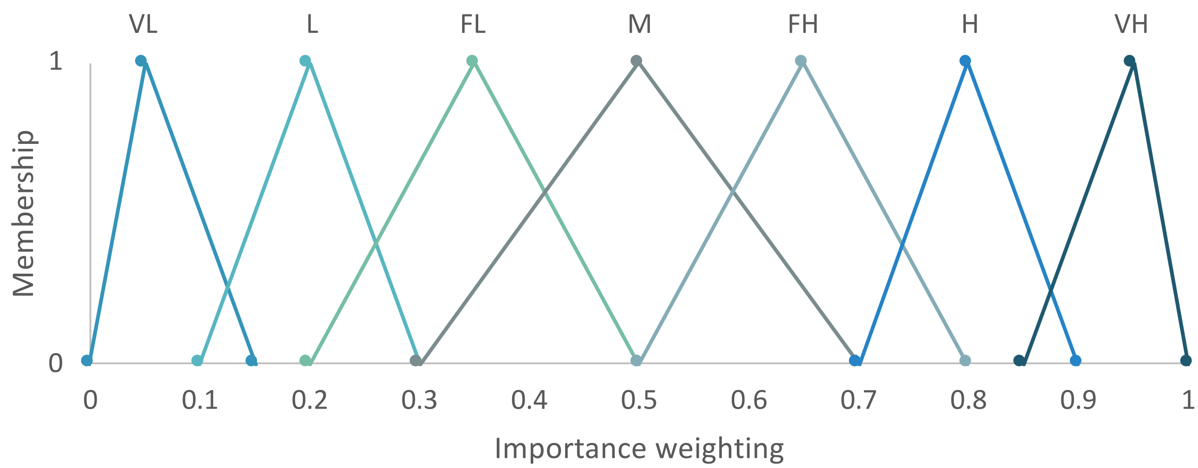


Figure 6.6 Importance weighting membership function

6.3.2 LINGUISTIC ASSESSMENT AND LINGUISTIC TRANSLATION

Once the assessment parameters and variable scale for indicating their implementation and importance have been determined, the parameters can be measured. The data provided through a linguistic assessment of the various parameters presented in Section 6.1 is used to do this. The implementation rating provides the degree to which each leanness indicator has been implemented, and the importance weighting is used to assign a relevant weight to each leanness parameter. All responses are collected in natural language expressions and translated to the representative fuzzy numbers using the membership functions defined in Table *6.4* (Singh *et al.*, 2006; Vinodh and Balaji, 2011). For example, if the user rated the implementation of a measurement system as “Good”, this was converted to the number (5, 6.5, 8). Translating the responses allows for further quantitative data analysis to be executed.

Sample values for leanness indicators of the fourth principle (Establish pull) are used to demonstrate this translation. The mathematical form of the sample responses in Table *6.5* can thus be found in Table *6.6*. The median operation can aggregate responses if multiple experts assess leanness for a single hospital (Lin and Chiu, 2006).

Table 6.5 Sample response for establishing pull

LS_i	LS_{ij}	LS_{ijk}	W_i	W_{ij}	W_{ijk}	R_{ijk}
LS_4	LS_{41}	LS_{411}	FH	M	M	G
	LS_{42}	LS_{421}		FH	M	VG
		LS_{422}			H	F
	LS_{43}	LS_{431}		FH	M	VG
		LS_{432}			FH	P
		LS_{433}			H	G

Table 6.6 Data input for workforce leanness

LS_i	LS_{ij}	LS_{ijk}	W_i	W_{ij}	W_{ijk}	R_{ijk}
LS_4	LS_{41}	LS_{411}	(0.5, 0.65, 0.8)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(5, 6.5, 8)
	LS_{42}	LS_{421}		(0.5, 0.65, 0.8)	(0.3, 0.5, 0.7)	(7, 8, 9)
		LS_{422}			(0.7, 0.8, 0.9)	(3, 5, 7)
	LS_{43}	LS_{431}		(0.5, 0.65, 0.8)	(0.3, 0.5, 0.7)	(7, 8, 9)
		LS_{432}			(0.5, 0.65, 0.8)	(2, 3.5, 5)
		LS_{433}			(0.7, 0.8, 0.9)	(5, 6.5, 8)

However, to simplify the evaluation process and avoid bias in assigning the importance rankings, the tool user will only provide the implementation rating. Importance weights will be pre-built into the tool. These importance weights are determined by experts who understand the subject matter and experience with its implementation in this context. For relevance to a specific context, the relative importance was determined iteratively through the execution of a Delphi study to allow a consensus on the rankings of the various assessment parameters included in the tool to be reached. The process of determining the assessment parameter weights through the Delphi methodology is discussed in Chapter 7.

6.3.3 CALCULATION OF THE FUZZY INDEX

Once the data for a given hospital has been collected, the overall index representing hospital leanness must be calculated. In fuzzy modelling, this is represented by the fuzzy lean index (FLI). This final leanness score determines the implementation rating for "holistic implementation of lean tools and practices" in the sustainability tool.

Determining the FLI starts at the indicator level, where the score for each leanness indicator is calculated using the implementation scores gathered and their respective importance weights. The practice scores are then calculated in the same way, and finally, by incorporating the importance weights of each lean principle, the FLI is calculated. Calculations are executed at three levels to realise the final score and are referred to here as the primary, secondary, and tertiary calculations. The steps of each assessment are explained in detail in this section. Sections 6.3.3.1, 6.3.3.2, and 6.3.3.3 describe the primary, secondary, and tertiary assessments, respectively. The sample data presented in Table *6.5* and Table *6.6* are used to demonstrate the process.

6.3.3.1 Primary assessment calculation

The calculation of the FLI begins at the third level of parameters. The ratings and weights provided for each leanness indicator must be translated to a score for each of the practices they represent. The leanness score of a level two parameter is obtained by substituting the weight and rating values for all of its indicators into Equation 1.

$$LS_{ij} = \frac{\sum_{k=1}^{n}(W_{ijk} \times R_{ijk})}{\sum_{k=1}^{n} W_{ijk}} \qquad (1)$$

LS_{ij} Leanness score of jth practice in the ith principle

W_{ijk} Importance weight of kth indicator in the jth practice of the ith principle

R_{ijk} Implementation rating of kth indicator in the jth practice of the ith principle

The weighted score of a given indicator is the product of its importance weight and implementation rating (Saleeshya and Binu, 2019). The leanness score of a given practice (level 2 parameter) is thus obtained by dividing the total weighted score of all its indicators by the total importance weights of those indicators (Saleeshya and Binu, 2019).

The arithmetic operations between two fuzzy numbers are briefly discussed to clarify how the computations were executed. The "⊗" symbol indicates the multiplication of fuzzy numbers. If the fuzzy number (a1, b1, c1) is multiplied by another fuzzy number (a2, b2, c2), the result is (a1*a2, b1*b2, c1*c2). If the fuzzy number (a1, b1, c1) is divided by another fuzzy number (a2, b2, c2), the result is (a1/a2, b1/b2, c1/c2). Similarly, the "⊕" symbol indicates the addition of fuzzy numbers. If the fuzzy number (a1, b1, c1) is added to another fuzzy number (a2, b2, c2), the result is (a1+a2, b1+b2, c1+c2) (Saleeshya and Binu, 2019).

The model calculation for the third practice of the 'Establish pull' principle is demonstrated below. Scores for all tier-two attributes are obtained using the same equation and shown in Table *6.7Table 6.7*. The leanness score for each of the total 14 leanness practices that make up the leanness portion of SLAT is then calculated similarly.

LS_{43} Leanness score of the third practice in the fourth principle

$$LS_{43} = \begin{bmatrix} (7,8,9)\otimes(0.3,0.5,0.7)\oplus \\ (2,3.5,5)\otimes(0.5,0.65,0.8)\oplus \\ (7,8,9)\otimes(0.7,0.8,0.9) \end{bmatrix} \Big/ \begin{bmatrix} (0.3,0.5,0.7)\oplus \\ (0.5,0.65,0.8)\oplus \\ (0.7,0.8,0.9) \end{bmatrix}$$

$$LS_{43} = (4.4, 5.88, 7.29)$$

Table 6.7 Fuzzy index for each practice of the 'Establish pull' principle

LS_i	LS_{ij}	W_i	W_{ij}	R_{ij}
LS_4	LS_{41}	(0.5, 0.65, 0.8)	(0.3, 0.5, 0.7)	(5, 6.5, 8)
	LS_{42}		(0.5, 0.65, 0.8)	(7, 8, 9)
	LS_{43}		(0.5, 0.65, 0.8)	(4.4, 5.88, 7.29)

6.3.3.2 Secondary assessment calculation

The same procedure is executed for each practice using the weight data for each level two parameter determined through the Delphi study. By using Equation 2, the secondary assessment for the hospital is calculated.

$$LS_i = \frac{\sum_{j=1}^{n}(W_{ij} \times R_{ij})}{\sum_{j=1}^{n} W_{ij}} \quad (2)$$

LS_i Leanness score of the ith principle

W_{ij} Importance weight of jth practice in ith principle

R_{ij} Implementation rating of jth practice in the ith principle

The model calculation for the "Establish pull" principle is shown below, and the results are represented in Table *6.8*, along with sample values for the other level one leanness parameters.

LS_4 Leanness score of the fourth principle

$$LS_4 = \begin{bmatrix} (5, 6.5, 8) \otimes (0.3, 0.5, 0.7) \oplus \\ (5, 6.5, 8) \otimes (0.5, 0.65, 0.8) \oplus \\ (4.4, 5.88, 7.29) \otimes (0.5, 0.65, 0.8) \end{bmatrix} \Big/ \begin{bmatrix} (0.3, 0.5, 0.7) \oplus \\ (0.5, 0.65, 0.8) \oplus \\ (0.7, 0.65, 0.8) \end{bmatrix}$$

$$LS_4 = (4.77, 6.28, 7.75)$$

Table 6.8 Fuzzy index for each of the LAT lean principles

LS_i	W_i	R_i
LS_1	(0.3, 0.5, 0.7)	(5, 6.5, 8.)
LS_2	(0.3, 0.5, 0.7)	(5, 6.5, 8)
LS_3	(0.3, 0.5, 0.7)	(3.67, 5, 6.33)
LS_4	(0.5, 0.65, 0.8)	(4.77, 6.28, 7.75)
LS_5	(0.3, 0.5, 0.7)	(4.33, 6, 7.67)

6.3.3.3 Tertiary assessment

Finally, by substituting the weights of each lean principle provided into Equation 3 the FLI of the hospital is calculated. FLI is the leanness of the whole hospital and represents the implementation of the various lean principles, and thus the implementation rating of the sustainability practice "Holistic implementation of the lean philosophy".

$$FLI = \sum_{i=1}^{N} \frac{R_i \times W_i}{W_i} \tag{3}$$

FLI Fuzzy lean index

R_i Implementation rating of the ith principle

W_i Importance weight of the ith principle

The model calculation for the hospital using the sample values is shown below.

$$FLI = \begin{bmatrix} (5, 6.5, 8)\otimes(0.3, 0.5, 0.7)\oplus \\ (5, 6.5, 8)\otimes(0.3, 0.5, 0.9)\oplus \\ (3.67, 5, 6.33)\otimes(0.3, 0.5, 0.7)\oplus \\ (4.77, 6.28, 7.75)\otimes(0.5, 0.65, 0.8)\oplus \\ (4.33, 6, 7.67)\otimes(0.3, 0.5, 0.7) \end{bmatrix} \Bigg/ \begin{bmatrix} (0.3, 0.5, 0.7)\oplus \\ (0.3, 0.5, 0.7)\oplus \\ (0.3, 0.5, 0.7)\oplus \\ (0.5, 0.65, 0.8)\oplus \\ (0.3, 0.5, 0.7) \end{bmatrix}$$

$$FLI = (4.58, 6.07, 7.56)$$

6.3.4 CALCULATION OF EUCLIDEAN DISTANCE

The FLI calculated is still in the form of a fuzzy number. Therefore to more practically present the results, it needs to be matched with an appropriate linguistic leanness level (Vimal and Vinodh, 2013). Several methods are available for matching the leanness level. Some of the basic techniques are (1) the Euclidean distance method, (2) successive approximation, and (3) piecewise decomposition (Guesgen and Albrecht, 2000). Guesgen and Albrecht (2000) found the Euclidean distance method to be the most commonly used and is thus employed for this study. It is simply the geometric distance between two points in the multi-dimensional space. The main advantage of the Euclidean method over other methods is that the distance between any two objects is not affected by adding new objects to the analysis (Vinodh and Vimal, 2012).

A language scale to categorise the hospital's leanness level had to be identified (Saleeshya and Binu, 2019). A scale of five points with the natural language expression set LL = {Extremely lean [EL], Very lean [VL], lean [L], fairly lean [FL], poorly lean [PL]} was chosen, which was identified from literature (Lin and Chiu, 2006). The linguistics and corresponding fuzzy numbers are shown in Table *6.9*. Then, using Equation 4, the Euclidean distance D from the FLI to each member in set LL is calculated (Lin and Chiu, 2006).

Table 6.9 Fuzzy numbers for approximating linguistic leanness scores

Leanness score	
Linguistic variable	Fuzzy number
Poorly lean (PL)	(0, 1.5, 3)
Fairly lean (FL)	(1.5, 3, 4.5)
Lean (L)	(3.5, 5, 6.5)
Very lean (VL)	(5.5, 7, 8.5)
Extremely lean (EL)	(7, 8.5, 10)

$$D(FLI, LL_i) = \left\{ \sum_{xep} \left(f_{FLI}(x) - f_{LL_i}(x) \right)^2 \right\}^{1/2} \quad (4)$$

$D(FLI, LL_i)$ Euclidean distance between FLI and LL_i

FLI Fuzzy leanness index

LL_i Corresponding fuzzy number for natural-language expression

$f_{FLI}(x)$ Triangular fuzzy number of FLI

$f_{LL_i}(x)$ Triangular fuzzy number of LL_i

Where $x =$ lower, middle, and upper triangular numbers

The model calculation for $D(FLI, LL_i)$ is shown as follows:

$D(FLI, LL_i) = \{(4.58 - 7)^2 + (6.07 - 8.5)^2 + (7.56 - 10)^2\}^{1/2}$

$D(FLI, EL) = 4.21$

$D(FLI, VL) = 1.61$

$D(FLI, L) = 1.91$

$D(FLI, F) = 5.31$

$D(FLI, P) = 7.91$

A hospital's leanness label is determined by the distances between the calculated FLI and each possible linguistic leanness score. The organisation belongs to the category of leanness with the lowest Euclidean distance value (Saleeshya and Binu, 2019). In this case, $D(FLI, VL)$ is the lowest, with a value of 1.61. The hospital is therefore deemed as "Very lean".

6.4 PROCEDURE FOR LEAN SUSTAINABILITY ESTIMATION

Following the determination of how leanness will be calculated through considering existing leanness assessment approaches, the same methodology is adopted for determining sustainability capability. The same variable and linguistic scales are used for the sustainability parameters. However, because there are only two levels of sustainability parameters (as opposed to the three used for determining leanness), the fuzzy index method is adapted to include only a primary and a secondary calculation. Additionally, different linguistic terms are used for the final index. These differences are shown through the discussion that forms this section.

6.4.1 CALCULATION OF THE FUZZY INDEX

To calculate an overall summary score for the various sustainability practices, the implementation ratings provided by the user of the tool for these practices are similarly used. Such a score represents the hospital's capability to sustain lean and can be tracked over time to determine if any improvement has been made. For the sustainability portion of the assessment tool, having adopted fuzzy modelling, this will be represented by the fuzzy sustainability index (FSI). Calculating this index starts by combining the pre-determined practice weights and the implementation ratings provided at the practice level. The scores calculated for each sustainability practice are then combined with the pre-determined weights for each sustainability area and, finally, used to calculate the FSI. Calculations are thus done at two levels to realise the final sustainability score and are referred to here as the primary and secondary calculations. The steps of each assessment are explained in detail in Sections 6.4.1.1 and 6.4.1.2 below.

6.4.1.1 Primary assessment calculation

The calculation of the FSI begins at the second level of parameters. Ratings and weights for each sustainability practice must be translated to a score for the sustainability area they represent. To obtain an area's sustainability score, the values for all practices of that area are substituted into Equation 5.

$$SS_i = \frac{\sum_{j=1}^{n}(W_{ij} \times R_{ij})}{\sum_{j=1}^{n} W_{ij}} \qquad (5)$$

SS_i Sustainability score of the ith area

W_{ij} Importance weight of jth practice in ith area

R_{ij} Implementation rating of jth practice in the ith area

The model calculation for the "Leadership" area is shown below. The results are represented in Table *6.10*, along with sample values for the other level one parameters contained within the SLAT.

SS_5 Sustainability score of the fifth area

$$SS_5 = \begin{bmatrix} (3,5,7)\otimes(0.5,0.65,0.8)\oplus \\ (3,5,7)\otimes(0.7,0.8,0.9)\oplus \\ (5,6.5,8)\otimes(0.3,0.5,0.7)\oplus \\ (7,8,9)\otimes(0.7,0.8,0.9) \end{bmatrix} \Bigg/ \begin{bmatrix} (0.5,0.65,0.8)\oplus \\ (0.7,0.8,0.9)\oplus \\ (0.3,0.5,0.7)\oplus \\ (0.7,0.8,0.9) \end{bmatrix}$$

$$SS_5 = (4.55, 6.15, 7.76)$$

Table 6.10 Fuzzy index for each of the SLAT sustainability areas

SS_i	W_i	R_i
SS_1	(0.7, 0.8, 0.9)	(3, 5, 7)
SS_2	(0.5, 0.65, 0.8)	(5, 6.5, 8)
SS_3	(0.5, 0.65, 0.8)	(5, 6.5, 8)
SS_4	(0.7, 0.8, 0.9)	(2.5, 4.25, 6)
SS_5	(0.85, 0.95, 1)	(4.55, 6.15, 7.76)
SS_6	(0.7, 0.8, 0.9)	(2.5, 4.25, 6)
SS_7	(0.7, 0.8, 0.9)	(4.14, 5.86, 7.57)
SS_8	(0.7, 0.8, 0.9)	(4.5, 5.75, 7)

SS_9	(0.85, 0.95, 1)	(4, 5.5, 7)
SS_{10}	(0.7, 0.8, 0.9)	(2, 3.5, 5)

6.4.1.2 Secondary assessment

Finally, by substituting the weights and ratings of each sustainability practice into Equation 6, the FSI of the hospital is calculated. The FSI represents the hospital's capability to sustain its implementation of lean.

$$FSI = \sum_{i=1}^{N} \frac{R_i \times W_i}{W_i} \tag{6}$$

FSI Sustainability lean index

R_i Implementation rating of the ith area

W_i Importance weight of the ith area

The model calculation for the hospital using the sample values is shown below.

$$SLI = \begin{bmatrix} (3,5,7)\otimes(0.7,0.8,0.9)\oplus \\ (5,6.5,8)\otimes(0.5,0.65,0.8)\oplus \\ (5,6.5,8)\otimes(0.5,0.65,0.8)\oplus \\ (2.5,4.25,6)\otimes(0.7,0.8,0.9)\oplus \\ (4.55,6.15,7.76)\otimes(0.85,0.95,1)\oplus \\ (2.5,4.25,6)\otimes(0.7,0.8,0.9)\oplus \\ (4.14,5.86,7.57)\otimes(0.7,0.8,0.9)\oplus \\ (4.5,5.75,7)\otimes(0.7,0.8,0.9)\oplus \\ (4,5.5,7)\otimes(0.85,0.85,2)\oplus \\ (2,3.5,5)\otimes(0.7,0.8,0.9) \end{bmatrix} \Big/ \begin{bmatrix} (0.7,0.8,0.9)\oplus \\ (0.5,0.65,0.8)\oplus \\ (0.5,0.65,0.8)\oplus \\ (0.7,0.8,0.9)\oplus \\ (0.85,0.95,1)\oplus \\ (0.7,0.8,0.9)\oplus \\ (0.7,0.8,0.9)\oplus \\ (0.7,0.8,0.9)\oplus \\ (0.85,0.85,2)\oplus \\ (0.7,0.8,0.9) \end{bmatrix}$$

$$SLI = (3.67, 5.3, 6.92)$$

6.4.2 CALCULATION OF EUCLIDEAN DISTANCE

Like the FLI, the FSI is matched to an appropriate linguistic level for sustainability using the Euclidean distance method. For sustainability, the language scale to categorise the hospital's capability to sustain lean is one with the expression set SL = {Extremely capable [EC], Very capable [VC], capable [C], fairly capable [FC], poorly capable [PC]} was chosen. The linguistics and corresponding fuzzy numbers are shown in Table *6.9*. Then, by using Equation 7, the Euclidean distance D from the FSI to each member in set LS is calculated (Lin and Chiu, 2006).

Table 6.11 Fuzzy numbers for approximating linguistic sustainability scores

Sustainability score	
Linguistic variable	Fuzzy number
Poorly capable (PC)	(0, 1.5, 3)
Fairly capable (FC)	(1.5, 3, 4.5)
Capable (C)	(3.5, 5, 6.5)
Very capable (VC)	(5.5, 7, 8.5)
Extremely capable (EC)	(7, 8.5, 10)

$$D(FSI, SL_i) = \left\{ \sum_{xep} \left(f_{FSI}(x) - f_{SL_i}(x) \right)^2 \right\}^{1/2} \tag{7}$$

$D(FSI, SL_i)$	Euclidean distance between SLI and SL_i
FSI	Fuzzy leanness index
SL_i	Corresponding fuzzy number for natural-language expression
$f_{FSI}(x)$	Triangular fuzzy number of FSI
$f_{SL_i}(x)$	Triangular fuzzy number of SL_i

Where $x =$ lower, middle, and upper triangular numbers

The model calculation for $D(FSI, SL_i)$ is shown as follows:

$$D(FSI, SL_i) = \{(3.67 - 7)^2 + (5.3 - 8.5)^2 + (6.92 - 10)^2\}^{1/2}$$

$$D(FSI, EC) = 5.55$$

$$D(FSI, VC) = 2.96$$

$D(FSI, C) = 0.62$

$D(FSI, FC) = 3.98$

$D(FSI, PC) = 6.58$

The distances between the FSI and each possible linguistic sustainability score determine the hospital's sustainability label. The category with the lowest Euclidean distance value is chosen (Saleeshya and Binu, 2019). In this case, $D(FLI, C)$ is the lowest, with a value of 0.62. The hospital is therefore deemed as "Capable" of sustaining lean.

6.5 TOOL OUTPUT

The tool output refers to the result of the assessment and how it is presented. It communicates the findings and is thus used to inform decisions regarding lean implementation and improvement, making it an important consideration.

6.5.1 OUTPUTS OF EXISTING LEANNESS ASSESSMENT APPROACHES

In the systematic review executed in Chapter 5, eight different types of outputs were found, which were categorised into four groups: 1) the report of a leanness level, which was either linguistic or numerical; 2) some visual form of results (e.g. graphs, charts, etc.); 3) a form of decision support, which included the identification of weak gaps or areas, a prioritisation or implementation strategy, or an optimised setting or design; and 4) a display of how the leanness elements are interrelated. Refer to Section 5.4.5 for a detailed discussion of the different outputs identified. Figure 5.11 also showed the frequency with which each was found in the studies reviewed.

An optimised design or setting was only used in cases using performance data. The measures being used for the SLAT meant this form of output was not considered an option. Similarly, not adopting a methodology studying the relationships and interdependencies between parameters meant reporting on these relationships was also excluded as a possibility.

The ability of the fuzzy approach to identify weak areas makes it possible to include a form of decision support in the tool. The hospital could use the weak areas identified to prioritise practices for better lean implementation. A more comprehensive improvement plan that provides the strategy for improving lean success is beyond the scope of this study. Defining such a plan would require additional considerations outside the lean's implementation, such as the cost, administrative constraints, possible benefits, time it would take to implement, and possible risks of implementing various practices (Almomani *et al.*, 2014). How the areas for improvement are identified using the fuzzy approach is explored in Section 6.5.2.

Srinivasaraghavan and Allada (2006) pointed out that for a specific direction of future improvements to be realised, it is critical to assess leanness over time instead of treating it as a one-time procedure. Thus, reporting a single score as the assessment result is of value, as it can be used to benchmark against other organisations, can be observed over time, and simplistically communicates the degree of leanness. The fuzzy approach's ability to calculate an overall score meant a leanness level could be provided. In the studies reviewed, this was done either linguistically or numerically. The fuzzy methodology calculates a numerical index, but a triangular number represents it, which may be difficult for tool users to understand. Thus, for a more intuitive result, it is matched to a linguistic score. Therefore, it was decided for the SLAT also to provide a linguistic leanness level.

While no studies using the fuzzy approach used visual graphs to represent the score, it could give further insights into the overall score and reveal the scores of the different areas and how they compare. A radar chart (the most common form of visual output) was thus also chosen to show the lean scores of the individual lean principles.

6.5.2 DETERMINING AREAS FOR IMPROVEMENT WITH THE FUZZY APPROACH

The method adopted by the fuzzy approach is used to determine which sustainability practices have to be focused on for better implementation. It involves calculating the performance scores for each assessment parameter and using them to establish its ranking score. The areas identified for improvement are based on this ranking. This section details the steps involved in executing this procedure.

6.5.2.1 Calculation of performance scores

The process of determining areas for improvement begins by calculating a fuzzy performance importance index (FPII). The FPII combines each sustainability practice's performance rating and importance weight to consider the degree to which it has been implemented and the effect an improved implementation would have on the overall sustainability score (Madhan and Suresh, 2017). Then, for example, if two sustainability practices are rated poorly in their degree of implementation, the one whose low score will have a more significant impact on the sustainability of lean in the hospital will have a lower FPII score. Therefore, the lower the FPII of a parameter is, the higher its degree of contribution (Lin and Chiu, 2006). If W_{ij} is high, the transformation $\left[(1,1,1) - W_{ij}\right]$ is low (Vinodh and Vimal, 2012). Consequently, for each leanness parameter ij, $FPII_{ij}$ is defined as:

$$FPII_{ij} = W'_{ij} \otimes R_{ij} \tag{8}$$

Where $W'_{ij} = \left[(1,1,1) - W_{ij}\right]$, W_{ij} is the fuzzy importance weight of the sustainability practice ij (Lin and Chiu, 2006)

The FPIIs of all the sustainability practices are calculated using Equation 8 above. These indices are used to identify parameters that are weak and, thus, in need of improvement. The sample calculation for the FPII of sustainability practice 'Measurement system' is shown below.

$$FPII_{11} = (3,5,7) \otimes (0.7,0.5,0.3)$$

$$FPII_{11} = (2.1,2.5,2.1)$$

6.5.2.2 Identification of areas for improvement

While the FPII numbers were calculated to help identify the biggest sustainability obstacles, the resulting index is fuzzy and, in this form, makes identifying which areas are weakest difficult (Vimal and Vinodh, 2013). Because fuzzy numbers represent many possible real numbers with different membership functions, they do not always result in an ordered set the way real numbers do (Singh *et al.*, 2006). Therefore, to identify the areas that need to be prioritised for improvement, the FPIIs must be converted to a crisp number so they can be ranked in some way (Saleeshya and Binu, 2019). In this case, the centroid method is used. Equation 5 shows how the ranking score for a membership function (a, b, c) is determined, where a, b, and c are the lower, middle, and upper numbers of a triangular fuzzy number, respectively.

$$Ranking\ score = \frac{a + 4b + c}{6}$$

Using the $FPII_{111}$ previously calculated

$$Ranking\ score = \frac{2.1 + 4 \times 2.5 + 2.1}{6} = 2.367$$

This calculation is repeated for all the remaining sustainability practices, and the ones with the lowest scores are deemed the most needed improvement.

6.6 ASSESSMENT PROCESS OVERVIEW

The process begins by performing a linguistic assessment of the various sustainability practices. The decision maker provides an implementation rating for each practice. However, for the "Holistic implementation of lean philosophy" practice, instead of directly providing an implementation rating, the supplementary assessment form for leanness is used. Using the supplementary assessment, implementation ratings are provided for each of the leanness indicators. The ratings provided for the indicators are then used to calculate and implementation rating for the "Holistic implementation of lean philosophy" practice. Once both forms have been completed, the linguistic scores are converted to relevant fuzzy numbers. These are then used to calculate the FSI and FLI by employing simple fuzzy arithmetic operations. The Euclidean distance between these scores and the various linguistic score labels is then calculated to match the indexes with a linguistic term, indicating the hospital's leanness and capability to sustain lean. These linguistic terms are reported in the tool output. The performance scores of all the sustainability practices are then calculated to identify weaker areas and provide a scope for improvement. Figure *6.7* below shows the various steps that form part of the adopted assessment methodology.

The implementation rating for the second practice is determined by calculating the FLI for leanness and is thus the only sustainability practice not directly provided by the user. Instead, they are instructed to use the indicators provided in the leanness assessment.

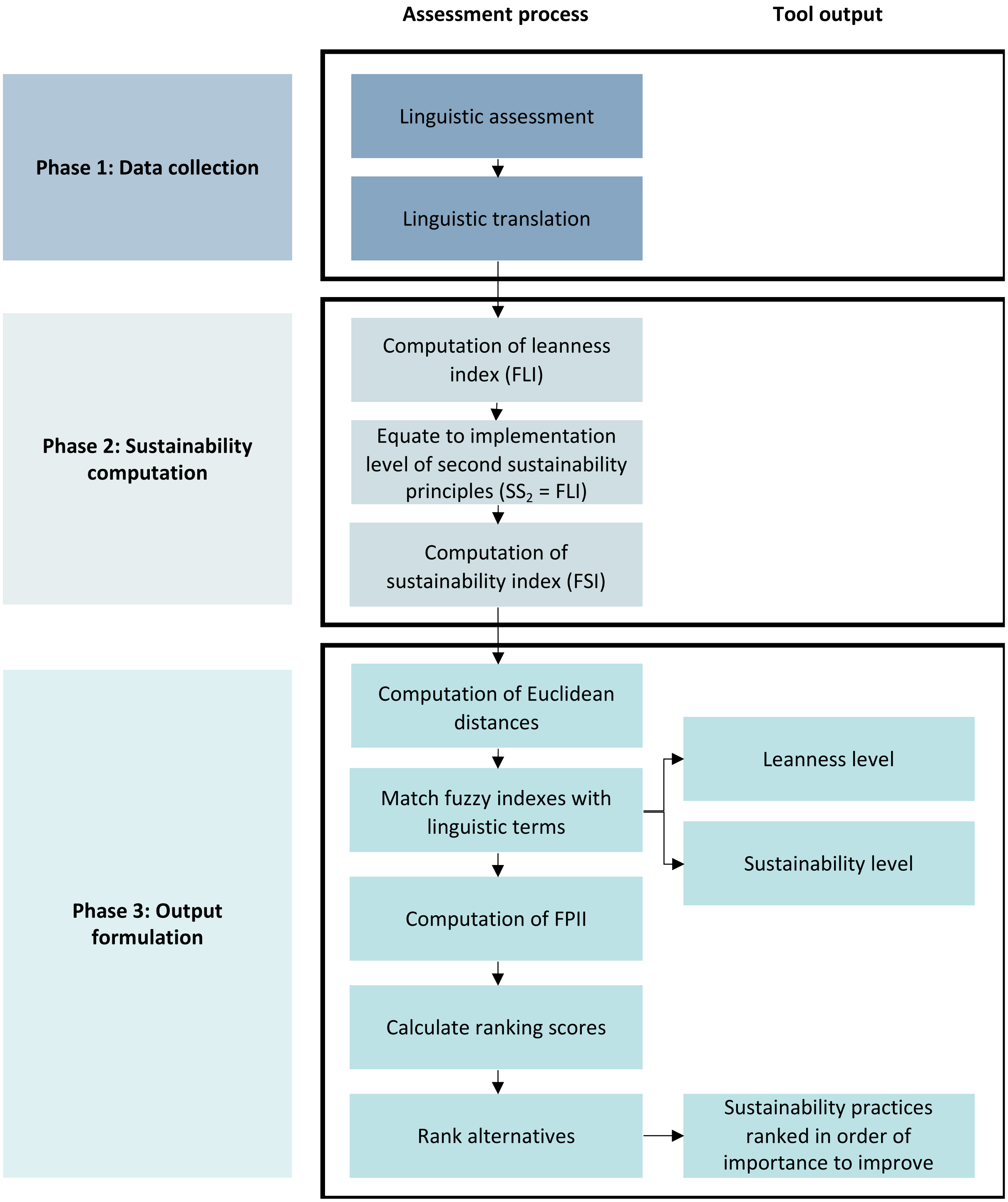


Figure 6.7 Overview of the leanness assessment process

6.7 PRELIMINARY ASSESSMENT TOOL

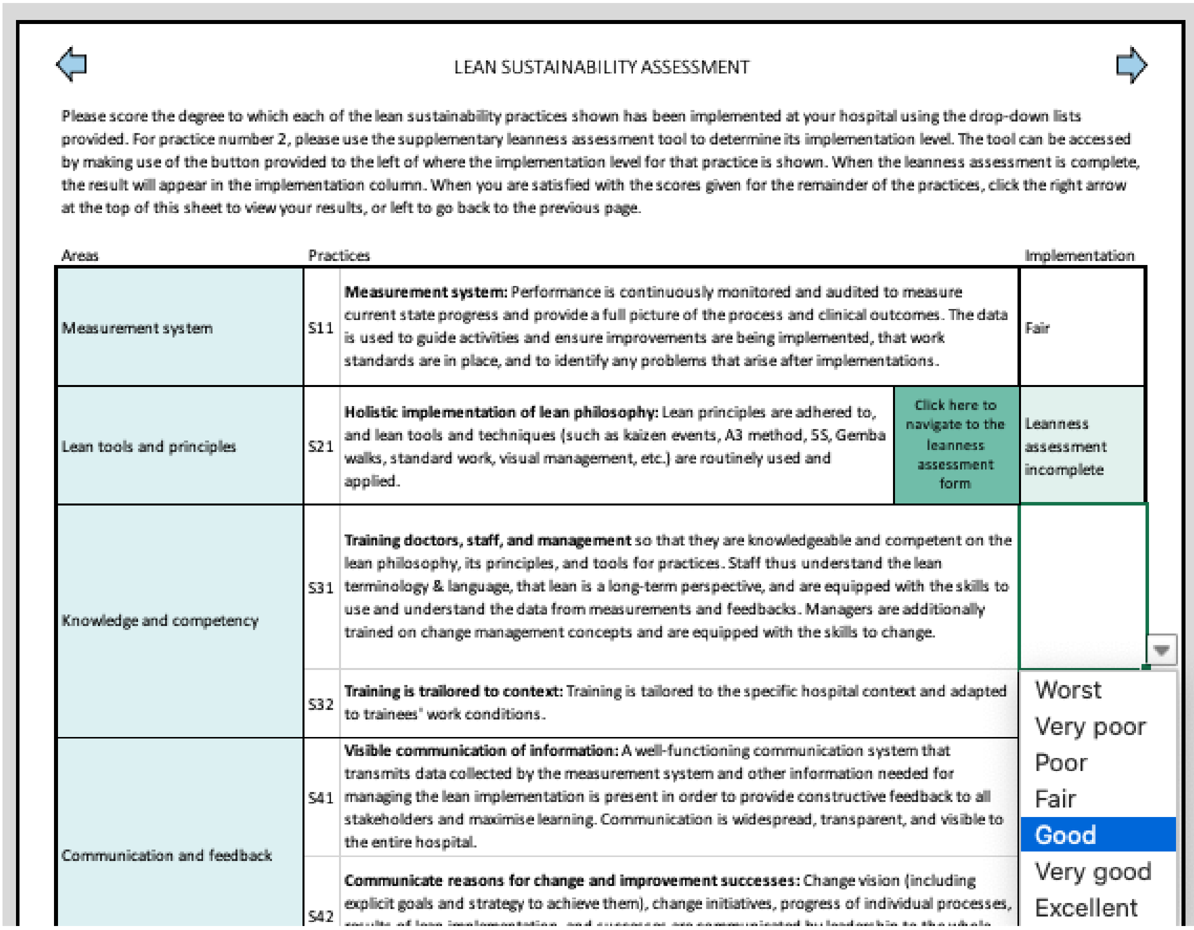
The SLAT interface contains three main sections: 1) the landing page, which offers an introduction to the tool and serves as a navigation page for the various other pages contained in the tool, 2) the assessment form, where the various areas described in Section 6.1 and shown in Tables 4.1 and 6.1 need to be assessed, and 3) the output, which presents the results from the assessment.

6.7.1 LANDING PAGE

The landing page is the first page in the tool. It offers an introduction to the tool, explains its structure, the various steps required to perform the assessment and obtain its results, and explains the output received and how to interpret them. Including this page ensures the tool is used correctly, and the results are understood. The landing page is shown in Figure E.1 in Appendix E.

6.7.2 ASSESSMENT INPUT FORMS

The tool uses user-provided ratings as its input data and thus uses assessment forms to guide these ratings. A drop-down list with linguistic terms accompanies each assessment parameter, which is used to score the degree of its implementation. The main assessment form is the sustainability assessment, and the leanness assessment serves as a supplementary assessment form for its second practice. Therefore, instead of rating that practice directly, the user is directed to another form, the leanness assessment, with additional indicators. The tool uses the ratings given for these indicators to determine the implementation rating for that second practice. The tool user needs to provide the implementation rating for each sustainability practice and leanness indicator to complete the assessment and obtain the results. Figure *6.8* shows an excerpt of the main sustainability assessment form before the completion of the leanness assessment. Figure *6.9* shows the supplementary leanness assessment form accessible through the button shown in Figure *6.8*, and Figure *6.9* shows the sustainability assessment form once the leanness assessment form has been completed.



LEAN SUSTAINABILITY ASSESSMENT

Please score the degree to which each of the lean sustainability practices shown has been implemented at your hospital using the drop-down lists provided. For practice number 2, please use the supplementary leanness assessment tool to determine its implementation level. The tool can be accessed by making use of the button provided to the left of where the implementation level for that practice is shown. When the leanness assessment is complete, the result will appear in the implementation column. When you are satisfied with the scores given for the remainder of the practices, click the right arrow at the top of this sheet to view your results, or left to go back to the previous page.

Areas	Practices			Implementation
Measurement system	S11	**Measurement system:** Performance is continuously monitored and audited to measure current state progress and provide a full picture of the process and clinical outcomes. The data is used to guide activities and ensure improvements are being implemented, that work standards are in place, and to identify any problems that arise after implementations.		Fair
Lean tools and principles	S21	**Holistic implementation of lean philosophy:** Lean principles are adhered to, and lean tools and techniques (such as kaizen events, A3 method, 5S, Gemba walks, standard work, visual management, etc.) are routinely used and applied.	Click here to navigate to the leanness assessment form	Leanness assessment incomplete
Knowledge and competency	S31	**Training doctors, staff, and management** so that they are knowledgeable and competent on the lean philosophy, its principles, and tools for practices. Staff thus understand the lean terminology & language, that lean is a long-term perspective, and are equipped with the skills to use and understand the data from measurements and feedbacks. Managers are additionally trained on change management concepts and are equipped with the skills to change.		
	S32	**Training is trailored to context:** Training is tailored to the specific hospital context and adapted to trainees' work conditions.		
Communication and feedback	S41	**Visible communication of information:** A well-functioning communication system that transmits data collected by the measurement system and other information needed for managing the lean implementation is present in order to provide constructive feedback to all stakeholders and maximise learning. Communication is widespread, transparent, and visible to the entire hospital.		
	S42	**Communicate reasons for change and improvement successes:** Change vision (including explicit goals and strategy to achieve them), change initiatives, progress of individual processes,		

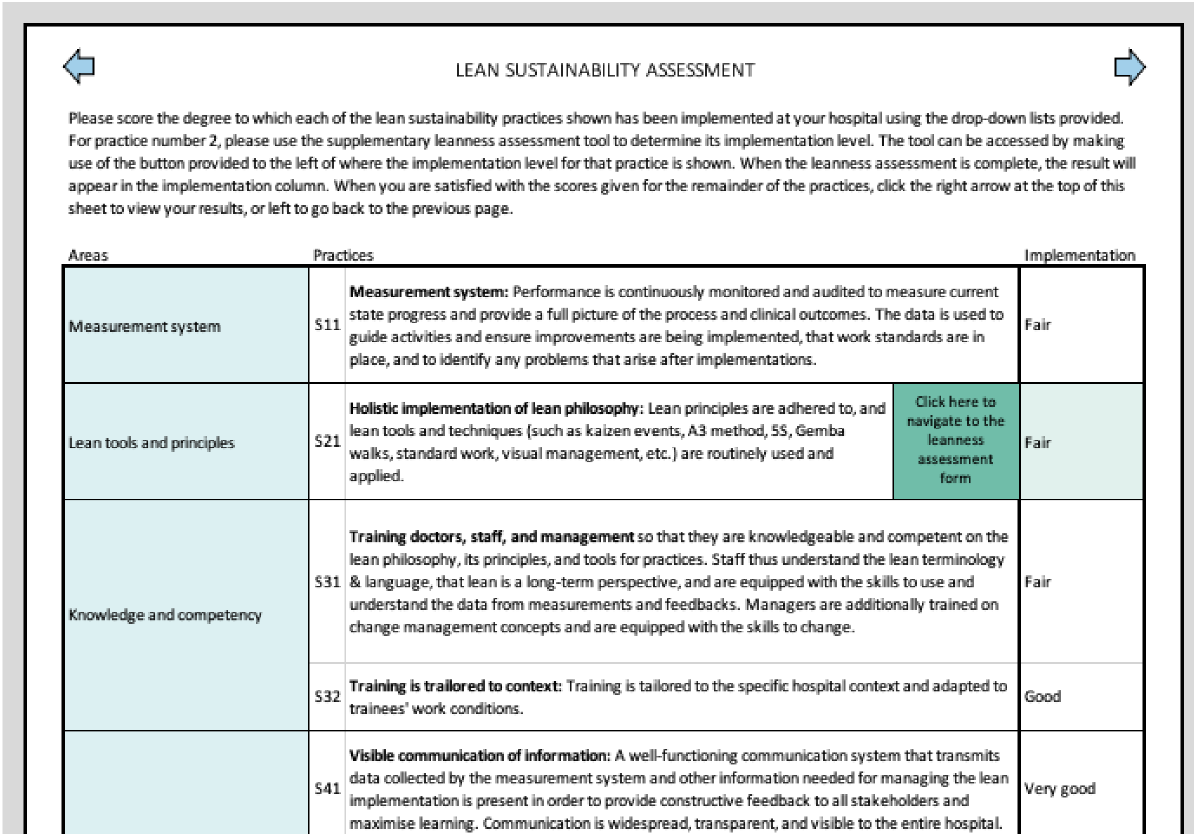
Figure 6.8 Incomplete lean sustainability assessment form

LEANNESS ASSESSMENT

Please score the degree to which each of the lean practices shown and has been implemented at your hospital using the drop-down lists provided. When you are satisfied with the scores given, click the right arrow at the top of this sheet to view your results, or left to go back to the previous page.

Principles	Practices		Indicators	Implementation
Identify value	Define customer expectations	L1	There is a formal and informal "voice of customer" system that allows close cooperation, collaboration, and information sharing with the customer in order to prioritise and adopt customer requirements, needs, and preferences.	Worst Very poor Poor Fair Good Very good Excellent
Map the value stream	Identify and eliminate wastes	L2	Process and value streams are mapped and analysed in order to classify activities as VA, NVA, or NNVA. This allows wastes to be identified so that they can be minimised, or eliminated, where possible. Tools such as value stream mapping (VSM), 5 Whys, PDCA cycle, A3 report, DMAIC, RCA are used to map the value stream and identify and eliminate wastes.	
	Workload levelling (Heijunka)	L3	Optimisation of processing sequence and reduction of process variation in order to level workload, ensuring smooth flow with no interruptions, delays, or bottlenecks.	
		L4	Execution of short- and long-term planning for resource management. This includes scheduling workers, workstations and equipment, and planning task precedence in order to maximise concurrency. Physicians are engaged in forecasting the planning process.	
		L5	Streamline processes by reducing cycle or lead time through practices such as layout optimisation, quick changeover, setup time reduction, etc. to reduce patient throughput.	

Figure 6.9 Leanness assessment form



LEAN SUSTAINABILITY ASSESSMENT

Please score the degree to which each of the lean sustainability practices shown has been implemented at your hospital using the drop-down lists provided. For practice number 2, please use the supplementary leanness assessment tool to determine its implementation level. The tool can be accessed by making use of the button provided to the left of where the implementation level for that practice is shown. When the leanness assessment is complete, the result will appear in the implementation column. When you are satisfied with the scores given for the remainder of the practices, click the right arrow at the top of this sheet to view your results, or left to go back to the previous page.

Areas		Practices		Implementation
Measurement system	S11	**Measurement system:** Performance is continuously monitored and audited to measure current state progress and provide a full picture of the process and clinical outcomes. The data is used to guide activities and ensure improvements are being implemented, that work standards are in place, and to identify any problems that arise after implementations.		Fair
Lean tools and principles	S21	**Holistic implementation of lean philosophy:** Lean principles are adhered to, and lean tools and techniques (such as kaizen events, A3 method, 5S, Gemba walks, standard work, visual management, etc.) are routinely used and applied.	Click here to navigate to the leanness assessment form	Fair
Knowledge and competency	S31	**Training doctors, staff, and management** so that they are knowledgeable and competent on the lean philosophy, its principles, and tools for practices. Staff thus understand the lean terminology & language, that lean is a long-term perspective, and are equipped with the skills to use and understand the data from measurements and feedbacks. Managers are additionally trained on change management concepts and are equipped with the skills to change.		Fair
	S32	**Training is trailored to context:** Training is tailored to the specific hospital context and adapted to trainees' work conditions.		Good
	S41	**Visible communication of information:** A well-functioning communication system that transmits data collected by the measurement system and other information needed for managing the lean implementation is present in order to provide constructive feedback to all stakeholders and maximise learning. Communication is widespread, transparent, and visible to the entire hospital.		Very good

Figure 6.10 Completed lean sustainability assessment form

6.7.3 ASSESSMENT TOOL OUTPUT

The output of the SLAT developed consists of three main elements: the sustainability assessment result, the leanness assessment result, and a ranking of sustainability areas for improvement. The sustainability assessment result is given as a linguistic score indicating the degree to which the hospital is capable of sustaining lean. A five-level linguistic scale makes up the possible output options, including: extremely capable, very capable, fairly capable, or poorly capable. The leanness assessment results include a linguistic leanness score and a radar chart comparing the scores of the different lean principles for further detail. The leanness score given once again is one of a five-level linguistic scale. The options include: extremely lean, very lean, fairly lean, or poorly lean. Lastly, a list of practices in ranking order of importance for improving the hospital's capability to sustain lean is provided. Figure *6.11* gives an example output for a lean hospital.

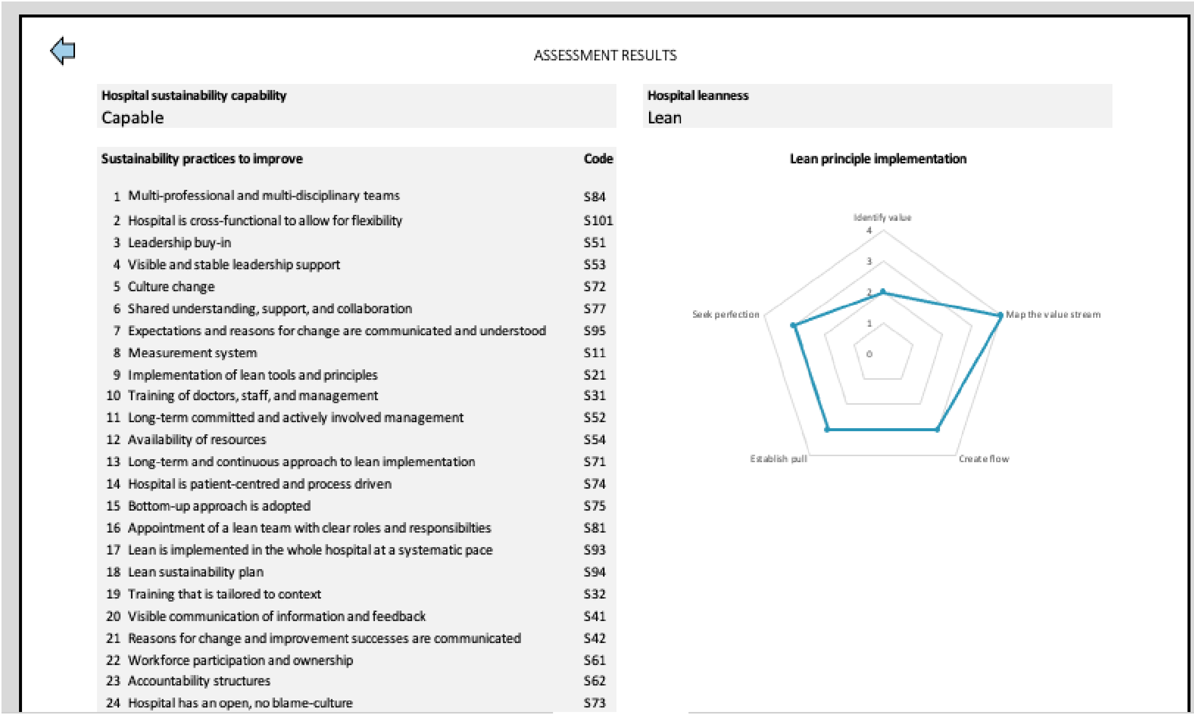


Figure 6.11 Example tool output

6.8 CHAPTER 6: CONCLUSION

This chapter detailed the final phase of the tool development process, which involved structuring the tool and its assessment parameters using the information obtained in Chapter 4 and Chapter 5. First, the assessment parameters were developed and organised into overarching sustainability practices and subsidiary indicators for leanness. Thereafter, existing approaches to leanness assessments were considered, and fuzzy logic was chosen as the methodology to measure the parameters and calculate overall sustainability and leanness. It was then decided to present the findings in the form of two linguistic scores, accompanied by a radar chart to display the implementation of different lean principles and a ranking of the sustainability practices that need to be prioritised for improvement. Following this process, the preliminary tool was realised, concluding the "preliminary tool development" stage of the research. Chapter 7 commences the "tool evaluation" stage, which evaluates this tool to improve its applicability and is used to determine the relative importance weights of the assessment parameters. In the preliminary tool, all the parameters are equally weighted. The results from Chapter 7 are used to determine their relative weights, which are then updated for the final version of the tool.

Chapter 7 Tool evaluation

This chapter outlines the evaluation process executed to verify and validate the preliminary tool developed in Chapter 6. The evaluation aims to compare the preliminary SLAT to its design objectives and ascertain how well it addresses the problem it is aimed at, allowing for refinement of the tool in the process. The evaluation feedback is used to improve and make changes to the SLAT in an iterative process, leading to a final version of the tool.

The chapter begins by first discerning the difference between verification and validation, the two aspects of evaluation being considered, and outlining the procedure followed in Section 7.1. The participant selection is then explained in Section 7.2, followed by an explanation of the questionnaire used to carry out the evaluations in Section 7.3 and the stopping criteria used for the study in Section 7.4. After that, the feedback obtained, changes made, and assessments carried out for each evaluation round are detailed in Sections 7.5 and 7.6. A summary of the execution of the tool evaluation is then provided in Section 7.7. Lastly, the chapter is concluded in Section 7.8.

7.1 EVALUATION STRATEGY

Evaluation is the systematic study of a research artefact to determine its usefulness, effect, or impact (Wynekoop and Russo, 1997). It is intended to assess the appropriateness of the tool given the context it was developed for and therefore ensures that the artefact effectively solves the problem (Recker, 2005). A Delphi study using relevant and knowledgeable subject matter experts (SMEs) was executed to ensure a comprehensive evaluation and demonstration of the SLAT.

7.1.1 VERIFICATION AND VALIDATION

Verification and validation are the methods used to confirm that a design meets the necessary specifications and fulfils its intended purpose, respectively (Maropoulos and Ceglarek, 2010). Thus, verification and validation aim to increase the credibility of the artefact developed by providing evidence of correctness and suitability. Verification is the process used to evaluate whether or not the artefact developed complies with the regulations, specifications, or conditions imposed at the start of the development phase. Validation, on the other hand, is the process used to establish evidence that the artefact accomplishes its intended use requirements (Maropoulos and Ceglarek, 2010). The verification will therefore confirm the correctness of the SLAT on a conceptual level, while the validation will ensure that it is suitable for practical use. These two processes can be used together to ascertain whether the design objectives are met, and the problem is addressed, thus making up the two aspects of the evaluation executed. The focus of each is shown in Figure 7.1.

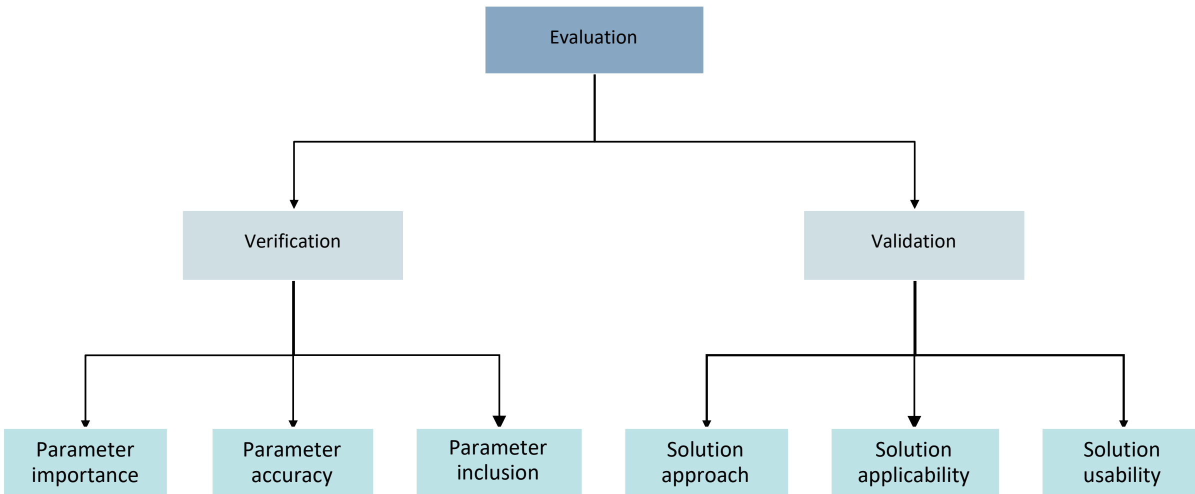


Figure 7.1 Evaluation criteria

The verification aimed to assess each of the SLAT assessment parameters in the following dimensions:

1. **Importance:** The degree to which each assessment parameter contributes to either leanness or the hospital's capability to stay lean (depending on the parameter in question).
2. **Correctness:** The assessment parameter is correctly formulated for the context of South African public hospitals.
3. **Relevance:** The assessment parameter is relevant to the aspect it supports and is included in the relevant assessment area.

The ensure validity of SLAT and demonstrate its ability to meet the design objectives, questions related to three different aspects of the tool were formulated:

1. **Approach**: The solution approach itself contributes to solving the problem being addressed.
2. **Applicability:** The tool achieved is applicable to public hospitals in South Africa.
3. **Usability:** The overall structure of the tool is logical and easy to follow for the intended user.

7.1.2 EVALUATION PROCESS

Delphi study with verification and validation questions addressing the criteria outlined in Section 7.1.1 was used to execute the evaluation. A simplified version of the Delphi procedure outlined in Chapter 2 is shown in Figure 7.2 to aid navigation of the chapter.

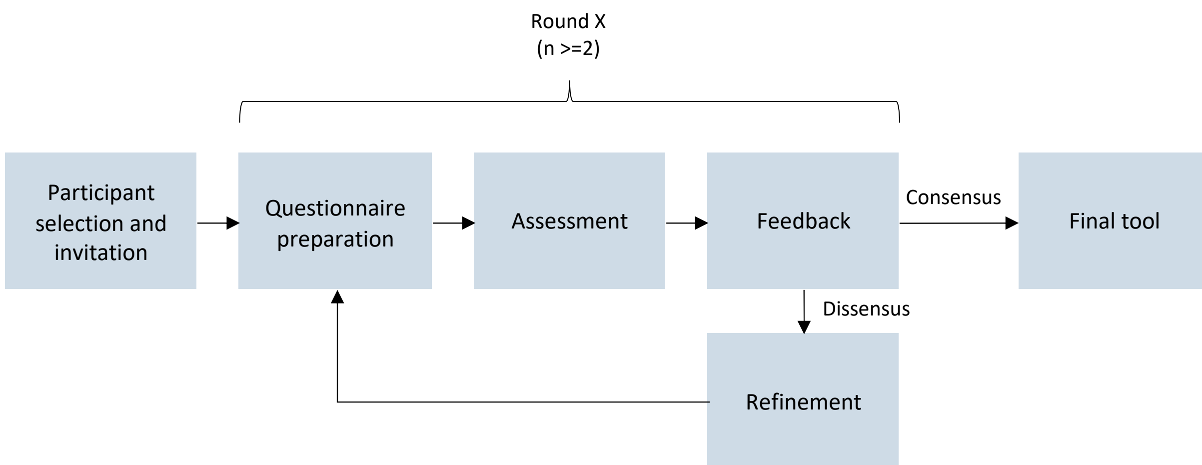


Figure 7.2 Evaluation process

The evaluation process thus begins by creating a panel of participants that provided feedback for all the subsequent stages of the process. Relevant SMEs are contacted to participate in the study, and those who agreed to participate form the panel. The SME selection criteria and recruitment process followed are outlined in Section 7.2. Following its completion, the first round of evaluation can begin.

A single evaluation round involves using the questionnaire developed at the onset of that round to gather the independent participant opinions. Section 7.3 explores the preparation of the questionnaire used for the first round, its questions and overall structure is discussed. This questionnaire was updated for each feedback stage, but the overall questionnaire structure and questioning approach remained the same. Once all assessment responses are received, the data is reviewed and aggregated into a summary report issued to each expert as feedback. The summary report provides all participants' feedback, including the score given and any comments provided. This summary report is anonymous and does not reference the identity of the experts who provided the responses.

The panellists then review the summary report and can use the opportunity to update their responses, given the opinion of the rest of the group. No changes to the tool were made between the assessment and feedback stages of the process, as any suggested changes had to be accepted by the participants first. The summary report also allows participants to provide further explanations for any scores differing from the opinion of the rest of the group. These comments would be provided to other participants in the next evaluation round to motivate a different score.

Following the updated responses and feedback received from the summary report, changes can be made to the tool to reflect the findings. The stopping criteria must then be evaluated to discern if another evaluation round is needed. The assessment, feedback, and refinement process repeat until all stopping criteria (discussed in Section 7.4) are met. Once satisfied, the evaluation is concluded, and the tool is deemed acceptable for its intended use.

7.2 SELECTION OF SUBJECT MATTER EXPERTS

Due to the influence hospital context has on lean's performance, and the importance of considering specific macro-level (system) contexts, such as differences in funding models between different governments when implementing it (Flynn *et al.*, 2019), the relevance of the SLAT practices could vary depending on a given context. In this research, the SLAT was refined and validated for a specific environment. However, during this process, the generalisability and how the results may be different for other contexts was also considered.

For the purposes of the SLAT validation and refinement, the specific context of South African public hospitals was chosen as a focal environment. When considering this context, it was clear that while a substantial amount of literature describes the use of lean in healthcare, the focus is mainly on developed countries. Less is known about its use in developing countries (Kelendar *et al.*, 2020). South Africa, in particular, is still facing many challenges negatively impacting its healthcare quality and much still needs to be done to address the issues of poor-quality service delivery (Maphumulo and Bhengu, 2019). South African hospitals, like the rest of the world, started applying lean to achieve the much-needed improvements. However, its use is still in its infancy, and there is a lack of literature focusing on this context. Furthermore, in South Africa, most of the population (72%) rely on the public system for their care (Statistics South Africa (Stats SA), 2020). But the public health performance and outcomes remain poor (Malakoane *et al.*, 2020). Thus, due to the relevancy of public hospitals in South Africa and South Africa's need for lean research, it formed the focus of the evaluation.

Consequently, the evaluation process aimed to engage with SMEs who have been involved with implementing lean in public hospitals in South Africa. Using SMEs with this experience ensures accurate and relevant feedback for the context. Since no practical demonstration is being executed, people with this experience and knowledge of how it would work in practice were necessary to validate it. Additionally, it was required that they have headed such projects or be at a management level in a hospital. Such experts will still have valuable insights regarding lean in healthcare in general, but their feedback will highlight instances where further contextualisation might be necessary for particular health systems.

Respondents were only required to give their opinion on public hospitals in South Africa in general. Therefore, participants were required to have experience implementing lean in a hospital, but there was no requirement for them to work at or with one currently.

According to Cantrill, Sibbald and Buetow (1996), the size and composition of Delphi panels should be governed by the purpose of the investigation, using pragmatic consideration to determine its composition. In their review of Delphi techniques used in health services research, the included number of experts ranged from 4 to 3000. Similarly, in their analysis of system reviews of Delphi techniques used in health sciences, Niederberger and Spranger (2020) found that panel sizes varied from 3 to 731 experts. Thus, there appears not to be an optimal participant number. Therefore, the aim was to explore the network of possible participants as extensively as possible and include the maximum available number of relevant participants in the panel for the study.

To gather relevant SMEs that could form the Delphi panel, an initial investigation into public hospitals in South Africa that have rolled out lean initiatives needed to be done. A consulting company that has done significant work implementing lean in this context was contacted to query the hospitals and professionals they have worked with and are aware of working with lean. Through this, nine potential SMEs were identified. The SMEs were contacted via e-mail to request an initial introductory meeting. Five of the initial nine experts responded and were willing to discuss the prospect further. The study was explained in more detail in this meeting, and their participation in the Delphi process was requested. The experts were also asked if they have any further knowledge of other experts with a similar scope of expertise that could contribute to the study so that additional possible candidates can be contacted. Through this process, three more people were contacted, who was then also asked the same question. However, to their knowledge, they were unaware of other people working on lean in public hospitals in South Africa.

Additionally, every SME suggested engaging with the original institution contacted. The possible network was thus considered exhausted after twelve people were contacted.

While more professionals may have engaged with lean in this context, these twelve were the only ones who had headed lean initiatives, not just participated in them. Of these twelve SMEs contacted, seven people (58%) responded after multiple follow-up e-mails. Additionally, after an initial response, two of these seven failed to continue communication and never proceeded with the first round, resulting in five SMEs forming the final panel. The profiles of the group of participants used and their relevant experience is summarised in Table 7.1. The profiles show how many years of experience the experts have with lean in healthcare and whether this experience comes from working at a hospital and implementing lean (internal) or whether the experience comes from an external role (such as consulting). Lastly, any additional relevant experience is also shown.

Table 7.1 SMEs selected for the evaluation process

SME	Years of experience with lean healthcare	Internal/ external	Other relevant experience
SME 1	> 7 years	Internal	Working as a lean facilitator in a hospital. Current role is to institutionalise a culture of continuous improvement. Co-facilitated many lean workshops in hospitals.
SME 2	> 10 years	Internal	PhD research on CSF for lean initiation in hospitals. Action research for a Master's degree in public health on lean implementation in a rural hospital OPD. Attended several lean workshops & training courses.
SME 3	> 3 years	Internal	Worked on lean continuous improvement implementation with various sectors. Previously worked for a company with 50 years of experience in CI implementation with a background in 20 Keys implementation.
SME 4	> 5 years	External	Completed Masters on the following topic: Developing a maturity model to facilitate the sustainability of lean implementations in hospitals.

			Co-developed and co-presented a lean healthcare short course at a private hospital in the North West.
SME 5	> 15 years	External	PhD research on Toyota SA in 1983-1986. Partner at a management consulting business that has consulted in lean to many SA and international companies from 1990. Continued research into lean, particularly in public healthcare in SA, with a primary focus on effectively introducing lean to a multi-site operation, like a provincial health system.

7.3 QUESTIONNAIRE PREPARATION

The questionnaire issued to participants is used to determine the accuracy and importance of the assessment parameters that the tool uses and to evaluate whether it meets the research aim and solution objectives. A questionnaire that suitably assesses these aspects thus had to be developed. This section discusses the questioning approach and overall structure of such a questionnaire.

Firstly, the assessment parameters themselves are evaluated. A separate question was presented for each set of parameters. Each question addresses the verification criteria outlined in Section 7.1.1. Question 1 tests these aspects for the sustainability factors, while Question 2 tests these aspects for the leanness factors. Question 1 thus considers a) the importance of a given practice regarding its contribution to supporting sustainable lean implementation, b) if any practices need to be adjusted or removed, and c) if there are any necessary practices not yet considered. The importance of a given practice is gauged by asking the respondent the degree to which, in their opinion, a given practice contributed to the overall capability to sustain lean by making use of the following scale: *(1) Very low; (2) Low; (3) Fairly low; (4) Medium; (5) Fairly high; (6) High; or (7) Very high*.

To assess aspects b) and c), respondents were asked to indicate any additional practices not included that need to be considered or any other adjustments that should be made to any of the existing practices in a space provided at the end of the question. Here, a more open-ended approach to questioning was taken to allow unstructured comments and feedback on the tool parameters.

Question 2 is structured in the same way. However, the respondent must specify a given indicator degree of contribution to overall leanness (instead of sustainability). The respondent is also asked to use the space provided at the end of the question to indicate any cases where they find additional practices not included that need to be considered or any other adjustments that should be made to any of the existing indicators. Question 1 and 2 were thus directed at the tool verification.

The remainder of the questionnaire was targeted at determining whether the solution approach addresses the problem and meets the solution objectives. An agreement scale was used for these questions. The SME could specify the extent to which they agreed with a statement provided using the following five-point Likert scale: *(1) Strongly disagree; (2) Disagree; (3) Neutral; (4) Agree; (5) Strongly agree*. A criterion is considered met if there are no cases of disagreement for any of its questions. Additionally, open-ended questions for further suggestions and recommendations were used.

To assess the validity of the LAT along all the dimensions outlined, statements for three questions aimed at each validation dimension were included. Table 7.2 below compares the specific questions and the objectives it seeks to validate.

Table 7.2 Validation questions

Questions	Objectives
Question 3	
3.1. An assessment of the degree to which sustainability practices have been implemented is a good approach to address the problem.	Solution approach
3.2. There is a need for a tool that reveals the practices necessary to sustain lean in hospitals.	Solution approach
3.3. There is a need for a tool guiding the assessment of leanness designed from a hospital perspective specifically.	Solution approach
3.4. Adopting practices that aid a more long-term implementation of the lean principles could lead to improved outcomes from lean implementation in hospitals.	Research aim
Question 4	
4.1. The sustainability assessment parameters are representative of the necessary real-world practices that would enable hospitals to better sustain lean.	SO2

4.2. The leanness assessment parameters are representative of the necessary real-world lean practices relevant to hospitals at a facility level.	SO2
4.3. The SLAT can be used to identify practices that need to be improved to better sustain lean.	SO4
4.4. The overall tool predicts the hospital's capability to sustain lean with a fair degree of accuracy.	SO3
4.5. The leanness score provided predicts the hospitals leanness with a fair degree of accuracy.	SO3
4.6. The tool allows the user to assess the extent to which the practices that support the sustainable implementation of lean and lean's principles have been adopted.	SO1
Question 5	
5.1. Managers of hospitals who have implemented lean will find it easy to use the SLAT to assess the capability of the hospital to sustain lean.	SO5
5.2. The structure of the SLAT is easy to understand and follow.	SO5
5.3. It is easy to navigate the SLAT.	SO5
5.4. It is easy to interpret the results of the assessment.	SO5

Lastly, a space is provided at the end to allow for any additional comments or recommendations. Also included as part of the questionnaire was an ethics agreement, shown in Appendix A. To summarise, following five questions were used to evaluate the work presented:

Question 1: Assesses the correctness and importance of the sustainability assessment parameters included.

Question 2: Assesses the correctness and importance of the leanness assessment parameters included.

Question 3: Assesses the degree to which the tool is needed and addresses the problem at which it is aimed. This question is intended to validate that the tool meets the research aims.

Question 4: Assesses the degree to which the tool is applicable to practice.

Question 5: Assesses the degree to which the tool is usable.

7.4 STOPPING CRITERIA

The iterations of a Delphi study are brought to a conclusion when pre-defined stopping criteria are met (Cantrill, Sibbald and Buetow, 1996). Thus, the last thing considered before commencing the first evaluation round was the criteria to determine whether another is needed. The criteria used are usually related to “consensus”, “stability”, or both (Cantrill, Sibbald and Buetow, 1996). There is no uniform definition of what these criteria have to be. Both consensus and stability have been defined and measured in different ways. In their systematic review of Delphi techniques from various health sciences sectors, Niederberger and Spranger (2020) found that different definitions and measurements for reaching consensus were used. Measures such as per cent agreement, units of central tendency, or a combination of per cent agreements within a specific range and for a certain threshold were used (Niederberger and Spranger, 2020). Jünger *et al.* (2017) found that most studies conceptualised consensus using statistical measures which depended on the type of rating used in the study.

The Delphi study aims to develop a tool that meets the design objective and is as accurate as possible. Given the different verification and validation questions, three stopping criteria were set. Firstly, the tool could not be considered valid if there was disagreement with any of the verification questions (Questions 3-5). Thus, all participants must provide a score of 3 or higher for all the statements in Questions 3, 4, and 5. If this was achieved, the verification was considered next. A measure of central tendency, the interquartile range (IQR), was used for the importance ratings. An IQR of 1 or less had to be achieved for all assessment parameters. Lastly, the tool development could not be concluded if there were still areas of concern or suggestions that needed to be addressed. Thus, the stopping criteria were conceptualised as follows:

1. Each participant has provided a score of 3 or higher for all Questions 3 – 5,
2. An IQR of 1 or less has been achieved for all assessment parameters in Questions 1 and 2, and
3. No more changes are suggested.

7.5 ROUND 1

The first round of assessment was performed on the preliminary tool presented in Chapter 6. This section details the responses and comments received from the initial evaluation round, the summary report issued, and changes made to the tool based on this feedback.

7.5.1 ASSESSMENT FEEDBACK

Question 1 was focused on the verification of the sustainability assessment parameters. Importance ratings were given as a score from 1 to 7 using the scale discussed in Section 7.3 , the median responses for each practice ranged from four to seven. The IQR of these ratings was greater than in 16 cases, showing dissensus in opinion for 53% of the assessment parameters. In addition to importance ratings, several comments and suggestions were received regarding the parameters. Table 7.3 demonstrates these comments along with the SME it received from and the practice to which it relates. The complete responses are shown in Table F.1 in Appendix F.

Table 7.3 Round 1 Question 1 comments

Sustainability practice and code	SME	Comments
Training doctors, staff, and management (S31)	SME 2	Must be ongoing training and not just limited to doctors, “staff”, and “management”.
Team are multi-professional and multidisciplinary (S84)	SME 2	Depends on the role and the purpose of the team.
Gain stakeholder commitment and buy-in (S95)	SME2	More appropriate under “Workforce empowerment”.
General	SME 5	We have to have “commitment” that is visible and not just verbal.
General	SME 5	We need stability of leadership. If committed senior people move, even if replaced by “good” people, it signals that the initiative is not all that important. If movement does happen, e.g. upon retirement of the CEO, a period of handover must show that the lean transformation exercise is not only because of the person leaving.
General	SME 5	‘Culture’ is a very loose term, so I have difficulty relating to it in the above. What do we mean by culture? What kind of culture sustains lean, and how do we achieve that culture? We don’t want a culture that is dependent on a few people, but equally, it is unlikely that a ‘lean culture’ can survive without the seniors modelling the behaviour desired within the culture.

Question 2 focused on verifying the leanness assessment parameters included in the LAT. These responses can be found in Table F.2 in Appendix F. Again, a scale ranging from 1 to 7 was used. The medians for these parameters ranged from three to seven, and the IQR was greater than one for only nine assessment parameters (35%). In addition to the importance ratings, several comments and suggestions regarding their accuracy and applicability were also received. Table 7.4 demonstrates these comments along with the SME it received from and the practice to which it relates.

Table 7.4 Round 1 Question 2 comments

Leanness indicator and code	SME	Comments
A formal and informal "voice of customer" system is in place for close cooperation, collaboration, and information sharing with the customer, allowing their requirements, needs, and preferences to be adopted and prioritised (L1)	SME 2	Some examples need to be listed otherwise the indicator could be easily misunderstood.
	SME 3	The patients in a government hospital often aren't open to constructive communication and can only be engaged to a certain extent. So our focus is more on using their feedback to guide our decisions, but not quite cooperation. However, this is the case when we consider the next person in our processes as our customer. I think inexperienced implementors can get confused.
The processing sequence is optimised, and its variation is reduced to level workload for smooth flow without interruptions, delays, or bottlenecks (L3)	SME 3	I agree it is important. However, I believe most managers wouldn't understand what it means or how to achieve it. Perhaps you could use laymen's terms?
Usage of automated tools to enhance processing time (L6)	SME 2	Automation/automated tools may not always be possible in hospitals, especially in public sectors, to "create flow". It shouldn't affect the degree of "leanness".
	SME 3	While the use of automation is great, resource scarcity and long processes filled with red tape make this less important. Autonomation, i.e. automation of processes with a human touch (e.g. A seamless system of daily measurements) is more attainable.
Productivity is measured, and optimisation tools are used to improve resource productivity. Quality is not infused at the cost of productivity (L7)	SME 2	Provide examples [of optimisation tools].
	SME 3	Quality is not infused at the cost of productivity - I think this could perhaps be stated better? A balance of quality and

		productivity is required. You will easily find the imbalance to one side or the other, both having negative effects.
Maintenance techniques such as TPM are employed to reduce disruptions caused by tool and equipment downtime. Staff are also trained to maintain competency in providing uninterrupted care without error (L8)	SME 2	+Andons.
	SME 3	This point is very "equipment" focused. I think you could personalise it to, e.g. Patient flow. It is normally clinical professionals in charge of managing the equipment, and their asses management skills aren't a priority. Perhaps rather effective asset management processes?
To quickly adapt to changes, there is flexibility and adaptability in the service provided, as well as flexibility in the workforce, layout, and set-up (L14)	SME 2	May not always be possible in public sectors "tender system" and should not determine degree of leanness.
	SME 3	Government institutions aren't allowed to select suppliers. They are dependent on the tendering system. Many times the suppliers have no interest in engaging and blacklisting a supplier is not that easy and largely ineffective. I do agree that one should engage and discuss performance.
Visual management (such as Kanban) is used to manage inventory levels and patients as they move through the system so that inventory levels and overproduction waste is minimised for better material, patient, and workflow (L16)	SME 5	'Visual management' has a narrow focus (i.e. mentioning Kanban). VM is broader in providing simple and timeous feedback on key parameters which 'drive' the improvement trajectory, as well as those that are important but do not directly 'move the needle'.
A pull system is used to determine the supply of sundries and jobs. The hospital thus executes healthcare demand analysis and forecasting. It has a capacity management system/ programme to ensure new work is started only when there is demand for it and the staff has spare capacity (L17)	SME 3	While this is a good strategy, it is extremely difficult in government hospitals. The data quality is low and Covid has changed all patterns. Also, due to the shortage of staff, most hospitals tend to run "rich" at this stage to protect against understaffing during a wave. I think this is a good point to keep for the future, but I would note it as a current obstacle.
	SME 2	The focus for pull is too much on supplies/ sundries/ inventory instead of also including what happens in the service delivery points, e.g. outpatient departments with "patients" as the "production unit".
Inventory and work-in-process (WIP) items must be limited while ensuring that the requisite materials and information are available for a smooth workflow. Therefore, inventory and material logistics are managed to monitor and reduce inventory and lot	SME 3	JIT - applicable in certain cases, but not all. For example, inefficient supply chain processes make small lost sizes difficult to manage. These processes also cannot be changed at hospital level. Perhaps some more customised examples of JIT? Therefore also, a zero inventory system is highly unlikely and extremely risky in our country.

sizes, and just- in-time (JIT) techniques are employed (L18)		
Techniques are employed to minimise the number of patients waiting in the system (L19)	SME 3	Be more specific with examples.
Supplier delivery and responsiveness (L20, L21, L22)	SME 2	May not always be possible in public sectors "tender system" and should not determine degree of leanness.

Question 3 was focused on validating the tool in general as a solution. There was no disagreement concerning any of its statements. However, it was clear that some changes would need to be made to improve the applicability and usability of the tool. There were four instances of disagreement for Question 4 (statements 4.2, 4.3, 4.5, and 4.6), which focused on its applicability. Regarding statements 4.3 and 4.6, SME 2 indicated that more information was needed on the results page to address this. SME 3 disagreed with statements 4.2 and 4.5 due to the improvements that still needed to be made based on their feedback. In this case, this would be addressed by implementing the suggested changes. For Question 5 (the tool's usability), two SMEs disagreed with statement 5.1, and there was another case of disagreement when it came to statement 5.4, once again relating to the request for more information on the results page that was also requested in statements 4.3 and 4.6. The complete responses given can be found in Table F.3 of Appendix F.

7.5.2 SUMMARY REPORT

Once all participant feedback had been received, a summary of the responses was compiled. This was issued to the panel in a summary report, which allowed each SME to compare their response to those given by the rest of the panel. At this point, no changes were made to the tool. It was simply an opportunity for the participants to reflect on their scores and update them.

According to Cantrill, Sibbald and Buetow (1996), statistical feedback is the most commonly used technique for providing feedback. However, editing techniques such as content analysis can summarise qualitative responses (Cantrill, Sibbald and Buetow, 1996). In the case of this study, the two methods were combined. Scored responses were reported statistically, and any commentary received was provided as text. No editing techniques were used, as all the comments received were given to the other participants in full.

Participants were provided with the other SMEs' scores, their scores, and the median score. An excerpt from the summary report is shown in Figure 7.3. An agreement scale accompanied the qualitative feedback so participants could react to them. Whether any suggested changes should be included could be determined from this. Furthermore, the participants were asked to motivate any score outside one deviation from the median. These motivations would be provided to the rest of the participants in the following round.

1.1. PRACTICE RATINGS		SME1	SME2	SME3	SME4	YOUR RESPONSE	MEDIAN	REVISED SCORE
AREAS	PRACTICES							
Measurement system	**Measurement system:** Performance is continuously monitored and audited to measure current state progress and provide a full picture of the process and clinical outcomes. The data is used to guide activities and ensure improvements are being implemented, that work standards are in place, and to identify any problems that arise after implementations.	6	7	7	6	6	6	
Lean tools and principles	**Holistic implementation of lean philosophy:** Lean principles are adhered to, and lean tools and techniques (such as kaizen events, A3 method, 5S, Gemba walks, standard work, visual management, etc.) are routinely used and applied.	5	6	4	7	5	5	
Knowledge and competency	**Training doctors, staff, and management** so that they are knowledgeable and competent on the lean philosophy, its principles, and tools for practices. Staff thus understand the lean terminology & language, that lean is a long-term perspective, and are equipped with the skills to use and understand the data from measurements and feedback. Managers are additionally trained on change management concepts and are equipped with the skills to change.	5	7	5	7	5	5	
	Comments: *SME2*: Must be ongoing training and not just limited to doctors, "staff" and "management"			Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	Training is tailored to the hospital's context and adapted to trainees' work conditions.	6	6	7	N/A	5	6	

Figure 7.3 Round 1 summary report excerpt

Responses for the summary report can be found in Appendix G. Following the summary report, the IQR for all assessment parameters were below 1, indicating consensus had been reached regarding their importance. However, the first and third stopping criteria had not yet been met, and several changes still had to be incorporated. The changes made to the tool to address commentary received are discussed in Section 7.5.3. After which, another round of assessment is executed.

7.5.3 TOOL REFINEMENT

Once the summary report feedback had been received, the commentary provided and agreed upon could be addressed by making appropriate changes to the tool. Changes were made to the assessment parameters and the tool itself, with the majority relating to the assessment parameters. Changes were made in response to suggestions and for reasons not prompted by participant feedback but from further reflection. The changes and the reasoning for their incorporation are provided in Table 7.5. for the sustainability practices and in Table 7.6.

Table 7.5 Round 2 sustainability assessment parameters changes

Assessment parameter	Change made and reason
Ongoing training on the lean philosophy, its principles, and tools for practices, as well as the skills necessary to fully integrate it into everyday practice Previously: **Training doctors, staff, and management** so that they are knowledgeable and competent on the lean philosophy, its principles, and tools for practices. Staff thus understand the lean terminology & language, that lean is a long-term perspective, and are equipped with the skills to use and understand the data from measurements and feedback. Managers are additionally trained on change management concepts and are equipped with the skills to change.	Updated to reflect feedback received that training must be ongoing and not just limited to doctors, "staff", and "management" as it previously was
Stable support: The management/leadership guidance and support of the change program is stable over time Previously: **Visible and stable support:** The management/leadership guidance and support of the change program is visible and stable over time.	Leadership visibility is reflected in the "long-term visibly committed and actively involved management" practice and thus redundant here. This practice was therefore updated to reflect only the stability of leadership.
Lean is part of daily work. Lean is viewed by staff as something valuable to daily operations as opposed to something that takes time away from their routine activities and adds to their workload. The hospital thus achieves a culture where lean is part of daily work and is viewed as a valuable job resource to them and their patients. **Willing to change.** Culture is open and willing to change to adopt the new mentality fully. Previously: **There is a culture change:** All stakeholders adopt the new mentality of making quality an integral part of everyday work and view lean as a job resource as opposed to something that takes time away from their routine activities. The culture must therefore be open and willing to change to adopt the new mentality fully. All stakeholders are committed to change and invest the necessary time into adapting to the approach.	Previously "there is a culture change", it was deemed that this practice was too broad. The ultimate goal of all the sustainability practices is to change the hospital culture. This area represents characteristics of the culture that, if achieved, will help support a successful and sustainable lean implementation. Thus, two new practices were added in lieu of the former one.
Clear lean vision and goals: There is a change vision that communicates explicit, clear, and measurable goals for lean implementation. Previously: **Strategic planning:** There is a transformation or improvement plan that has been customised to the hospital's context. The plan has a clear change vision that communicates explicit, clear, and measurable goals and contains the set of steps to be followed in implementing to achieve them (action plan). The link between the organisational goals, key objectives, and lean project activities is clear.	Action plan (i.e., a set of steps to be followed to achieve change vision and goals) was removed from the practice. The practice name was changed from "strategic planning" to "Clear vision and goals" following feedback that it is difficult to compile a plan and actions since the process is very variable and dependent on staff and their acuity. Thus, it seldomly goes according to plan. The feedback indicated that having a strategic vision and yearly goals is still important. Therefore, these aspects of the practice remained.

Contextual influence is understood: The differences in macro level contexts, such as differences in funding between different provincial governments or differences in insurance models, etc., need to be accounted for when implementing lean. Additionally, differences between hospitals and the manufacturing industry must be accounted for when implementing tools. For example, a zero inventory approach is challenging to achieve and risky in healthcare. Previously: **Contextual influence is understood:** There is an understanding of how and why the complexity of context influences the use of lean and the process of its normalisation.	The practice was updated to clarify what contextual influences need to be understood.

Table 7.6 Round 1 leanness assessment parameters changes

Assessment parameter	**Change made and reason**
Feedback on quality/service from follow-ups are used to prioritise and adopt care to patient requirements, needs, and preferences. Previously: There is a formal and informal "voice of customer" system that allows close cooperation, collaboration, and information sharing with the customer in order to prioritise and adopt customer requirements, needs, and preferences	The indicator was changed to more clearly specify that a "voice of customer" system – the term that was previously used – means using feedback obtained from follow-up activities. It was also updated to no longer include in-depth cooperation with the customer, as it was agreed that patients in a government hospital often aren't open to constructive communication to that degree.
Equalise work distribution among employees or better match staffing to demand in areas where the demand cannot be managed (such as the ED) to ensure smooth flow through the process with no interruptions, delays, or bottlenecks. Cross-training employees (where possible), ensuring a flexible workforce, and standardising processes between floors and departments can aid this. Previously: Optimisation of processing sequence and reduction of process variation in order to level workload, ensuring smooth flow with no interruptions, delays, or bottlenecks.	Reworded indicator to make more sense for managers and provide more clarity on how this can be done following agreement from SMEs that the previous wording may have made it difficult for managers to understand.
Indicator "Usage of automated tools to enhance processing time" was removed	Following the agreement of all SMEs that autonomation is not always possible in hospitals and thus should not affect the degree of leanness, this indicator was removed
Productivity is measured and improved through lean tools (such as VSM, 5S, Kanban, Kaizen, etc.). Previously: Productivity is measured, and optimisation tools are used to improve resource productivity. Quality is not infused at the cost of productivity.	Examples of lean tools that can be used to improve productivity were provided following feedback received that this would be helpful. The indicator was further updated to reflect that it refers more to measuring productivity to

	ensure changes are working than to whether specific productivity-enhancing tools are being used – as most lean tools aim to improve productivity. "Quality is not infused at the cost of productivity" was removed from this indicator due to comments that this may not apply to hospitals and that quality of care should not be ignored.
Effective asset management processes are used to prevent disruptions in flow. TPM can be used to prevent tool and equipment breakdowns, while Andon and staff competency training can ensure the provision of uninterrupted care without error. <u>Previously:</u> To prevent tools and equipment from breaking down and disrupting flow, maintenance techniques such as TPM are employed to reduce equipment downtime. Staff are also educated and trained to maintain competency in providing uninterrupted care without error.	Andon was added as a tool following the agreement of all SMEs. The indicator was updated to be more personalised to patient flow by referring to "effective asset management processes", as was agreed between the SMEs in the previous round.
Indicator "Quality of materials received from suppliers is ensured through supplier selection and development activities, such as providing technical and financial assistance and training in quality issues" was removed	The indicator was removed as all SMEs agreed that the tender system makes it challenging to apply in the public sector and, thus, should not determine leanness.
Visual management (such as Kanban) is used to provide timeous feedback on key parameters. The information is used to manage improvements, inventory levels, and patients as they move through the system. Thus, continuous improvements can be made, and inventory levels and overproduction waste can be minimised for better material, patient, and workflow. <u>Previously:</u> Visual management (such as Kanban) is used to manage inventory level and patients as they move through the system so that inventory levels and overproduction waste is minimised for better material, patient, and workflow.	Visual management to provide timeous feedback on key parameters was added to the indicator to reflect its use for managing improvements instead of only using it to manage flow following comments received that the indicator was too narrow.
A pull system determines where care providers spend their time and where patients move in the system. The hospital thus executes healthcare demand analysis and forecasting. It has a capacity management system/ programme to ensure new work is started only when there is demand for it (when the patient needs it) and the staff has spare capacity. <u>Previously:</u> A pull system is used to determine the supply of sundries and jobs. The hospital thus executes healthcare demand analysis and forecasting and has a capacity management system or programme to ensure new work is started only when there is demand for it and the staff has spare capacity.	The indicator was changed so that there is less focus on supplies, sundries, and inventory, following the agreement that it focused too much on those aspects
Work-in-process (WIP) items must be limited while ensuring that the requisite materials and information are available for a smooth workflow. Material logistics are therefore managed to monitor and reduce items waiting. <u>Previously:</u> Inventory and work-in-process (WIP) items must be limited while ensuring that the requisite materials and information are available for a smooth flow of work. Inventory and material logistics are therefore managed to monitor and reduce inventory and lot sizes, and just-in-time (JIT) techniques are employed.	This practice has been updated to only reflect limiting work in process items (such as samples that need to be tested, etc.) and not inventory, as feedback that this is not applicable in all cases was received.
Indicator "A strategic network is utilised to exercise a zero inventory system. Suppliers must thus have minimum delivery lead time and on-time delivery to	Indicator removed following agreement on comments that this is not always

ensure hospital consumables are delivered when needed or in emergency cases" was removed	possible in public sectors due to the tender system and that a zero inventory system is highly unlikely in risky in South Africa

Further changes made that related to the tool itself and not its assessment parameters included:

1. A space to capture the hospital information on the introduction page.
2. Guidelines on how often the assessment should be carried out on the introduction page.
3. Further information on the results page for each of the sustainability practices by means of a drop-down list.

7.6 ROUND 2

The second evaluation round was performed on the refined tool with the changes discussed in Section 7.5.3. The responses and comments received from the second assessment and its summary report are discussed, as well as changes made to the tool based on the feedback received.

7.6.1 UPDATED QUESTIONNAIRE

Following these changes, the refined SLAT had to be evaluated. The same structure of the first-round questionnaire was followed, with the addition of a scale to indicate if the expert was satisfied with any changes made. Additionally, if motivations for why a participant thinks the median score should be lower or higher were previously received, it was included for the participants to reflect on when they scored again. Respondents only had to provide a new score if no longer agreed with their previous score and wanted to update it.

The agree-disagree scale was given to validate the changes, while other experts' motivations were given to justify why they may disagree. An example of how these were incorporated is shown in Figure 7.4.

1.1. PRACTICE RATINGS		MEDIAN	YOUR PREVIOUS SCORE	NEW SCORE
AREAS	PRACTICES			
Measurement system	**Measurement system:** Performance is continuously monitored and audited to measure current state progress and provide a full picture of the process and clinical outcomes. The data is used to guide activities and ensure improvements are being implemented, that work standards are in place, and to identify any problems that arise after implementations.	6	6	
Lean tools and principles	**Holistic implementation of lean philosophy:** Lean principles are adhered to, and lean tools and techniques (such as kaizen events, A3 method, 5S, Gemba walks, standard work, visual management, etc.) are routinely used and applied.	5	5	
Knowledge and competency	**Ongoing training** on the lean philosophy, its principles, and tools for practices, as well as the skills necessary to fully integrate it into everyday practice.	5	5	
	Motivation for a higher rating: *SME2 (Rating: 7)*: Training is critical. How else would people who haven't heard about lean learn about lean especially at the outset?			
	Changes made: Updated to reflect feedback received that training must be ongoing and not just limited to doctors, "staff" and "management" as it previously was.	Strongly disagree / Disagree	Neutral	Agree / Strongly agree
	Training is tailored to the hospital's context and adapted to trainees' work conditions.	6	5	

Figure 7.4 Round 2 assessment questionnaire excerpt

7.6.2 ASSESSMENT FEEDBACK

After the second assessment round, the median responses to Question 1 now range from five to seven. Previously the lower median was 4. The percentage of IQRs greater than one increased to 3%. However, this related to one of the added parameters. Additionally, four more comments were received, which are demonstrated in Table 7.7. The complete responses can be found in Table H.1 in Appendix H.

Table 7.7 Round 2 Question 1 comments

Sustainability practice and code	SME	Comments
A bottom-up approach is adopted (S77)	SME 5	It is extremely difficult, if not impossible, to overcome the red tape that would allow a system of monetary rewards in the public sector. Even if achieved, it would become the basis for disputes, corruption and allegations of favouritism. Recognition, however, is essential so that behaviours of continuous improvement are "seen" and appreciated. This should become part of the supportive behaviours exhibited by managers to subordinates.
Contextual influence is understood (S94)	SME 3	I firmly believe that "understanding" only comes from doing. The buy-in is thus really just to support the "experiment" of applying lean.
Contextual influence is understood (S96)	SME 2	The description provided is still not clear. Why would you say there are differences in funding between provincial governments if they are funded through the same mechanism from Treasury? Perhaps use a different example to explain this, or say "the funding SOURCES for some hospitals may differ (some receive grants and others do not).

Culture (S7)	SME3	I agree that the culture we are talking about should be defined. Such a culture includes self-accountability, people that are problem solvers, people that strive for the best, people that highlight issues rather than hide them

Only one case of disagreement was received for the changes made to the sustainability parameters, practice S96 (Contextual influence is understood). The SME disagreed with the change because they were still unsatisfied with its description (also reflected in the comments in Table 7.7). A further refinement of this description was suggested in the summary report, which is discussed in Section 7.6.3. However, the rest of the changes discussed in Section 7.5.3 were kept.

Question 2 focused on verifying the leanness assessment parameters included in the LAT. All responses to Question 2 can be found in Table H.2 in Appendix H. The medians for these parameters ranged from four to seven. Previously the lowest median was three. The percentage of IQRs that was greater than one again saw an increase, with dissensus in one parameter. Table 7.8 also demonstrates the additional comments received for the leanness practices and the SME from which it was received.

Table 7.8 Round 2 Question 2 comments

Leanness indicator code	SME	Comments
Workplaces are organised and standardised with the application of an activity policy (such as 5S) to help keep work areas clean, tidy, and uncluttered (L8)	SME 2	Rather state “Effective asset and inventory management…”.
Number of patients waiting in the system is minimised (L18)	SME 2	State the example “such as samples that need to be tested” just after “Work in process (WIP) items”.

Only one of the changes to the leanness assessment parameters received a response disagreeing with its incorporation. The SME was not yet satisfied with the description, and their suggested change for indicator L8 is shown in Table 7.8.

Questions 3 through 5 only presented one case where an SME did not agree with one of the validation statements, the usability statement “Managers of hospitals who have implemented lean will find it easy to use the SLAT for assessing the capability of the hospital to sustain lean". The comments provided for why the SME disagreed was that it could not be determined without observing a practical implication. When further queried about the response, it was clear that no further improvements could be made to the tool to improve this aspect. It was merely a case of being unable to explicitly give an opinion without observing it in practice. Thus, it was not flagged as something that should influence the stopping criteria as being met, as additional round would not change the score.

7.6.3 SUMMARY REPORT

Once all second assessment round feedback had been received, a summary report was compiled. Feedback was structured the same way as for the first round, where scored responses were given statistically, and any commentary received was provided as text. In this round, suggested changes based on the feedback received were also included so participants could indicate whether they agreed with its inclusion. All the suggested changes, based on the comments received in the second assessment round, are shown in Table 7.9 and Table 7.10.

Table 7.9 Round 2 suggested sustainability practice changes

Assessment parameter	Suggested change
Rewards and recognition: Improvements are recognised by celebrating successes and rewarding employees based on implemented improvement ideas or performance goals achieved. A structured incentive system that is correlated to the performance achieved concerning the overall objectives pursued and supported by accurate measurement mechanisms can be implemented.	Remove the "reward" aspect of this practice based on the comments received from SME5 shown in Table 7.7.
Contextual influence is understood: The differences in macro level contexts, such as differences in funding between different provincial governments or differences in insurance models, etc., need to be accounted for when implementing lean. Additionally, differences between hospitals and the manufacturing industry need to be taken into account when implementing tools. For example, a zero inventory approach is difficult to achieve and risky in healthcare.	Change the description to: "Organisational characteristics that influence the effectiveness of lean's implementation must be taken into account when deciding on the implementation strategy. Aspects include the hospital's drive to improve processes and the staff's current knowledge and experience in process improvement initiatives. Additionally, the differences between hospitals and the manufacturing industry must be considered when implementing tools. For example, a zero inventory approach is difficult to achieve and risky in healthcare."

Table 7.10 Round 2 suggested leanness practice changes

Assessment parameter	Suggested change
Reduce delays and interruptions: Effective asset management processes prevent flow disruptions. TPM can be used to prevent tool and equipment breakdowns, while Andon and staff competency training can ensure uninterrupted care without error is provided.	SME2 suggested changing the practice to "Effective asset and inventory management…".
Minimise inventory and patients waiting: Work in process (WIP) items must be limited while ensuring that the requisite materials and information are available for a smooth workflow. Material logistics are therefore managed to monitor and reduce items waiting.	SME 2 suggested including the example "such as samples that need to be tested" after "work in process (WIP)".

Only one of the changes shown in Table 7.9 and Table 7.10 was not unanimously accepted. Three SMEs agreed with the change suggested for *Rewards and recognition*, while one disagreed and another strongly disagreed. The reason given for not wanting to remove rewards was that "One shouldn't change this just because of current red tape in public sector for granting monetary reward. Rewards can and should also be in non-monetary form as well. Several public hospital do indeed give non-financial rewards. A simple policy change could remove the red-tape of monetary reward, then your tool will have to change if you never included "reward". The tool must stand the test of time". Therefore, after consulting with the experts a compromise was made where "rewards" was removed from the practice name, because the reason for using rewards is to recognise employees for their contributions. However, rewards remained in the description as an example of how it can be achieved. This change means rewards is one way to achieve recognition, but does not have to be done. Other forms of rewards that are non-monetary can also be used.

Responses for the summary report can be found in the Appendix I. Following this summary report, the IQR for all assessment parameters was below one, indicating consensus for the relative importance of the parameters had been reached. Additionally, no further changes were suggested, and the validation criteria had all been satisfied. Thus, all stopping criteria were met and the study could be concluded. The final accepted changes were included in the tool, resulting in the final validated and verified version, which is presented in Section 7.7.

7.7 EVALUATION SUMMARY

Throughout the evaluation process, 22 changes were made to the preliminary tool. Three of these related to the tool presentation and the remaining changes were made to the assessment parameters. Three of the parameters were outrightly removed (all of these were related to leanness), while the other 15 changes were adjustments to the tool to make them more applicable. Of the 15 changes, seven related to the sustainability practices and eight to the leanness practices. There were no cases where additional parameters were suggested by the SMEs. Additionally, 18 of the overall 22 changes were made after the first round, showing that few concerns remained after the initial tool refinement.

Following the conclusion of the Delphi study, the agreed-upon importance weightings for the assessment parameters could be included into the tool's calculations. The membership function shown in Figure *6.6* was used to convert the importance ratings to fuzzy numbers used in the tool. Table 7.11 shows the associations that were used to translate the median responses to a triangular fuzzy number to be used in the assessment calculations.

Table 7.11 Fuzzy numbers for approximating importance ratings

Importance weighting	
Median response	Fuzzy number
Very low (VL)	(0, 0.05, 0.15)
Low (L)	(0.1, 0.2, 0.3)
Fairly low (FL)	(0.2, 0.35, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Fairly high (FH)	(0.5, 0.65, 0.8)
High (H)	(0.7, 0.8, 0.9)
Very high (VH)	(0.85, 0.95, 1.0)

Lastly, the satisfaction of all validation criteria confirmed that the final collection of practices and the tool developed to assess it meets all the solution objectives outlined in Section 3.5. The final collection of assessment parameters and their importance weights can be found in Table 7.12 and Table 7.13. A discussion of these finding is presented in Chapter 8. The updated introduction page can be found in Appendix J. No changes were made to the tool's functioning throughout the study; thus, that aspect remained unchanged.

As part of the evaluation process, the tool was sent to the SMEs so its functioning could be tested and used to answer the validation questions. One SME commented, “I did the entire tool according to where we are currently, and I feel the results were very accurate”. However, for an additional level of validation, various inputs were tested to see if the expected output was given.

If the leanness assessment tool has not been completed, no results can be presented. Thus, if this is the case, the resulting output displayed in Figure 7.5 indicates this. Alternatively, if the leanness assessment is completed but the sustainability assessment is not, the leanness results are presented, but the sustainability results still indicate that the assessment is incomplete, and no practices are ranked. Figure 7.6 displays the output shown for such a case. Additionally, the use of the drop-down list for further detail is optional. Thus, no information is provided if no practice is selected. A sample output of a lean hospital capable of sustaining lean is shown Figure 7.7 with no additional information requested.

Figure 7.8 displays an output where the entire assessment for a very lean hospital capable of sustaining lean is complete. A sustainability practice has been chosen from the drop-down list, and the additional requested information is provided.

Different inputs were also tested to see if the ranking worked correctly. If a practice’s implementation was changed to poor after being rated highly, it moved higher on the list of ranked practices. Following these additional validation tests, the tool was again deemed valid.

7.8 CHAPTER 7: CONCLUSION

This chapter presented the evaluation process executed to verify and validate the preliminary tool developed in Chapter 6. A Delphi study using experts with knowledge of lean’s application in South African public hospitals showed the ability of the SLAT to meet the design objectives and address the problem. The information obtained from the SMEs was presented, and the necessary changes made according to their suggestions were explained. Through two rounds of feedback, the tool output and the applicability of the assessment parameters were improved, and their importance weights were determined. The final tool, with relative importance weights, was realised following this process. Thus, concluding the “tool evaluation”, “tool refinement”, and “final tool presentation” stages of the research. Chapter 8 commences the “discussion and conclusion” stage by discussing the findings from the evaluation process.

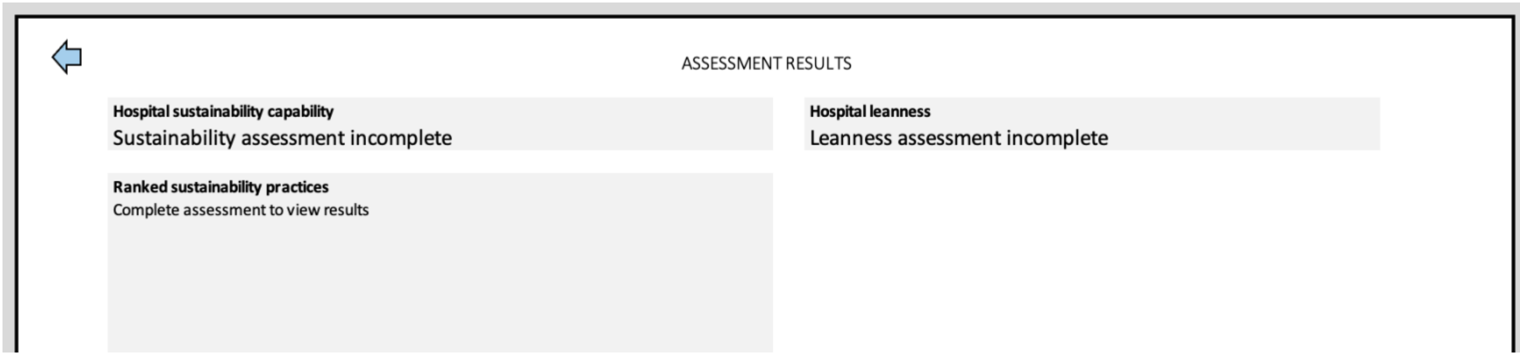


Figure 7.5 Incomplete leanness ratings output

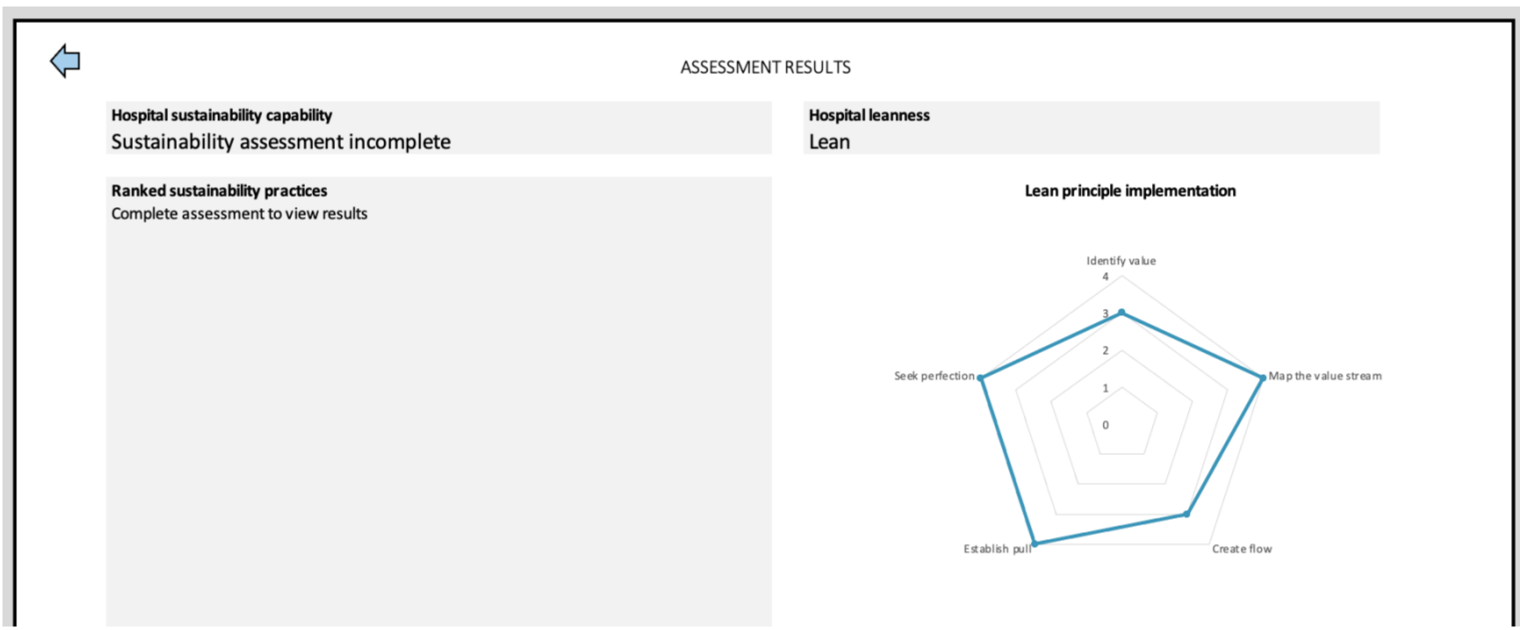


Figure 7.6 Incomplete sustainability ratings output

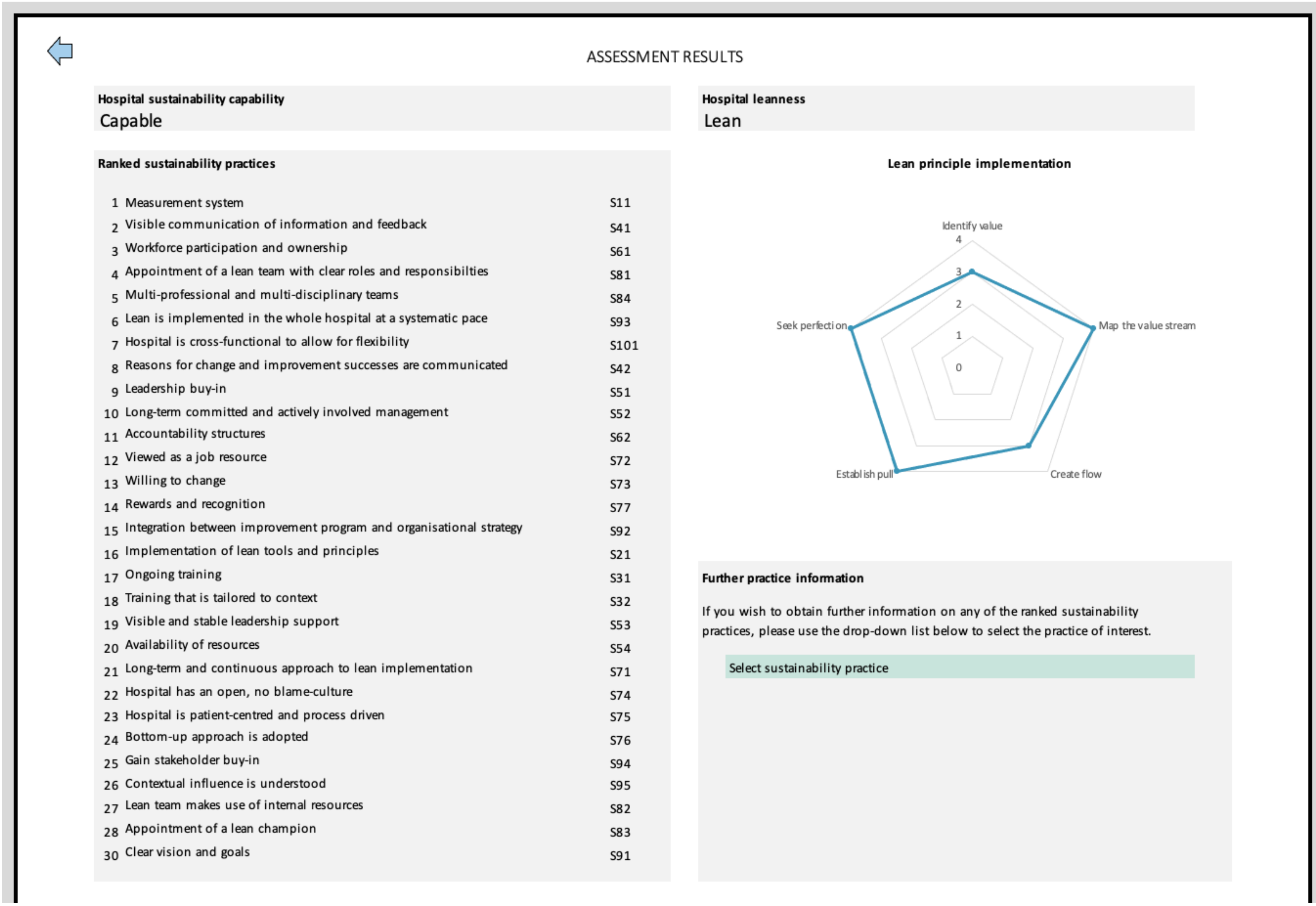


Figure 7.7 Output of complete SLAT with no practice selected

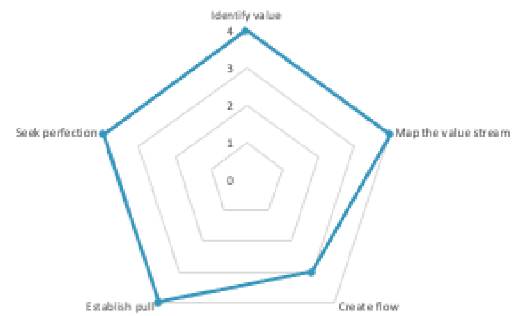
ASSESSMENT RESULTS

Hospital sustainability capability
Capable

Hospital leanness
Very lean

Ranked sustainability practices		**Code**
1	Visible communication of information and feedback	S41
2	Workforce participation and ownership	S61
3	Appointment of a lean team with clear roles and responsibilties	S81
4	Multi-professional and multi-disciplinary teams	S84
5	Lean is implemented in the whole hospital at a systematic pace	S93
6	Hospital is cross-functional to allow for flexibility	S101
7	Measurement system	S11
8	Reasons for change and improvement successes are communicated	S42
9	Leadership buy-in	S51
10	Long-term committed and actively involved management	S52
11	Accountability structures	S62
12	Viewed as a job resource	S72
13	Willing to change	S73
14	Rewards and recognition	S77
15	Integration between improvement program and organisational strategy	S92
16	Implementation of lean tools and principles	S21
17	Ongoing training	S31
18	Training that is tailored to context	S32
19	Visible and stable leadership support	S53
20	Availability of resources	S54
21	Long-term and continuous approach to lean implementation	S71
22	Hospital has an open, no blame-culture	S74
23	Hospital is patient-centred and process driven	S75
24	Bottom-up approach is adopted	S76
25	Gain stakeholder buy-in	S94
26	Contextual influence is understood	S95
27	Lean team makes use of internal resources	S82
28	Appointment of a lean champion	S83
30	Clear vision and goals	S91

Lean principle implementation



Further practice information

If you wish to obtain further information on any of the ranked sustainability practices, please use the drop-down list below to select the practice of interest.

Measurement system

KPIs designed to adequately measure the hospital's current state performance and target goals for value stream improvements must be clearly defined. The should be continuously measured as part of a well-defined follow-up routine and made available to all stakeholders.

Figure 7.8 Completed SLAT with practice selected

Table 7.12 Final collection of sustainability practices and their importance

Areas	Practices	Importance weight
Measurement system	**Measurement system:** Performance is continuously monitored and audited to measure current state progress and provide a full picture of the process and clinical outcomes. The data is used to guide activities and ensure improvements are being implemented, that work standards are in place, and to identify any problems that arise after implementations.	(0.7, 0.8, 0.9)
Lean tools and principles	**Holistic implementation of lean philosophy:** Lean principles are adhered to, and lean tools and techniques (such as kaizen events, A3 method, 5S, Gemba walks, standard work, visual management, etc.) are routinely used and applied.	(0.5, 0.65, 0.8)
Knowledge and competency	**Ongoing training** on the lean philosophy, its principles, and tool for practices, as well as the skills necessary to integrate it into everyday practice	(0.5, 0.65, 0.8)
	Training is tailored to the hospital's context and adapted to trainees' work conditions.	(0.7, 0.8, 0.9)
Communication and feedback	**Visible communication of information:** A well-functioning communication system that transmits data collected by the measurement system and other information needed for managing the lean implementation is present in order to provide constructive feedback to all stakeholders and maximise learning. Communication is widespread, transparent, and visible to the entire hospital.	(0.7, 0.8, 0.9)
	Communicate reasons for change and improvement successes: Change vision (including explicit goals and strategy to achieve them), change initiatives, progress of individual processes, results of lean implementation, and successes are communicated by leadership to the whole hospital to align and engage people in change.	(0.7, 0.8, 0.9)
Leadership	**There is leadership buy-in:** Top management understands the benefits of lean and is assured of its effectiveness.	(0.85, 0.95, 1.0)
	Long-term committed and actively involved management: Management actively participates in day-to-day continuous improvement activities, spends time providing guidance, leadership, and oversight of staff (both frontline and medical) and jointly work with them to resolve problems and implement improvements. Leaders use their time to work and prioritise lean initiatives in addition to routine activities.	(0.7, 0.8, 0.9)
	Stable support: The management/leadership guidance and support of the change program is visible and stable over time.	(0.85, 0.95, 1.0)

	Availability of resources: Management ensures sufficient resources are available for implementation, such as adequate human resources to support it and funding for training and education, external consultants, resources for data analysis, workshops, or incentives.	(0.5, 0.65, 0.8)
Workforce empowerment	**Participation:** Professionals at all levels of the organisation (frontline staff and clinical staff, management, physicians, etc.) are committed and engaged in the design and implementation of lean. This means real-time, active participation, cooperation, and responsibility in the process. Every person is encouraged to continuously identify value in their work environment and contribute to generating solutions to problems.	(0.7, 0.8, 0.9)
	Ownership: There are clear accountability structures that ensure long-term accountability at both operational and administrative levels. Operational accountability means there is process ownership for the quality of their work and for continually improving their work and workplace. They take ownership of the changes, the lean implementation, and their area of application.	(0.7, 0.8, 0.9)
Culture	**Long-term and continuous implementation:** Lean is viewed as a continuous, long-term approach. It is thus practised day after day, decisions are made based on long-term thinking instead of short term gains, the commitment to improvement work continues even when results are not immediately shown, and actions are continuously reassessed to identify further improvement opportunities.	(0.7, 0.8, 0.9)
	Lean is part of daily work. Lean is viewed by staff as something that is valuable to their daily operations as opposed to something that takes time away from their routine activities and adds to their workload. The hospital thus achieves a culture where lean is part of daily work and viewed as a job resource that is valuable to them and patients.	(0.85, 0.95, 1.0)
	Willing to change. Culture is one of openness and willingness to change in order to fully adopt the new mentality.	(0.7, 0.8, 0.9)
	An **open, no-blame culture** exists in the hospital to foster an environment where people feel safe and free to report errors or issues.	(0.7, 0.8, 0.9)
	The hospital is both patient-centred and process-driven: The focus is oriented to the patients and their needs, as well as to the integrated and dynamic management of processes.	(0.7, 0.8, 0.9)
	A bottom-up approach is adopted where ideas and proposals generated by professionals at all levels of the organisation are fed into improvement initiatives. Decisions are taken in consensus, not top-down, allowing people more freedom to generate new ideas for improvement and discuss them to decide the best for the organisation.	(0.5, 0.65, 0.8)
	Recognise successes: Employees are appropriately recognised for improvement ideas implemented or performance goals achieved. This can be done by celebrating successes or giving rewards. If monetary rewards are used, a structured incentive system correlated to the performance achieved with respect to	(0.7, 0.8, 0.9)

	the overall objectives pursued can be implemented. Recognition of successes is supported by accurate measurement mechanisms.	
	Teamwork: There is a culture of shared understanding, awareness, support for co-workers, and accountability that builds teamwork at all levels to provide a clear vision to guide the program. There is interaction and collaboration within the multidisciplinary teams.	(0.7, 0.8, 0.9)
Lean team	**Clarity of roles and responsibilities:** A team dedicated to supporting and facilitating the implementation of lean and continuous improvement activities is appointed. The team is responsible for guiding the transformation process, managing the dynamics of continuous improvements, and providing support for bottom-up project development. The various figures and roles in this team are made clear, and the responsibility and ownership of each role are specified, giving power and authority to the necessary roles (such as the power to allocate resources).	(0.7, 0.8, 0.9)
	Utilisation of internal resources: A lean team can make use of external consultants, but it is vital that once staff has developed the necessary knowledge and skills to manage the lean process, the lean team employs staff from within the organisation to make up the lean team, thus making use of internal human resources to run the change.	(0.7, 0.8, 0.9)
	A **lean champion** (preferably someone from within the organisation) is appointed to promote the change, act as a catalyst, and motivate the employees in order to keep their attention and involvement high. They train colleagues to make sure employees understand lean and support them in developing projects. They additionally act as the link between employees and leadership and must work in synergy with top management.	(0.85, 0.95, 1.0)
	Teams are multi-professional and multidisciplinary: Where applicable, team members span across departments and are responsible for cross-functional tasks.	(0.5, 0.65, 0.8)
Change management	**Clear vision and goals:** There is a change vision that communicates explicit, clear, and measurable goals for the lean implementation.	(0.7, 0.8, 0.9)
	Improvement program and organisational strategy integration: There is integration between the improvement program and organisational strategy. The change program must be incorporated and developed within the organisation's strategy. Lean is integrated into the organisational strategic planning (e.g., into the annual budget), and similarly, the change/ improvement program is aligned with the organisation's strategy.	(0.85, 0.95, 1.0)
	Paced hospital-wide implementation: Along with lean implementation being organisation-wide and continuing, it is paced and systematic. Each step is adequately completed, and the implementation is not rushed or done too quickly before the previous stage has been fully integrated into the organisation. This change is driven and supported across the entire hospital and all workplace levels.	(0.85, 0.95, 1.0)

	Gain stakeholder commitment and buy-in: Prepare staff and ensure that they understand the expectations and reasons for change, accept the reasons for implementing change, and understand how the change will benefit them and the patients.	(0.85, 0.95, 1.0)
	Contextual influence is understood: Organisational characteristics that influence the effectiveness of lean's implementation must be taken into account when deciding on the implementation strategy. Aspects include the hospital's drive to improve processes and the staff's current knowledge and experience in process improvement initiatives. Additionally, the differences between hospitals and the manufacturing industry must be considered when implementing tools. For example, a zero inventory approach is difficult to achieve and risky in healthcare.	(0.5, 0.65, 0.8)
Organisation structure	**There are no functional and professional silos.** There is collaboration between different departments and units and flexibility to adapt procedures, processes, behaviours, and skills to changes. Additionally, there is alignment from senior leadership to frontline staff so plans, visions, resources, actions, and results to support system-wide gaols are consistent.	(0.7, 0.8, 0.9)

Table 7.13 Final collection of leanness practices and their importance

Lean principle	Lean practice	Leanness indicators	Importance weight
Identify value	Define customer expectations	Feedback on quality/service from customers are used to prioritise and adopt care to patient requirements, needs, and preferences.	(0.7, 0.8, 0.9)
Map the value stream	Identify and eliminate wastes	Process and value streams are mapped and analysed to classify activities as value-added (VA), non-value added (NVA), or necessary but non-value added (NNVA). These activities identify wastes so that they can be minimised or eliminated where possible. Tools such as value stream mapping (VSM), 5 Whys, plan-do-check-act (PDCA) cycle, A3 report, DMAIC, and root cause analysis are used to map the value stream and identify and eliminate wastes.	(0.85, 0.95, 1.0)
Create flow	Workload levelling (Heijunka)	Equalise work distribution among employees or better match staffing to demand in areas where the demand cannot be managed (such as the ED) to ensure smooth flow through the process with no interruptions, delays, or bottlenecks. Cross-training employees (where possible), ensuring a flexible workforce, and standardising processes between floors and departments can aid this.	(0.7, 0.8, 0.9)
		Plans for resource management are drawn up for the short- and long-term, including worker, workstation, and equipment schedules. In these plans task precedence is organised to maximise concurrency. Physicians are engaged in forecasting the planning process.	(0.85, 0.95, 1.0)
	Process time improvement	Streamline processes to improve patient throughout. Cycle or lead time reduction techniques such as layout optimisation, quick changeover, set-up time reduction, etc., can be used.	(0.85, 0.95, 1.0)
		Productivity is measured and improved through the use of lean tools (such as VSM, 5S, Kanban, Kaizen, etc).	(0.5, 0.65, 0.8)
	Reduce delays and interruptions	Effective asset and inventory management processes to prevent disruptions in flow. TPM can be used to prevent tool and equipment breakdowns, while Andon and competency training of staff can be used to ensure uninterrupted care without error is provided.	(0.7, 0.8, 0.9)
	Workplace organisation	Workplaces are organised and standardised with the application of an activity policy (such as 5S) to help keep work areas clean, tidy, and uncluttered.	(0.7, 0.8, 0.9)

	Quality	The hospital has a formal quality system and program that ensures the provided service exceeds customer expectations. Measurable quality objectives are set regularly to monitor quality status, and quality issues are tracked, reported, and communicated.	(0.85, 0.95, 1.0)
		Implementation of Total Quality Management (TQM) practices.	(0.7, 0.8, 0.9)
		Quality is built-in by preventing errors (implementing poka-yoke methods) and having visual controls (such as signs, pictures, or procedures) to identify errors.	(0.7, 0.8, 0.9)
		The Jidoka principle (autonomation) is implemented.	(0.3, 0.5, 0.7)
	Flexibility	To quickly adapt to changes, there is flexibility and adaptability in the service provided, as well as flexibility in the workforce, layout, and set-up.	(0.7, 0.8, 0.9)
	Visual management	Visual management (such as Kanban) is used to provide timeous feedback on key parameters. The information is used to manage improvements, inventory levels, and patients as they move through the system. Thus, continuous improvements can be made, and inventory levels and overproduction waste can be minimised for better material, patient, and workflow.	(0.7, 0.8, 0.9)
Establish pull	Pull system	A pull system determines where care providers spend their time and where patients move in the system. The hospital thus executes healthcare demand analysis and forecasting. It has a capacity management system/ programme to ensure new work is started only when there is demand for it (when the patient needs it) and the staff has spare capacity.	(0.3, 0.5, 0.7)
	Minimise inventory and patients waiting	Work-in-process (WIP) items such as samples that need to be tested must be limited while ensuring that the requisite materials and information are available for a smooth workflow. Material logistics are therefore managed to monitor and reduce items waiting.	(0.3, 0.5, 0.7)
		Techniques are employed to minimise the number of patients waiting in the system.	(0.7, 0.8, 0.9)
	Supplier delivery and responsiveness	Hospital-supplier integration. There is a proactive and long-term relationship established with suppliers. They are included in planning, goal-setting, continuous improvement, quality, and problem-solving activities.	(0.5, 0.65, 0.8)
		There are transparent communication systems between the hospital and supplier, where feedback is provided, and information is shared.	(0.7, 0.8, 0.9)

Seek perfection	Continuous improvement	Tools such as kaizen and Gemba walks are used to engage with employees and explore opportunities for continuous improvement. Employee suggestions are utilised when identifying possible improvements.	(0.85, 0.95, 1.0)
		Process and improvements are monitored, evaluated, and controlled to identify opportunities for improvement and allow data-based decision-making.	(0.85, 0.95, 1.0)
		Customers are involved in continuous improvement efforts to adapt the services to changing demands.	(0.7, 0.8, 0.9)
	Standardisation, systematisation, and simplification	Processes are continuously standardised, systematised, and simplified.	(0.85, 0.95, 1.0)

Chapter 8 Discussion of findings

Completing the evaluation resulted in the final tool and concluded the development process. A reflection on the findings made throughout is presented in this chapter. Therefore, the practices deemed most critical for sustainability (Section 8.1), the practicality of the research findings (Section 8.2), and the generalisability of the results (Section 8.3) are discussed. The chapter is then concluded in Section 8.4.

8.1 CRITICAL PRACTICES

While all the practices outlined in Table 7.12 were shown to be necessary for lean sustainability, naturally, some may be more critical than others, which was demonstrated by the varied importance rating each one received. Practices with high importance weights mean an improvement in their implementation would more significantly affect the ability of the hospital to sustain lean. There were only three sustainability practices that unanimously got the highest importance rating:

1. **There is leadership buy-in:** Top management understands the benefits of lean and is assured of its effectiveness.
2. **Stable support:** The management/leadership guidance and support of the change program is visible and stable over time.
3. **Improvement program and organisational strategy integration:** There is integration between the improvement program and organisational strategy. The change program must be incorporated and developed within the organisation’s strategy. Lean is integrated into the organisational strategic planning (e.g., into the annual budget), and similarly, the change/ improvement program is aligned with the organisation’s strategy.

The first two contributed to the *leadership* function, and the last to *change management*. These two areas of sustainability practices also had the highest average importance rating. The high leadership ratings were expected due to how frequently it is addressed in the literature (appearing in 78% of the studies reviewed). The integration aspect, however, was only found in three studies. It is interesting to note how important the SMEs deemed integration between the improvement program and organisational strategy, despite it not being recognised extensively in literature. This observation touches on another aspect of the findings discussed in more depth in Section 8.2: how the literature findings translated to practice and the differences between them. Nevertheless, leadership buy-in, their stability, and strategic integration were viewed as most critical for supporting lean sustainability in practice.

The considerable change required by a hospital when undertaking a lean transformation requires a strong driving force, which is why leadership is such a critical aspect of its sustainability. Without their support, a change in culture and long-term impact will never be realised (Sobek II, 2011; Centauri *et al.*, 2018; Leggat *et al.*, 2018; Kahm and Ingelsson, 2019). One SME said, "I regard leadership as the most necessary feature of sustained lean implementation, so I score it 7. All other scoring to my mind is relative to this 7." Leadership buy-in, in particular, is essential because of the influence they have over staff. If they view lean as something important, it promotes its use; thus, greater stakeholder buy-in is also achieved.

Additionally, due to the leadership responsibilities, several other practices are also influenced by it. For example, leaders can manage shifts and organise work to ensure employees can attend training and get involved in lean activities (Steed, 2012; Centauri *et al.*, 2016). They are responsible for critical communication throughout the hospital, such as the change vision and why lean is needed. Leadership even plays a vital role in developing the vision and goals set for lean and the improvement program realised. Thus, they are responsible for ensuring a link between this vision and efficient operations and quality of care (Sobek II, 2011; Centauri *et al.*, 2018). Thus, it also supports the other critical practice of ensuring that this aligns with the organisational strategy.

In developing the implementation plan for lean, it is vital to consider the strategic objectives already established in the hospital and its overall vision. At the same time, lean also needs to be integrated into the hospital's strategic planning from the beginning to ensure integration between lean and the hospital (Steed, 2012; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2018; Leggat *et al.*, 2018; Flynn *et al.*, 2019; Henrique *et al.*, 2020). If the improvement plan is not coupled with the hospital's strategy, sustaining and replicating any improvements can be challenging (Centauri *et al.*, 2016). Aligning the hospital's lean initiative goals and strategic objectives ensures they are moving towards achieving the same thing. Thus, the results will have more global impact (Bhasin, 2012b; Henrique *et al.*, 2020). Therefore, fully aligning the goals results in lean's integration into organisational activities, an essential aspect of sustainability (Steed, 2012; Centauri *et al.*, 2016; Flynn *et al.*, 2019).

While executing these three activities is the most critical to ensure sustained lean implementation, all the practices ultimately aim to realise a change in culture. An organisation's culture is the collection of values, expectations, and practices that guide and inform the actions of all team members. Thus, to completely integrate lean into a hospital where it has become the norm, there needs to be a culture change (Sobek II, 2011; Spagnol, Min and Newbold, 2013; Wood, 2014; Abuhejleh, Dulaimi and Ellahham, 2016; Centauri *et al.*, 2016, 2018). In 2.4, sustained lean was conceptualised as the state where a fundamental change in thinking and attitudes has occurred to the point where the new way of working has become the norm. A culture change was not an identified practice because it is not something that can be implemented directly. Rather, it is often the result from other activities, such as leadership directives and embedding practices into operations or processes. Anchoring a new way of thinking and acting into a hospital's culture is arguably the most critical step in ensuring the hospital's culture does not fall back into the old way of doing things (Breuer, 2013). All the identified practices are aimed at supporting this. Thus, the most critical thing that needs to happen for lean to be sustained is a culture change.

8.2 PRACTICALITY OF FINDINGS

The Delphi study highlighted conflicts between some of the theoretical practices identified and that which is achievable in practice. In some cases, to account for this difference, a practice could be modified or adapted for improved applicability to South African public hospitals or healthcare in general. However, in other cases, it could not be practically implemented and would thus be removed. This section discusses some examples of both instances and highlights their differences.

Because lean uptake is vulnerable to key personnel changes in the early stages of implementation, long-term, stable leadership was identified in literature as a necessary practice for sustainability. However, during the Delphi study, it was noted that personnel change all the time, and it is not something that can necessarily be prevented. Thus, it is not something that can practically be achieved. However, while it may be difficult to control, it is still relevant to the hospital's capability to sustain lean. If the leadership driving the change leaves before it has been embedded in the culture, the progress is often lost. Thus, the practice was kept but adjusted by adding the requirement for a handover period if leadership changes.

Similarly, one of lean's core pillars is system-wide implementation. Meaning lean should be adopted in the entire hospital, not just single departments or processes (Bartram *et al.*, 2020; Udod *et al.*, 2020). It was also a frequently identified issue with lean's current implementation throughout literature (Brandao de Souza, 2009; Radnor, Holweg and Waring, 2012; Breuer, 2013; Centauri *et al.*, 2018). However, authors still have contrasting opinions on how lean should be implemented. While many acknowledge this aspect of lean, practically implementing it this way is difficult (Breuer, 2013). Smaller, incremental changes or phased implementation strategies are often suggested. However, this again hinders sustainability because it does not accomplish a shift in the organisation's thinking. Many authors also criticise this approach and advocate for a hospital-wide roll-out of lean instead. However, this study only attempted to identify what needs to be in place for lean to be sustained without prescribing how it should be done. Thus, the juxtaposition between lean theory and practice is recognised by suggesting a hospital-wide implementation eventually needs to be in place for it to be sustained.

These two examples are of practices being kept despite their difficulty to implement and were both related to sustainability practices. Instances where practices were removed due to practicality all pertained to leanness practices. If they were removed as opposed to adapted, it was because the healthcare or South African public hospital context prevented them from being practised entirely.

One reason related to the South African public hospital context was its supplier tendering system. Not being able to control the criteria with which suppliers are selected means a strategic network can not be realised. Additionally, a hospital-supplier integration through establishing a long-term proactive relationship with suppliers is not feasible. Thus, aspects related to the incapability of controlling supplier selection and relationships had to be removed. However, this also presents a case where a change may not be true for all hospitals. Therefore, impacting the generalisability of the results. Further discussions on the generalisability can be found in Section 8.3.

A case where an indicator was removed due to relevance to all hospitals was the usage of automated tools to enhance processing time. Automation is frequently used in manufacturing. However, all the SMEs agreed that it is not always possible in hospitals and should not affect the degree of leanness. It is also important to note why leanness indicators were sometimes removed, but sustainability practices were always adapted. For leanness, multiple indicators are used to determine the extent to which a given practice is adopted. If one cannot be implemented in all cases for a given context, that specific indicator does not mean the practice is not being implemented, as it is only one way to realise it. Its removal does not mean that aspect of lean is ignored, but rather, that other indicators are used to determine its degree of adoption. For example, once the autonomation indicator was removed, the remaining indicators of streamlining processes and improving productivity could still be used to determine if process times are being reduced through lean implementation.

8.3 GENERALISABILITY OF RESULTS

There are three levels of generalisability regarding the practices deemed necessary for sustainability, including those only applicable or not applicable to: South African public hospitals, healthcare in general, or all industries. The practices that apply to each will be discussed to address the generalisability of the results.

One example of a generalisability being cause for dispute was issuing rewards to recognise employees for improvements made. Due to possible budgetary constraints in healthcare, monetary rewards are not something that can necessarily be provided. For the public health sector specifically, an SME commented that it is "extremely difficult, if not impossible, to overcome the red tape that would allow a system of monetary rewards in the public sector. Even if achieved, it would become the basis for disputes, corruption, and allegation of favouritism". Thus, it was considered to remove this aspect of the practice. However, not all SMEs agreed because there are other ways to issue rewards that are not monetary. Additionally, another SME noted that "One shouldn't change this just because of current red tape in public sector for granting monetary reward. Rewards can and should also be in non-monetary form as well. Several public hospital do indeed give non-financial rewards. A simple policy change could remove the red-tape of monetary reward, then your tool will have to change if you never included "reward". The tool must stand the test of time". Thus, the practice name was changed to only reference that continuous improvement efforts be recognised to make employees feel appreciated and want to continue participating. Rewards were provided as an example of how this could be implemented, but it is not a requirement for sustainability. Therefore, the practice remains relevant to all contexts.

The leanness aspects of sustainability saw a lot more adaptation to healthcare than the sustainability practices. This is likely due to the fact that they were derived from all industries. Unlike the sustainability practices, which were gathered specifically for the context of hospitals. For example, the changes made due to the supplier tender system in South Africa are only applicable to South Africa. It may be more feasible for private hospitals to have more control over how they select their suppliers, thus allowing them to choose those that ensure a short lead time and more collaboration and cooperation with the suppliers.

Further changes saw adapting practices for the terminology to be more applicable to healthcare. For example, inventory and work-in-process items must be limited to establish pull in manufacturing.

However, considering the healthcare context, this had to be tailored by referring to minimising patients waiting instead. This indicator applies to all healthcare but not other industries.

A case where a practice applied to manufacturing but not to healthcare was with productivity. An indicator extracted from a manufacturing context stated that “quality is not infused at the cost of productivity”. In healthcare, however, quality of care is crucial and should not be ignored. Thus, this aspect was not included in the practices identified for healthcare. However, this may be applicable in other industries.

Overall, however, the practices identified are not context-specific and is largely relevant to all industries. It was the indicators used to determine their implementation where the greater adaptation to context was made. And thus, where the activities identified become less generalisable.

8.4 CHAPTER 8: CONCLUSION

This chapter reflected on the evaluation findings by identifying the critical practices for lean’s sustainability and making observations on the practicality and generalisability of the results. Leadership buy-in, stability of this leadership, and strategic integration were viewed as most critical for supporting lean sustainability in practice by the experts participating in the Delphi study. The Delphi study also highlighted conflicts between some of the theoretical practices identified and that which is achievable in practice. How these differences were accounted for was discussed, and examples were provided. Thereafter, the three levels of generalisability of the final collection of practices regarding their applicability to South African public hospitals, healthcare in general, and all industries implementing lean were reflected on. Chapter 9 that follows continues the final “discussion and conclusion” research stage by concluding the study.

Chapter 9 Conclusion

This final chapter concludes by summarising the research presented (Section 9.1) and discussing how the research questions proposed in Section 1.2 were answered (Section 9.2). Thereafter, the theoretical and practical implications of the study are addressed (Section 9.3), and opportunities and recommendations for future research are made (Section 9.4).

9.1 RESEARCH OVERVIEW

This research outcome is a collection of practices required for a sustainable lean transformation in hospitals and a tool that assesses the extent to which they have been adopted. This section explores how this was achieved by summarising the chapters presented in the dissertation.

The study opened in Chapter 1 by introducing the research focus (lean application in hospitals) and identifying the problems of unsuccessful and unsustainable implementations it faces. Consequently, the research aimed to investigate how it can be sustained in this context and to develop an artefact that encapsulates this knowledge and supports its practical implementation. Then, the questions to realise these aims and the scope and ethical considerations were outlined. How the research questions were responded to is addressed in Section 9.2.

In Chapter 2, the method of answering the research questions was outlined. The underlying pragmatic philosophical assumptions and research aim led to the adoption of the DSRP to execute the research. The methodologies used for specific stages were also identified. Following the realisation of the research strategy, toward the first step of the process (problem identification and motivation), an explorative literature review was presented in Chapter 3. It outlined the lean philosophy and its history, then investigated its application in healthcare and the problems observed to motivate the problem and identify a solution to address it. The findings were used to determine the solution objectives. Thus, also completing the second step of the research process.

After that, the preliminary tool development stage began by executing two systematic reviews in Chapter 4 and Chapter 5. The SLR presented in Chapter 4 focused on uncovering what has been found to aid or inhibit lean's sustainability in hospitals. The analysis of the findings resulted in a collection of 30 lean sustainability practices, one of which was a holistic implementation of lean. This practice would form the focus of the following review executed in Chapter 5.

In Chapter 5, a structured review of existing leanness assessment methods was carried out. This review aimed to uncover the parameters used in literature to determine leanness and investigate the characteristics and methodologies adopted to assess them. Thus, a collection of leanness determinants relevant to all industries was realised, and considerations for the tool's development were uncovered. The measurement types, data, assessment methodologies used, and the different capabilities of these existing tools were all analysed. These were the aspects considered when developing the tool, the process of which was detailed in Chapter 6. Firstly, the practices uncovered in Chapter 4 and Chapter 5 were synthesised to structure the tool's assessment parameters. Secondly, the method suited to assess them and derive results was chosen. The last step involved deciding how these results would be presented. The result was a self-assessment tool using linguistic input from users to determine a hospital's leanness and sustainability scores and to prioritise the sustainability practices that need to be improved. Fuzzy logic was utilised to translate the input to the desired output.

Following the development of the preliminary tool from literature, it needed to be refined to ensure its contents are accurate and that it is usable in practice. Thus, an evaluation process was executed in Chapter 7 using a Delphi procedure. This process was also used to determine the relative importance of the different parameters so they could be weighted accordingly in the tool when calculating its results. The information obtained from the SMEs was presented, and the necessary changes made according to their suggestions were explained. This process resulted in a final iteration of the SLAT. Chapter 7 thus also presented the execution of the tool evaluation, refinement, and final tool presentation stages of the research strategy. Chapter 8 then discussed the final tool and findings from executing the study. The practicality of the practices developed and the generalisability of the tool contents were considered.

9.2 ANSWERING RESEARCH QUESTIONS

The research questions (RQs) identified in Section 1.2 were defined so, through their investigation, the research aim would be realised. This section shows how each question was answered through the completion of this study.

RQ 1a: How might lean holistically be implemented?

The investigation, development, and evaluation processes executed in Chapters 5, 6, and 7 all contributed toward answering this research question. Chapter 5 uncovered parameters used to determine leanness in existing leanness assessment approaches. These parameters were then adapted to the healthcare context. Their significant overlap with the sustainability practices meant the practices relating to leanness (as defined in this research) had to be isolated. Thus, in Chapter 6, the leanness practices and already-determined sustainability practices were synthesised. The result was a list of practices needed to holistically implement lean in hospitals grouped to represent each of the five lean principles. In Chapter 7, these were further verified for South African public hospitals and refined to apply more to healthcare in general. The final list of practices needed for holistic lean implementation can be found in Table 7.13.

RQ 1b: What aids a sustainable implementation of lean?

The investigation into what aids lean sustainability executed in Chapter 4 was the first step toward answering this research question. Here, a list of thirty practices was determined from literature. Thereafter, in Chapter 7, they were further refined through two rounds of a Delphi study. The also revealed stable leadership, leadership buy-in, and integration between the improvement program and organisational strategy to be the most important for sustainability. The final list of practices needed to support a long-term holistic lean implementation and their importance can be found in Table 7.12.

RQ2a: What is the ideal format for an artefact that could support the improved implementation of lean in hospitals?

In Chapter 3, the investigation into lean's implementation in healthcare identified a lack of correctly targeted lean assessments. The review found that assessment tools focused on assessing the degree to which lean has been adopted are commonly used to help sustain lean implementation in the manufacturing industry. Thus, the need for a self-assessment tool comprised of parameters representing the first research question findings was realised as the ideal format. The tool aimed to aid the practical application of this knowledge.

In Chapter 6, the practices derived were synthesised and combined into sustainability assessment parameters and supplementary leanness indicators. The evaluation executed in Chapter 7 confirmed that the tool assesses the extent to which practices that support the sustainable implementation of lean and lean's principles to a fair degree of accuracy and that it comprises of all the practices necessary to support the sustainable implementation of lean in a hospital setting.

RQ 2b: What output might the artefact present and how is it determined?

After reviewing possible data collection and evaluation approaches in Chapter 5, the options were analysed against the tool objectives and considered for their practicality. Resultantly, a fuzzy logic approach utilising linguistic input from users and translating it into an overall score was deemed the most appropriate approach to determining the tool output. A Delphi study was executed in Chapter 7 to determine the relative weights of the different assessment parameters that would be built into the tool in determining these scores.

Based on the adoption of fuzzy logic to assess input, an overall linguistic score for leanness and the hospital's capability to sustain lean were assumed as one of the tool outputs. A radar chart showing the implementation of different lean principles was also included. Additionally, a ranked list of the sustainability practices in order of most critical for improvement is provided. Later, following a request for more information on the results page, a drop-down list of all the sustainability practices was added that can be used to provide further detail on how to improve a selected practice.

9.3 IMPLICATIONS OF STUDY

The research study and the LAT developed during the study present a number of theoretical and practical implications to the field of lean's application in healthcare. This section outlines the contributions made in both the theoretical (Section 8.3.1) and practical perspective (Section 8.3.2).

9.3.1 THEORETICAL CONTRIBUTION

While exploring the literature on lean's application in healthcare, it was apparent that there is a lack of complete lean implementations and, consequently, a lack of sustainability. This observation raised the question of what aspects of lean need to be implemented to completely transform into a lean hospital and what other aspects of its implementation are essential to sustain it. Another area lacking maturity in the healthcare space was lean assessments focusing on the implementation itself instead of its results. This study addressed these gaps in research by investigating what has been found to aid or inhibit lean sustainability in hospitals and analysing all the existing approaches to leanness assessment across multiple sectors to establish a set of hospital-specific practices required for lean transformation. This study thus contributes to the understanding of how lean could be more sustainably implemented within the context of hospitals in the future. A collection of practices combining sustainability aspects and indicators for leanness in hospitals has not been realised in literature. In the evaluation process, all SMEs agreed that the practices represent real-world practices that would enable hospitals to better sustain lean. The study also consolidates the theoretical developments in general leanness assessment before adapting these to the hospital environment. This consolidation could be of theoretical value beyond just the context of hospitals.

9.3.2 PRACTICAL CONTRIBUTION

The study also developed a lean sustainability assessment tool. Practically, the tool enables hospitals that have adopted lean thinking to assess the extent to which it has been implemented in the facility and to what degree it has equipped itself with the ability to sustain the transformation. It does so by providing an easy-to-use self-assessment with set criteria that determines these aspects based on the input provided. The single score result allows hospitals to compare their results over time or for multiple hospitals to compare results across different facilities. In addition to the scores provided, it prioritises the practices that need improvement and provides information on how this could be achieved. This information could inform decisions regarding how to improve and better support its implementation. In the evaluation process, all SMEs agreed that implementing the practices identified could lead to improved outcomes from lean implementation in the hospital.

9.4 SUGGESTED FUTURE WORK

The investigation of what is needed to sustain lean implementations in hospitals led to several practices for sustainable and holistic lean implementation being identified. In determining a hospital's leanness and sustainability capability, these practices were weighted according to their importance, which was determined through the Delphi study. Alternatively, their influence could be derived from the interrelationships between the parameters. In the discussion of how each practice contributes to sustained leanness, it was clear that the practices interact to support sustainability. For example, gaining stakeholder commitment and buy-in was identified as necessary for sustainability because it encourages participation, without which lean will not be sustained. There thus exists a positive relationship between workforce participation and gaining buy-in. Conversely, implementing a measurement system could negatively affect stakeholder buy-in because of the increased workload such a practice entails. However, ensuring enough resources are available could negate this negative impact. These examples illustrate the complex interrelatedness of the effects of lean practices. While these interactions are noted, inferences about these interrelationships could not definitively be drawn from literature, as any connections made were not necessarily done through verified testing. Thus, a research avenue that could be explored is the interrelationships between these practices and how they influence sustainability. Through this, the practices that carry the most influence could be prioritised above those with less influence. This approach is an alternative to the weighting method adopted in this research.

The second possibility for future work relates to the assessment tool presented. Currently, it only has the capability to reveal leanness and the hospital's ability to sustain lean and prioritise the practices for improvement. The tool output could be developed further by considering additional parameters such as time and costs to improve identified parameters and presenting a more extensive implementation plan. A whole other aspect of research looking at how to improve the practices would be required. This research only sought to determine what needed to be in place to support sustainability but did not detail how to achieve this. An investigation into this aspect could be beneficial for practical implementation.

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Appendix A Delphi participant consent form

This appendix presents the Research and Ethics Committee (REC) consent form given to participants forming the Delphi panel. The form was provided along with the questionnaire and was signed by each subject matter expert (SME). It is shown in Figure A.1.

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STELLENBOSCH UNIVERSITY
ELECTRONIC CONSENT TO PARTICIPATE IN RESEARCH

TITLE OF RESEARCH PROJECT:	Identifying key factors for sustaining lean in hospitals
REFERENCE NUMBER:	ING-2021-23303
PRINCIPAL INVESTIGATOR:	Bronwyn Joubert
ADDRESS:	Industrial Engineering Building, Banhoek Road, Stellenbosch, 7600
CONTACT NUMBER:	0832552111
E-MAIL:	18175996@sun.ac.za

Dear participant

Kindly note that I am a PhD student at the Department of Industrial Engineering at Stellenbosch University, and I would like to invite you to participate in a research project entitled *Identifying key factors for sustaining lean in hospitals*.

Please take some time to read the information presented here, which will explain the details of this project and contact me if you require further explanation or clarification of any aspect of the study. This study has been approved by the Research Ethics Committee (REC) at Stellenbosch University and will be conducted according to accepted and applicable national and international ethical guidelines and principles.

1. **INTRODUCTION:** Despite widespread reports of the success of lean's application in hospitals, there are also numerous reports of cases where hospitals have struggled to sustain the resulting gains long-term. In order to support a long-term effective transition toward becoming a lean hospital, this research aims to develop a tool assessing the degree to which practices necessary for a holistic and sustainable adoption of the lean philosophy have been adopted in a hospital.
2. **PURPOSE:** The purpose of this study is to determine the importance of the various sustainability factors used in the tool as it relates to supporting the sustainability of lean, and to validate the applicability of the tool as a whole for practical use.
3. **PROCEDURES:** A Delphi round involves first providing feedback through the completion of the attached questionnaire. Once all the responses from the entire panel of experts taking part have been received, they are reviewed, and a summary report will be issued to each participant. The summary report is anonymous and will make no reference to which expert provided which score. The scores will be presented in an aggregate form only to communicate the average group response. The participant is then required to review this report, and give an updated response, agreeing or disagreeing with the other expert's answers. The data will once again be reviewed, and a second report is issued. This process will continue until all participants forming the panel have reached consensus.
4. **TIME:** Each Delphi round (consisting of the completion of the questionnaire) will take approximately 20 minutes to complete. The number of Delphi rounds to be completed for the study is determined by how long it takes to reach consensus. It is therefore not possible to determine the number of rounds until the study commences. However, for a Delphi study to be complete, at least two rounds must be executed.
5. **RISKS:** Participation in this study could results in a loss or breach of confidentiality which could put you at risk for stigmatisation or embarrassment based on the responses you have provided.
6. **BENEFITS:** The input from the participants taking part in this study will be used to formulate and tailor a tool designed specifically for hospitals to assess the degree to which they have implemented lean principles, and practices required for its sustainable implementation. This will allow hospitals to identify areas where implementation needs to be improved, thus potentially leading to more long-term improvements being

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realised. Not only will this help hospitals improve their implementation of lean, but the resulting improved performance will result in better and more efficient healthcare being provided to patients.

7. **PARTICIPATION & WITHDRAWAL:** Your participation in this study is entirely voluntary and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you agree to take part. If you decide to withdraw mid-way through the study and wish for you opinions and feedback given up until that point not to be used, all responses given will be disregarded. Furthermore, if you decide to withdraw after the completion of the study, your responses will not be incorporated into the research and any written notes or electronic copies related to your responses will be destroyed.
8. **CONFIDENTIALITY:** The information gathered during this questionnaire will only be used for research purposes, specifically related to the thesis. The only form of personal data required is the your name, email address, and a brief summary of experience working with lean. In order to protect your privacy these details will not be disclosed. Any personal identifiers will be replaced by ID codes in the research and summary reports, and no direct quotes or links to any personal identifiers will be included. Any form of correspondence with the investigator will be kept confidential, and only the principal investigator and study supervisor will have access to this information.
9. **RECORDINGS:** No voice of video recordings will be used as part of this study.
10. **DATA STORAGE:** Any contact details and questionnaire responses provided will be stored on a password protected device and backed up to a password protected cloud storage. Only the principal investigator will have access to this. Personal identifiers will be replaced by ID codes in the research report, and no direct quotes or links to any personal identifiers will be included. The data will not be transferred or shared with any collaborators or researchers (nationally or internationally).

If you have any questions or concerns about this research project, please feel free to contact myself, Bronwyn Joubert (email: 18175996@sun.ac.za or tel: 0832552111), or my supervisor Wouter Bam (email: wouterb@sun.ac.za or tel: 0218084085).

RIGHTS OF RESEARCH PARTICPANTS: You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché (mfouche@sun.ac.za / 021 808 4622) at the Division for Research Development. You have the right to receive a copy of this Consent form.

If you are willing to participate in this research project, please select the relevant box in the Declaration of Consent below and send it along with the completed questionnaire.

Figure A.1 REC consent form

Appendix B Sustainable parameter codes

This appendix presents all the codes used in the Chapter 4 analysis to identify practices that aid lean sustainability in Table B.1. It further shows how they were grouped into overarching areas and the references for the study in which each code was used. The text excerpts linked to each code were then used to formulate the practices shown and presented in Table 4.2 in Chapter 4.

Table B.1 Codes for identified sustainability practices

AREAS	CODES	REFERENCE
Measurement system	Audit process	(Leggat *et al.*, 2018), (Sobek II, 2011), (Henrique *et al.*, 2020)
	Monitoring	(Sobek II, 2011)
	Follow-up	(Lindskog *et al.*, 2016), (Henrique *et al.*, 2020), (Breuer, 2013), (Leggat *et al.*, 2018), Henrique *et al.*, 2020)
	KPIs	(Henrique *et al.*, 2020), (Breuer, 2013), (Leggat *et al.*, 2018), (Rotteau *et al.*, 2015), (Sobek II, 2011), (Abuhejleh, Dulaimi and Ellahham, 2016)
	Performance measurement	(Henrique *et al.*, 2020), (Steed, 2012)
	Data	(Sobek II, 2011)
	Measurement system	(Steed, 2012), (Centauri *et al.*, 2016)
	Assessment	(Sobek II, 2011),
	Visual control of improvement	(Barnas, 2011)
Lean tools and principles	Application of lean tools and techniques	(Steed, 2012), (Abuhejleh, Dulaimi and Ellahham, 2016), (Centauri *et al.*, 2018)
	A3 method	(Steed, 2012), (Centauri *et al.*, 2018), (Henrique *et al.*, 2020)
	5S	(Steed, 2012), (Centauri *et al.*, 2018)
	Kaizen event	(Steed, 2012), (Henrique *et al.*, 2020)
	Visual management	(Leggat *et al.*, 2018), (Henrique *et al.*, 2020), (Barnas, 2011)
	Gemba walks	(Steed, 2012), (Udod *et al.*, 2020), (Henrique *et al.*, 2020)

	VSM	(Henrique *et al.*, 2020), (Centauri *et al.*, 2018)
	Standardising	(Steed, 2012), (Barnas, 2011), (Henrique *et al.*, 2020), (Leggat *et al.*, 2018), (Sobek II, 2011)
	Adherence to lean principles	(Dickson *et al.*, 2009)
	Pull	(Centauri *et al.*, 2018)
	Flow	(Centauri *et al.*, 2018), (Henrique *et al.*, 2020), (Centauri *et al.*, 2016)
Knowledge and competency	Training	(Steed, 2012), (Udod *et al.*, 2020), (Abuhejleh, Dulaimi and Ellahham, 2016), (McCreery, Mazur and Rothenberg, 2011), (Centauri *et al.*, 2018), (Henrique *et al.*, 2020), (Stelson *et al.*, 2017), (Breuer, 2013), (Leggat *et al.*, 2018), (Sobek II, 2011), (Flynn *et al.*, 2019), (Steed, 2012), (Centauri *et al.*, 2016)
	Learning	(Steed, 2012), (Lindskog *et al.*, 2016), (Sobek II, 2011)
	Lean knowledge and experience	(Stelson *et al.*, 2017), (Centauri *et al.*, 2017), (Leggat *et al.*, 2018), (Spagnol, Min and Newbold, 2013), (Sobek II, 2011), (Kahm and Ingelsson, 2019), (Udod *et al.*, 2020), (Centauri *et al.*, 2016), (Flynn *et al.*, 2019), (Breuer, 2013)
	Competent employees	(Breuer, 2013), (Steed, 2012), (Spagnol, Min and Newbold, 2013), (Leggat *et al.*, 2018)
	Understand benefits of lean	(Sobek II, 2011), (Steed, 2012), (Flynn *et al.*, 2019)
Communication and feedback	Communication to whole organisation	(Henrique *et al.*, 2020), (Breuer, 2013)
	Communication	(Stelson *et al.*, 2017), (Breuer, 2013), (Leggat *et al.*, 2018), (Rotteau *et al.*, 2015), (Sobek II, 2011), (Kahm and Ingelsson, 2019), (Steed, 2012), (Wood, 2014), (Centauri *et al.*, 2016)
	Visual communication	(Breuer, 2013), (Leggat *et al.*, 2018)

	Visible communication	(Steed, 2012)
	Feedback	(Stelson *et al.*, 2017), (Leggat *et al.*, 2018)
	Information system	(Centauri *et al.*, 2016)
	Availability of information	(Leggat *et al.*, 2018)
	Transparency	(Abuhejleh, Dulaimi and Ellahham, 2016)
Leadership	Visibility	(Centauri *et al.*, 2018), (Steed, 2012), (Udod *et al.*, 2020), (Centauri *et al.*, 2016)
	Involvement	(Henrique *et al.*, 2020), (Stelson *et al.*, 2017), (Leggat *et al.*, 2018), (Sobek II, 2011), (Centauri *et al.*, 2018), (Centauri *et al.*, 2016), (Centauri *et al.*, 2017), (Steed, 2012)
	Participation	(Sobek II, 2011), (Kahm and Ingelsson, 2019)
	Leadership	(Kahm and Ingelsson, 2019), (Steed, 2012), (McCreery, Mazur and Rothenberg, 2011), (White and Waldron, 2014), (Wood, 2014), (Centauri *et al.*, 2018), (Bartram *et al.*, 2020), (Breuer, 2013), (Spagnol, Min and Newbold, 2013), (Sobek II, 2011), (Centauri *et al.*, 2017), (van Rossum *et al.*, 2016), (Henrique *et al.*, 2020)
	Leadership commitment	(Abuhejleh, Dulaimi and Ellahham, 2016), (McCreery, Mazur and Rothenberg, 2011), (Dickson *et al.*, 2009)
	Adequate/ sufficient resources	(Sobek II, 2011), (Udod *et al.*, 2020), (Bartram *et al.*, 2020), (Stelson *et al.*, 2017), (Leggat *et al.*, 2018), (McCreery, Mazur and Rothenberg, 2011), (Abuhejleh, Dulaimi and Ellahham, 2016)
	Adequate/ sufficient time available	(Barnas, 2011), (Stelson *et al.*, 2017), (Kahm and Ingelsson, 2019), (Udod *et al.*, 2020), (Centauri *et al.*, 2016)
	Support	(Dickson *et al.*, 2009), (Stelson *et al.*, 2017), (Leggat *et al.*, 2018), (Lindskog

		et al., 2016), (Sobek II, 2011), (Kahm and Ingelsson, 2019), (Abuhejleh, Dulaimi and Ellahham, 2016), (McCreery, Mazur and Rothenberg, 2011), (Centauri *et al.*, 2018), (Bartram *et al.*, 2020), (Centauri *et al.*, 2016)
	Consistency	(Spagnol, Min and Newbold, 2013)
Workforce empowerment	Ownership	(Bartram *et al.*, 2020), (Dickson *et al.*, 2009), (Breuer, 2013), (Leggat *et al.*, 2018), (Rotteau *et al.*, 2015), (Lindskog *et al.*, 2016), (Sobek II, 2011)
	Accountability	(Leggat *et al.*, 2018), (Steed, 2012), (Rotteau *et al.*, 2015), (Sobek II, 2011), (Flynn *et al.*, 2019)
	Involvement/ engagement/ participation	(Dickson *et al.*, 2009), (Stelson *et al.*, 2017), (Leggat *et al.*, 2018), (Rotteau *et al.*, 2015), (Lindskog *et al.*, 2016), (Sobek II, 2011), (Flynn *et al.*, 2019), (Steed, 2012), (Udod *et al.*, 2020), (Abuhejleh, Dulaimi and Ellahham, 2016), (White and Waldron, 2014), (Wood, 2014), (Centauri *et al.*, 2018), (Henrique *et al.*, 2020), (Bartram *et al.*, 2020), (Wood, 2014), (Centauri *et al.*, 2016), (Centauri *et al.*, 2017)
	Empowerment	(Abuhejleh, Dulaimi and Ellahham, 2016), (White and Waldron, 2014), (Centauri *et al.*, 2018), (Sobek II, 2011)
	Socio-technical perspective	(Lindskog *et al.*, 2016)
Culture	Long-term approach/ view/ vision/ focus	(Henrique *et al.*, 2020), (Breuer, 2013), (Leggat *et al.*, 2018), (Spagnol, Min and Newbold, 2013), (Rotteau *et al.*, 2015), (Sobek II, 2011), (Centauri *et al.*, 2018), (Woodnutt, 2018)
	Continuous improvement culture	(Rotteau *et al.*, 2015), (Sobek II, 2011), (Henrique *et al.*, 2020), (Breuer, 2013), (Leggat *et al.*, 2018), (Woodnutt, 2018), (Centauri *et al.*, 2016)
	Viewed as a job resource/ part of the job/ part of daily practice/ normalisation of lean in everyday practice	(Stelson *et al.*, 2017), (Sobek II, 2011), (Centauri *et al.*, 2017), (Flynn *et al.*, 2019)

	Culture	(Spagnol, Min and Newbold, 2013), (Sobek II, 2011), (Abuhejleh, Dulaimi and Ellahham, 2016), (Centauri *et al.*, 2018), (Dickson *et al.*, 2009), (Centauri *et al.*, 2016)
	Culture change	(Sobek II, 2011), (Flynn *et al.*, 2019), (Wood, 2014), (Breuer, 2013), (Centauri *et al.*, 2016)
	No-blame culture	(Sobek II, 2011)
	Patient-centred	(Centauri *et al.*, 2018), (Centauri *et al.*, 2016)
	Process based	(Centauri *et al.*, 2018), (Centauri *et al.*, 2016)
	Open/ willing to change	(Sobek II, 2011), (Abuhejleh, Dulaimi and Ellahham, 2016), (White and Waldron, 2014), (Spagnol, Min and Newbold, 2013), (Centauri *et al.*, 2016)
	Flexibility	(Dickson *et al.*, 2009), (Rotteau *et al.*, 2015), (van Rossum *et al.*, 2016)
	Commitment	(Steed, 2012), (Breuer, 2013), (Stelson *et al.*, 2017), (Spagnol, Min and Newbold, 2013)
	Rewards and recognition	(Henrique *et al.*, 2020), (Sobek II, 2011), (Abuhejleh, Dulaimi and Ellahham, 2016), (Wood, 2014), (Lindskog *et al.*, 2016), (Centauri *et al.*, 2016)
	Teamwork	(Abuhejleh, Dulaimi and Ellahham, 2016), (White and Waldron, 2014), (Centauri *et al.*, 2018)
	Employee assessment	(Henrique *et al.*, 2020)
	Bottom-up approach/ consensus	(Henrique *et al.*, 2020), (Centauri *et al.*, 2016), (Centauri *et al.*, 2017)
Lean team	Internal lean team	(Centauri *et al.*, 2018), (Scott *et al.*, 2011), (Henrique *et al.*, 2020), (Dickson *et al.*, 2009)
	Lean team	(Breuer, 2013), (Centauri *et al.*, 2017), (Centauri *et al.*, 2016)
	Lean champion	(Breuer, 2013), (Centauri *et al.*, 2016), (Dickson *et al.*, 2009)

	Role clarity (authority)	(Breuer, 2013), (Rotteau *et al.*, 2015), (Lindskog *et al.*, 2016), (Centauri *et al.*, 2018), (Centauri *et al.*, 2017)
	Multi-disciplinary	(van Rossum *et al.*, 2016), (Centauri *et al.*, 2018), (Centauri *et al.*, 2016)
	Cross-functional teams	(Sobek II, 2011), (Breuer, 2013)
	Multi-level	(Leggat *et al.*, 2018)
Change management	Implementation plan/ change program	(Henrique *et al.*, 2020), (Centauri *et al.*, 2016)
	Continuous improvement method (DMAIC/ PDCA)	(Henrique *et al.*, 2020), (Breuer, 2013)
	Strategic alignment	(Henrique *et al.*, 2020), (Leggat *et al.*, 2018), (Sobek II, 2011), (Centauri *et al.*, 2018), (Centauri *et al.*, 2016), (Centauri *et al.*, 2017)
	Aligned goals	(Steed, 2012)
	Strategic planning and control system	(Centauri *et al.*, 2018)
	System/ hospital-wide	(Bartram *et al.*, 2020), (Leggat *et al.*, 2018), (Rotteau *et al.*, 2015), (Flynn *et al.*, 2019), (van Rossum *et al.*, 2016), (Udod *et al.*, 2020)
	System view	(Breuer, 2013)
	Holistic implementation	(Udod *et al.*, 2020)
	Establish clear goals/vision	(Breuer, 2013), (Leggat *et al.*, 2018), (Lindskog *et al.*, 2016), (Sobek II, 2011), (Kahm and Ingelsson, 2019), (Steed, 2012), (Abuhejleh, Dulaimi and Ellahham, 2016), (Centauri *et al.*, 2016)
	Measurable goals	(Lindskog *et al.*, 2016)
	Shared values	(Flynn *et al.*, 2019)
	Clarity of how goals will be reached	(Abuhejleh, Dulaimi and Ellahham, 2016), (Leggat *et al.*, 2018)
	Transformation plan	(Breuer, 2013), (Centauri *et al.*, 2016)
	Change vision	(Breuer, 2013)
	Understanding that change is required/ scope and need for change is clear	(Stelson *et al.*, 2017), (Breuer, 2013), (Centauri *et al.*, 2016), (Sobek II, 2011), (Flynn *et al.*, 2019)

	Understanding reasons for change	(Steed, 2012), (Wood, 2014)
	Customisation to context	(Flynn *et al.*, 2019)
	Maintaining process changes	(Rotteau *et al.*, 2015)
	Sustainability plan/process	(Rotteau *et al.*, 2015)
	Clear structure with tools and methods	(Kahm and Ingelsson, 2019)
	Change management	(Steed, 2012), (Leggat *et al.*, 2018), (Centauri *et al.*, 2016)
	Action planning	(Steed, 2012), (Centauri *et al.*, 2016)
	Paced and systematic implementation	(Steed, 2012)
	Process-based	(Centauri *et al.*, 2016)
	Change management	(Sobek II, 2011)
	Buy-in/ Assuredness	(Bartram *et al.*, 2020), (Stelson *et al.*, 2017), (Breuer, 2013), (Sobek II, 2011), (Flynn *et al.*, 2019), (Steed, 2012), (Udod *et al.*, 2020), (Kahm and Ingelsson, 2017), (White and Waldron, 2014), (Wood, 2014), (Centauri *et al.*, 2016), (Centauri *et al.*, 2017)
	Multi-level	(Bartram *et al.*, 2020), (Stelson *et al.*, 2017), (Leggat *et al.*, 2018), (Centauri *et al.*, 2018), (Centauri *et al.*, 2016)
	Lean-management system	(Barnas, 2011), (Flynn *et al.*, 2019)
Organisation structure	Cross-functional/ cross functional view	(Stelson *et al.*, 2017), (Leggat *et al.*, 2018), (van Rossum *et al.*, 2016)
	Consistency	(Sobek II, 2011), (Flynn *et al.*, 2019)
	Organisational set-up/ structure	(Centauri *et al.*, 2016), (Flynn *et al.*, 2019)
	Alignment	(Flynn *et al.*, 2019)
	Layout	(Centauri *et al.*, 2016), (Centauri *et al.*, 2018)
	Multi-disciplinary	(van Rossum *et al.*, 2016)

Appendix C Identified assessment parameters

This appendix presents all the elements identified in the literature reviewed in Chapter 5 that assesses lean practices and how they were grouped to realise the leanness indicators included in the preliminary LAT. The included indicators, elements they resulted from, and source for each of these elements are shown in Table C.1.

Table C.1 Identified assessment parameters

Included leanness indicator	Practice-based assessment parameters identified from literature	Source index
Strong employee spirit, cooperation, and engagement	Strong employee spirit, cooperation, and engagement	(Vinodh and Chintha, 2011), (Vinodh and Balaji, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Employee work attitude	(Narayanamurthy and Gurumurthy, 2016a)
	Staff engagement	(Almutairi, Salonitis and Al-Ashaab, 2019)
Employees lead improvement efforts and resolve customer problems	Empowerment of personnel to resolve customer problems	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Employee's percentage of participation in at least one improvement project	(Guimarães and de Carvalho, 2014)
	Employees lead product/process improvement efforts	(Pakdil and Leonard, 2014)
Job enrichment used	Giving workers a broad range of tasks	(Thanki and Thakkar, 2014)
	Giving workers more planning responsibility	
	Giving workers more inspection/quality responsibility	
	Is the process of job enrichment used?	(Shetty, Ali and Cummings, 2010)
Implementation of job rotation system	Implementation of job rotation system	(Guimarães and de Carvalho, 2014), (Vinodh and Chintha, 2011), (Vinodh and Balaji, 2011),

		(Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Saleeshya and Binu, 2019)
Rewards and recognition system	Rewards and recognition system	(Duarte and Cruz Machado, 2017), (Doolen and Hacker, 2005), (Thanki and Thakkar, 2014), (Guimarães and de Carvalho, 2014)
	Continuous improvement and compensation link is evident	(Pakdil and Leonard, 2014)
	Is there any form of motivation for employees depending on process improvement? (The employees are always an important element of the Lean approach. This question searches for evidence of the participation of employees in the CI)	(Martinez, 2018)
Formal workforce training and improvement programs	Training	(Bon and Kee, 2015)
	The company invests number of hours per year in training production personnel.	(Shetty, Ali and Cummings, 2010)
	The company provides regular, formal training and refresher training for all employees on quality concepts, standards of quality and workmanship (yes/no).	
	Direct labour undergoes training to perform multiple tasks in the production process	(Thanki and Thakkar, 2014)
	Employee training	(Narayanamurthy and Gurumurthy, 2016a)
	Education and training	(Duarte and Cruz Machado, 2017)
	On-the-job coaching in Lean practices	(Guimarães and de Carvalho, 2014)
	Formal systems (meetings and training) for transferring lessons learned from improvement efforts	
	Training programs on standardise work procedures	
	External training programs	
	Cooperative endeavours with schools and training to ensure qualified workforce	
	Improving supervisor training	(Thanki and Thakkar, 2014)

	Employee improvement programs	(Saleeshya and Binu, 2019)
	Improvement	(Maasouman and Demirli, 2016)
	Individual or job-specific development plans	(Guimarães and de Carvalho, 2014)
	Workforce quality enhancement programmes	(Saleeshya and Binu, 2019)
	What percentage of personnel (ALL personnel) have received at least eight hours of teambuilding training?	(Taj, 2005)
	This is one of the critical leanness parameters. Every organisation should conduct safety and quality improvement program, as well as training of new technologies	(Yadav *et al.*, 2019)
	Skills and core competencies (Organisations should determine the necessary competences for employees)	(Duarte and Cruz Machado, 2017)
	Organise training immediately for any new standards incorporated	(Madhan and Suresh, 2017)
	Plant leadership lean training program	(Soliman and Gadalla, 2014)
	"Driven" line leaders lean training program	
	Competency building	
	Structured programs on continuous improvement concepts	(Guimarães and de Carvalho, 2014)
Workforce are cross-functionally trained	The operators are adequately cross-trained.	(Shetty, Ali and Cummings, 2010)
	Cross-training program and regular job rotation to maintain skills and enrich the job	(Guimarães and de Carvalho, 2014)
	Employees undergo cross functional trainings	(Pakdil and Leonard, 2014)
	Operators and supervisors are cross functionally trained and flexible to rotate into different jobs	
Flexible job responsibilities	Flexible job responsibilities/ Flexible workforce allocation	(Vinodh and Chintha, 2011), (Vinodh and Balaji, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Saleeshya and Binu, 2019), (Narayanamurthy and Gurumurthy, 2016a),

		(Pakdil and Leonard, 2014)
	Flexible workforce to accept the adoption of new technologies	(Vinodh and Chintha, 2011), (Vinodh and Balaji, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Saleeshya and Binu, 2019), (Almutairi, Salonitis and Al-Ashaab, 2019), (Narayanamurthy and Gurumurthy, 2016a)
Multi-skilled workforce	Multi-skilled workforce	(Vinodh and Chintha, 2011), (Vinodh and Balaji, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Saleeshya and Binu, 2019), (Almutairi, Salonitis and Al-Ashaab, 2019), (Narayanamurthy and Gurumurthy, 2016a), (Doolen and Hacker, 2005), (Sorli *et al.*, 2010), (Yadav *et al.*, 2019)
Employee evaluation system	Employee evaluation	(Saleeshya and Binu, 2019), (Doolen and Hacker, 2005)
	Performance appraisal system	(Saleeshya and Binu, 2019)
	Review meetings	(Maasouman and Demirli, 2016)
Hiring process matches the needs of the organisation	Ensuring hiring process match the needs of the bank	(Madhan and Suresh, 2017)
	Ensuring hiring process capable of identifying the right talent	
Education, awareness, and practices for employee health and safety	Education, awareness and practices for employee health and wellness	(Guimarães and de Carvalho, 2014)
	Employee safety programmes/safety-improvement programs	(Saleeshya and Binu, 2019), (Narayanamurthy and Gurumurthy, 2016a)

Environment safety conditions	Environmental conditions	(Maasouman and Demirli, 2016)
	Safety	
Ergonomic workplace design	Physiological work-cost measurement system	(Saleeshya and Binu, 2019)
	Cost implications guidelines	
	Research and development cells	
	Claim compensation guidelines for faulty ergonomic design	
	Virtual organisation for distributed work and extended work centres	
	Management support systems for human engineering	
	Professional ergonomic societies partnership	
	Applied anthropometric principles	
	Ergonomic workplace design guidelines	
	Design guidelines for physical environment (heat/cold-lighting/heating)	
	Industrial sound control norms	
	Human-machine visual interactive system	
	Human machine system description standards	
	Ergonomic work place design guidelines	
	Task and human-machines interaction system	
	Specifications of system design	
	Identification and analysis of core trends	
	Workplace	(Bon and Kee, 2015)
	Industrial safety norms	(Saleeshya and Binu, 2019)
	Ergonomics	(Maasouman and Demirli, 2016)
	Clinical assistance against work-related musculoskeletal disorders	(Saleeshya and Binu, 2019)
Use of work teams, quality teams, or problem-solving teams for improvement projects and decision making	Utilisation of formal work teams, quality teams, or problem-solving teams for decision making	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Madhan and Suresh, 2017), (Narayanamurthy and Gurumurthy, 2016a)
	Team management for decision making	(Taj, 2005), (Narayanamurthy and Gurumurthy, 2016a), (Maasouman and Demirli, 2016), (Saleeshya and

		Binu, 2019), (Thanki and Thakkar, 2014)
	Use of teams for problem solving and improvement projects/ Use of work team	(Guimarães and de Carvalho, 2014), (Shetty, Ali and Cummings, 2010), (Narayanamurthy and Gurumurthy, 2016a)
	The workforce has organised, empowered, and involved teams to address performance, quality, and safety issues (yes or no)	(Shetty, Ali and Cummings, 2010)
	Usage of formal improvement project teams for bank wide issues	(Madhan and Suresh, 2017)
	Existence of improvement team including physician, pharmacist or medical equipment engineer with an understanding of improvement tools such as 5s	(Almutairi, Salonitis and Al-Ashaab, 2019)
Teams are cross- and multi-functional	Cross-functional teams	(Saleeshya and Binu, 2019), (Duarte and Cruz Machado, 2017)
	Multifunctional teams	(Al-Ashaab *et al.*, 2016)
	Improvement multidisciplinary steering committees	(Guimarães and de Carvalho, 2014)
Shallow organisational structure	Shallow organisational structure	(Saleeshya and Binu, 2019), (Narayanamurthy and Gurumurthy, 2016a), (Madhan and Suresh, 2017), (Duarte and Cruz Machado, 2017)
	Flat organisational structure and flexible business systems	(Narayanamurthy and Gurumurthy, 2016a)
Decentralised responsibilities	Decentralised responsibilities	
	Decentralisation	(Saleeshya and Binu, 2019)
Smooth information flow and feedback system	Smooth information flow	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Madhan and Suresh, 2017), (Yadav *et al.*, 2019)

	Smooth information flow and feedback system within organisation and across supply chain	(Narayanamurthy and Gurumurthy, 2016a)
	Open-feedback system	(Saleeshya and Binu, 2019)
Active and transparent information sharing at all levels	Transparency in information sharing	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Madhan and Suresh, 2017)
	Active information sharing at all levels (second part of 138)	(Guimarães and de Carvalho, 2014)
Simple and visual communication of information	Simple and visual communication (To what extent is use of visual communication anchored in the culture?)	(Weloa, Tonninga and Rølvåga, 2013)
	Increased visualisation	(Salem *et al.*, 2006)
	We post equipment maintenance records on shop floor for active sharing with employees	(Pakdil and Leonard, 2014)
	Milestones' achievements visibility between departments	(Guimarães and de Carvalho, 2014)
Oral and written information provided regularly	Oral and written information are provided regularly	(Pakdil and Leonard, 2014)
	Written information is provided regularly	(Pakdil and Leonard, 2014)
Vertical communications	Vertical communication	(Weloa, Tonninga and Rølvåga, 2013), (Madhan and Suresh, 2017), (Bon and Kee, 2015), (Guimarães and de Carvalho, 2014), (Duarte and Cruz Machado, 2017), (Welo and Ringen, 2017), (Saleeshya and Binu, 2019)
	Clearly communicate hiring and promotion standards for leaders and associates	(Guimarães and de Carvalho, 2014)
	Communication of organisation performance (quality, cost & delivery)	
	Hoshin plans integration across departments	
Cross-functional collaboration and	Improving practices for transferring knowledge between functional departments	(Welo and Ringen, 2017)

knowledge transfer (Yokoten)	Deploy Yokoten	(Guimarães and de Carvalho, 2014)
	Cross-functional collaboration	(Almutairi, Salonitis and Al-Ashaab, 2019)
	Communication between employees	(Duarte and Cruz Machado, 2017)
	Cross-functional knowledge flow (Assess practices for transferring knowledge between functional departments)	(Weloa, Tonninga and Rølvåga, 2013)
Formal systems (meetings) for knowledge transfer	Regular meetings with medical staff	(Almutairi, Salonitis and Al-Ashaab, 2019)
	Formal systems (meetings) for transferring lessons learned from improvement efforts	(Guimarães and de Carvalho, 2014)
	Quality circles	(Saleeshya and Binu, 2019)
	Use a daily 15 minute meeting at change shifts	(Guimarães and de Carvalho, 2014)
	Trade-off curves: How frequent do you use trade-off curves as a knowledge provision tool?	(Al-Ashaab *et al.*, 2016)
	Huddle meetings	(Salem *et al.*, 2006)
Capture and revisit lessons learned for each improvement project	Is gained knowledge documented after solving a design problem?	(Al-Ashaab *et al.*, 2016)
	Lessons learnt: At what point are lessons learnt captured and reused during a project?	
	Failures as opportunity for learning	(Madhan and Suresh, 2017)
	Knowledge/experience learning tools	(Lemieux, Pellerin and Lamouri, 2013)
	Revisit lessons learned of each improvement process	(Guimarães and de Carvalho, 2014)
Use of knowledge management system	Knowledge management	(Narayanamurthy and Gurumurthy, 2016a)
	Knowledge value stream (Rate role of knowledge in terms of capturing new markets and growing the business)	(Weloa, Tonninga and Rølvåga, 2013)
	Leveraging the role of knowledge as a means to capture new markets and grow the business	(Welo and Ringen, 2017)
	Defining knowledge ownership and managing the knowledge transformation process	
	Knowledge management practice: How well is a knowledge management programme and practice implemented in the company?	(Al-Ashaab *et al.*, 2016)

	Pool of experts: How do you access your pool of experts?	
	Knowledge provision: How is the required knowledge provided during the product development process?	
	Use of knowledge management systems and active information and idea sharing at all levels	(Guimarães and de Carvalho, 2014)
	Lean knowledge systems	(Saleeshya and Binu, 2019)
	Knowledge ownership and management (Is knowledge ownership defined, and is capturing processes systematic managed?)	(Weloa, Tonninga and Rølvåga, 2013)
	Set-based concurrent engagement (To what extent is front loading and SBCE used in design and knowledge generation?)	
Clearly known management goals	Clearly known management goal	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Madhan and Suresh, 2017)
	Vision and mission	(Duarte and Cruz Machado, 2017)
	Goal setting and action planning	(Maasouman and Demirli, 2016)
Strategic planning and decision-making system	Strategic decision-making system	(Saleeshya and Binu, 2019)
	Enterprise's strategic planning	(Karvonen *et al.*, 2012)
	Long-term thinking	(Duarte and Cruz Machado, 2017)
	Mission driven strategy	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
	PD strategy alignment	(Al-Ashaab *et al.*, 2016)
Target setting	What is the management's target operating capacity for individual departments or machines?	(Taj, 2005)
Systematic approach to prioritising projects with resource allocation	Product and portfolio management (Is there a systematic approach to prioritise projects with resource allocation?)	(Weloa, Tonninga and Rølvåga, 2013)
	Lean approach is driven by top hospital management	(Almutairi, Salonitis and Al-Ashaab, 2019)

Lean approach is driven by top hospital management	Top-down leadership endorsement	(Duarte and Cruz Machado, 2017)
	All major department heads within our plant work to encourage just-in-time production	(Thanki and Thakkar, 2014)
Management involvement and active participation	Management involvement	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Madhan and Suresh, 2017)
	Active management participation	(Yadav *et al.*, 2019)
	Manufacturing engineer involvement	(Al-Ashaab *et al.*, 2016)
	Manufacturing's role in PD (What role (authority and responsibility) does manufacturing take in projects?)	(Weloa, Tonninga and Rølvåga, 2013)
Process-focused management is employed throughout the organisation	Process-focused management is employed in throughout the firm	(Pakdil and Leonard, 2014)
	Process-focused management	(Saleeshya and Binu, 2019)
Implementation of a risk management program for information, materials, and for patient safety	Risk and complexity quotation	(Lemieux, Pellerin and Lamouri, 2013)
	Implementation of a risk management program for information, materials, and for patient safety	(Guimarães and de Carvalho, 2014)
Usage of a balanced performance assessment system	Usage of a balanced performance assessment system	
Provide leadership for quality improvement	Leadership	(Yadav *et al.*, 2019)
	Lean leadership model	(Saleeshya and Binu, 2019)
	Chief engineer leader	(Al-Ashaab *et al.*, 2016)
	Plant management provides personal leadership for quality improvement	(Thanki and Thakkar, 2014)
	Leaders are responsible for how the value-added work gets done	(Pakdil and Leonard, 2014)
	Team leadership rotates among team members	
	Conflict resolution even at lower level	(Madhan and Suresh, 2017)
	All major department heads within our plant accept responsibility for quality	(Thanki and Thakkar, 2014)

	Team leaders spend their time either training employees, monitoring the process, or improving it	(Pakdil and Leonard, 2014)
	Clear definitions of positions and authority	(Narayanamurthy and Gurumurthy, 2016a)
	Mentoring and coaching guidelines	(Saleeshya and Binu, 2019)
Financial reporting system supported in Lean accounting	Financial reporting system supported in Lean accounting	(Guimarães and de Carvalho, 2014)
Adoption of information technology for communication and hospital SC applications	IT-based communication system	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Adoption of information technology for hospital SC applications	(Almutairi, Salonitis and Al-Ashaab, 2019)
Focus on creating value for customers	Creating value for customers	(Duarte and Cruz Machado, 2017)
	Customer value	(Welo and Ringen, 2017)
	Robust process to capture, disseminate customer value with clarity	(Madhan and Suresh, 2017)
	Services to enhance value	(Doolen and Hacker, 2005)
	Patient-oriented focus	(Almutairi, Salonitis and Al-Ashaab, 2019)
Utilisation of digital tools	Digital tools in product D&E (Assess the role tools in achieving business and PD improvement goals?)	(Weloa, Tonninga and Rølvåga, 2013)
	Utilisation of digital tools	(Welo and Ringen, 2017)
Employee ideas encourage and taken seriously	Management encourages employee involvement and ideas	(Thanki and Thakkar, 2014)
	Hospital employees' ideas taken seriously	(Almutairi, Salonitis and Al-Ashaab, 2019)
	Creativity and entrepreneurship (Is creativity encouraged, valued and part of in product and technology strategy?)	(Weloa, Tonninga and Rølvåga, 2013)
	Creativity and entrepreneurship	(Welo and Ringen, 2017)
Commitment to continuous improvement	Commitment to continuous improvement	(Narayanamurthy and Gurumurthy, 2016a), (Karvonen *et al.*, 2012), (Bon and Kee, 2015), (Madhan and Suresh, 2017), (Almutairi,

		Salonitis and Al-Ashaab, 2019)
	Prevalence of continuous improvement culture	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Promote idea of continuous improvement in the organisational culture	(Madhan and Suresh, 2017)
	Commitment to change assessment (Labour productivity - organisational physical or financial output as compared to labour quantity)	(Guimarães and de Carvalho, 2014)
	Commitment by medical staff	(Almutairi, Salonitis and Al-Ashaab, 2019)
	Physician buy-in	
Culture of problem prevention and waste elimination in hospital	Culture of problem prevention and waste elimination in hospital	
	Culture to stop and fix problems permanently	(Madhan and Suresh, 2017)
	Commitment to find and eliminate waste	(Guimarães and de Carvalho, 2014)
	There is a total commitment to waste culture	(Pakdil and Leonard, 2014)
Employee's attitude tunes to accept changes and be open to new ideas	Culture of acceptance of change to enhance patient safety	(Almutairi, Salonitis and Al-Ashaab, 2019)
	Hospital open to new ideas	
	Willingness to change	(Bon and Kee, 2015)
	Employee's attitude tuned to accept the changes	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Rate the level of employee acceptance of the new approach	(Shetty, Ali and Cummings, 2010)
	Positive attitude of employees	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015), (Sorli *et al.*, 2010)
Clear understanding of lean philosophy by the whole hospital community	The clear understanding of lean philosophy by hospital community	(Almutairi, Salonitis and Al-Ashaab, 2019)
	Lean philosophical framework	(Saleeshya and Binu, 2019)
	Lean cultural popularisation programmes	

Trust, respect, and responsibility are core values in the organisation	Trust, respect, and responsibility (To what extent are trust, respect, and responsibility core values in the organisation?)	(Weloa, Tonninga and Rølvåga, 2013)
	Mutual trust and support	(Madhan and Suresh, 2017)
	Respect for people	
	To what extent do people have job security?	(Taj, 2005)
Adoption of value stream mapping	Adoption of value stream mapping	(Saleeshya and Binu, 2019), (Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Almutairi, Salonitis and Al-Ashaab, 2019), (Guimarães and de Carvalho, 2014), (Pakdil and Leonard, 2014), (Shetty, Ali and Cummings, 2010), (Narayanamurthy and Gurumurthy, 2016a)
	Focus on the value stream	(Karvonen *et al.*, 2012)
	Driving "change", boundaryless and value stream map	(Soliman and Gadalla, 2014)
Match each process using SIPOC structure	Match each process using SIPOC structure	(Guimarães and de Carvalho, 2014)
Flow time reduction	Lead time assessment	(Saleeshya and Binu, 2019)
	Lead time reduction	(Guimarães and de Carvalho, 2014)
	Reduction in throughput time during the last year on the product(s)	(Shetty, Ali and Cummings, 2010)
	Setup time, cycle time, and lead time reduction through cellular layout, quick changeover, rapid replenishment, etc. practices	(Narayanamurthy and Gurumurthy, 2016a)
	Implement SMED for changeover improvement	(Guimarães and de Carvalho, 2014)
	Cycle time reduction	(Doolen and Hacker, 2005)
	Minimal equipment idle time	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)

Implementation of kaizen practices	Number of improvement process projects (monthly and annually)	(Guimarães and de Carvalho, 2014)
	Do you remember any process improvement for the last three months? (The question specifically asks for improvements in the organisation)	(Martinez, 2018)
	Kaizen frameworks	(Saleeshya and Binu, 2019)
	Kaizen	(Al-Aomar and Hussain, 2018)
	The company has a formal continuous improvement program	(Shetty, Ali and Cummings, 2010)
	Formal systems to improve visibility in Supply Chain is all nodes	(Guimarães and de Carvalho, 2014)
	Dedicated continuous improvement (kaizen) events held per year	(Shetty, Ali and Cummings, 2010)
	No. of kaizen events	(Srinivasaraghavan and Allada, 2006)
	Use activity-based costing as potential improvement finding system	(Guimarães and de Carvalho, 2014)
Emphasis on direct observation and data-based decision making	Emphasis on direct observation (Gemba walk) and data-based decision	
	Fact-based decision making (Rate culture to make fact-based decision in the organisation at all levels?)	(Weloa, Tonninga and Rølvåga, 2013)
Waste identification and quantification	Waste identification and quantification	(Saleeshya and Binu, 2019), (Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Laoha and Sukto, 2015)
	Waste identification and quantification of HSC processes	(Almutairi, Salonitis and Al-Ashaab, 2019)
Elimination of identified wastes	Elimination of identified wastes	(Maasouman and Demirli, 2016)
	Elimination of equipment's waste and anomalies	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
	Is all the material used after finishing the job? (The question explores Muda overproduction. For automotive industry the question changes	(Martinez, 2018)

	to: How often will completed products stay in the factory without a customer?)	
	Employees cannot do their job because they are waiting for material or information from other departments (This statement looks after evidence of Muda waiting times)	
	Do you know what the main processes in the firm are? (The question explores Muda production process/Over-processing. It focuses on understanding the firm's knowledge of the process that gives higher value to the customer)	
	How many signatures are required for the approval of the purchase of office supplies? (The specific question also explores Muda production process/over-processing but it focusses on the logical sequence of processes)	
	How often must an employee search for tools or materials outside the desk? (This question investigates Muda useless motions)	
	What percentage of orders need reworks to match customer requirements? (This specific question focuses on Muda scrap and defects)	
	What percentage of products is returned under warranty? (This question also searches for evidence about Muda scrap defects)	
Classification of activities (Value identification)	Classification of activities (Value identification)	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
	Value identification	(Doolen and Hacker, 2005)
	Value-oriented processing	(Saleeshya and Binu, 2019)
Conversion of non-value added (NVA) into necessary but non-value added (NNVA)	Conversion of non-value added (NVA) into necessary but non-value added (NNVA)	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
Utilisation of employee suggestions	Inclusion of employee suggestion scheme	(Guimarães and de Carvalho, 2014), (Shetty, Ali and Cummings, 2010), (Pakdil and Leonard, 2014), (Duarte and Cruz Machado, 2017),

		(Narayanamurthy and Gurumurthy, 2016a)
	Inclusion of employees' suggestion scheme	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015), (Bon and Kee, 2015)
	Utilising and rewarding bottom-up suggestions for employee level problem	(Madhan and Suresh, 2017)
Close contact with physicians to enable them to engage in continuous improvement projects	Close contact with physicians to enable them to engage in continuous improvement projects	(Almutairi, Salonitis and Al-Ashaab, 2019)
Benchmarking of processes' best practices	Benchmarking of processes' best practices	(Guimarães and de Carvalho, 2014)
	Best practices through benchmarking	(Madhan and Suresh, 2017)
	Competitive benchmarking	(Martinez, 2018)
	Benchmark results for clinical indicators' standards above last comparison	(Guimarães and de Carvalho, 2014)
Monitoring, evaluation, and control of processes (and systems) and their improvement	If so, do you know how to turn in an evaluation of the improvement process? (And the final question confirms the impact of the improvements in the system)	(Martinez, 2018)
	Lean assessment module	(Saleeshya and Binu, 2019)
	LA control methods	
	Process accountability system	
	Plant auditing system	
	The company uses an internal auditing program for monitoring the effectiveness of systems and processes, and the results are regularly and formally reported to management	(Shetty, Ali and Cummings, 2010)
	Monitoring project tools	(Lemieux, Pellerin and Lamouri, 2013)
Process selection and implementation plan	Conceptual design selection	(Al-Ashaab *et al.*, 2016)
	How would you rate the overall bias of the plant's process selection with respect to technology level?	(Taj, 2005)
	Conduct of pilot study on new	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)

	Communication of the product development model: How is the current formal product development model communicated and who administers its implementation?	(Al-Ashaab *et al.*, 2016)
	Product requirements finalisation	
	Project initiation	
	Create and refine a transformation plan	(Karvonen *et al.*, 2012)
Sustainability of improvements	Sustainability of improvements	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
Process safety norms and safety audits	Process safety norms	(Saleeshya and Binu, 2019)
	Safety audits	
	Failure mode and effect analysis module	
Inventory and lot size reduction	Produce small lot sizes	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Lot size reduction	(Doolen and Hacker, 2005)
	Inventory and lot size reduction	(Narayanamurthy and Gurumurthy, 2016a)
Limited WIP inventory	Limited WIP inventory	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
Implement JIT techniques	JIT delivery to customers	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	JIT (with sub-techniques: on time deliveries, on time services, Kanban system)	(Al-Aomar and Hussain, 2018)
	JIT delivery to customers	(Yadav *et al.*, 2019)
	JIT integration standards	(Saleeshya and Binu, 2019)
	Cellular manufacturing	(Doolen and Hacker, 2005)
	Our production system works on cellular manufacturing system	(Pakdil and Leonard, 2014)
	Focused factory production system	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh,
	Organisation of manufacturing operations around similar product families	
	Utilisation of manufacturing cells	

		2013), (Matawale, Datta and Mahapatra, 2015)
Supply medicine at the pull of the patients	Demand driven production	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
	Supply medicine at the pull of the patients	(Almutairi, Salonitis and Al-Ashaab, 2019)
	Pull production	(Vinodh and Chintha, 2011), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013)
	Pull system	(Narayanamurthy and Gurumurthy, 2016a)
	Pull flow control	(Doolen and Hacker, 2005)
	End to end (EDE) pull (change over, line configuration & productivity, end to end pull (pull system), takt time production)	(Soliman and Gadalla, 2014)
Jobs are pulled by each supply station from previous supply station	Jobs are pulled by each supply station from previous supply station	(Saleeshya and Binu, 2019), (Almutairi, Salonitis and Al-Ashaab, 2019)
	Production at the stations is pulled by the current demand of the next station	(Pakdil and Leonard, 2014)
	Production is pulled by the shipment of finished goods	
Optimisation of processing sequence and flow	Optimisation of processing sequence and flow in shop order	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Single piece flow programs or practices are in use	(Pakdil and Leonard, 2014)
Process adaptability	How easy is it to shift output when the product mix changes?	(Taj, 2005)
	How easy is it to alter the total production rate by +- 15%?	
Production levelling	Heijunka modules	(Saleeshya and Binu, 2019)
	Heijunka (level load, sequencing)	(Soliman and Gadalla, 2014)
	Order-levelling	(Bon and Kee, 2015)
	Use "Pitch" (tack time) calculations for each service reference	(Guimarães and de Carvalho, 2014)

Products exceeding the customers' expectations	Products exceeding the customers' expectations	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Madhan and Suresh, 2017), (Guimarães and de Carvalho, 2014)
	Customer satisfaction	(Duarte and Cruz Machado, 2017)
Conduct of survey/studies to ensure quality status	Conduct of survey/studies to ensure quality status	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Madhan and Suresh, 2017)
	Internal and external customer satisfaction surveys above last year/time average	(Guimarães and de Carvalho, 2014)
Usage of TQM tools/ implementation of TQM techniques	Usage of TQM tools/ implementation of TQM techniques	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Madhan and Suresh, 2017)
	Total quality management	(Narayanamurthy and Gurumurthy, 2016a)
	Quality management programs	
	Total quality management	(Doolen and Hacker, 2005)
	Quality management/ quality management system	(Omogbai and Salonitis, 2016), (Al-Aomar and Hussain, 2018)
	Total quality management guidelines	(Saleeshya and Binu, 2019)
	Executive and/or senior management defines and documents the company's commitment to quality with respect to elements such as fitness for use, safety, performance, and dependability of the company's products	(Shetty, Ali and Cummings, 2010)
	Right the first time attitude with robustness	(Madhan and Suresh, 2017)

The company has a formal quality system and program	The company has a formally quality system and program	(Shetty, Ali and Cummings, 2010)
	How does the company define quality?	
	What tasks and functions are being handles by the central quality function?	
	The company has an up-to-date quality manual that clearly defines the processes, procedures, and resources that assure the quality of products and processes	
	The company has a formal quality assurance program that uses quantitative (statistical) methods, SPC, benchmarking, quality function deployment, etc. to analyse products and processes	
	Applied reliability principles	(Saleeshya and Binu, 2019)
	Service quality guidelines	
Measurable quality objective set on a regular basis in order to monitor quality	The company has measurable, time-based quality objectives set on a regular basis by the management of the company	(Shetty, Ali and Cummings, 2010)
	What performance measures are used to assess quality?	
	The percentage of time the product(s) passes quality checks the first time through	
Quality issues are tracked, reported, and communicated on a regular basis/ formal methods for handling, tracking, and reporting of non-conforming or defective parts and/or products	The company tracks, reports, and communicated "cost of poor quality" to everyone in the company on a regular basis	
	What is the organisational structure for communication on quality issues and specific improvements?	
	The company tracks customer returns and analyses the reasons for them	
	Product returns due to damage during shipping are a problem	
	The company has a corrective and preventative action program and uses it to monitor and improve the quality of products, processes, suppliers, and customer satisfaction. This includes formal methods for handling, tracking, and reporting of non-conforming or defective parts and/or products	
	Reactivity	(Maasouman and Demirli, 2016)
	New ways of coordination of design and manufacturing issues	(Vinodh and Chintha, 2011), (Vinodh and Vimal,

		2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Formal systems (meetings and training tools such as FMEA) for error report and analysis	(Guimarães and de Carvalho, 2014)
Jidoka (stop at every abnormality, autonomation)	Jidoka	(Soliman and Gadalla, 2014)
	Employees identify defective parts and stop the line	(Pakdil and Leonard, 2014)
	Employees identify defective parts, but do not stop the line	
	Defective parts are sent back to the employees responsible for the defect to adjust it	
	Scrap rate	(Shetty, Ali and Cummings, 2010)
	Preliminary lean tools adoption such as, autonomation	(Narayanamurthy and Gurumurthy, 2016a)
Process capability analysis	Conducts process capability analysis	(Thanki and Thakkar, 2014)
	Process capability analysis and improvement (Maybe more of an L2 - but no L3, see notes on 24)	(Maasouman and Demirli, 2016)
	We conduct product capability studies before product launch	(Pakdil and Leonard, 2014)
Implementation of poka-yoke	Poka yoke frameworks	(Saleeshya and Binu, 2019)
	Mistake or error proofing	(Doolen and Hacker, 2005)
	The percent of all operations the company uses poka-yoke methods (mistake-proofing, source inspection, checklists, machine gauging)	(Shetty, Ali and Cummings, 2010)
	Implementation of Poka-Yoke	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
	Error prediction increasement	(Guimarães and de Carvalho, 2014)
	Errors reduction/elimination	
	Safety industry KPIs better than last benchmark results	
	Poka yoke	(Laoha and Sukto, 2015)
	Minimise handoffs to avoid rework	(Madhan and Suresh, 2017)

Use of Taguchi methods (design of experiments)	We implement experimental design or Taguchi methods into our continuous improvement studies	(Pakdil and Leonard, 2014)
	Use design of experiments (Taguchi method)	(Thanki and Thakkar, 2014)
Root cause analysis (RCA)	"5 why" and RCA methodologies	(Saleeshya and Binu, 2019)
	Problem approach and root cause systems such as PDCA, A3, and DMAIC	(Guimarães and de Carvalho, 2014)
	Root-cause problem solving is integrated into the management system	(Pakdil and Leonard, 2014)
	Understanding problem solving tools to enhance patient safety	(Almutairi, Salonitis and Al-Ashaab, 2019)
	A3 report	(Duarte and Cruz Machado, 2017)
	Problem-solving tools	(Lemieux, Pellerin and Lamouri, 2013)
Statistical process control	We use SPC techniques to reduce process variance	(Pakdil and Leonard, 2014)
	Statistical process control	(Saleeshya and Binu, 2019)
	Use statistical process control (SPC)	(Thanki and Thakkar, 2014)
Quality is not infused at the cost of productivity	Quality is not infused at the cost of productivity	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
Application of totality concepts in achieving productivity	Application of totality concepts in achieving productivity	
Measure and improve resource productivity	Labour productivity index above last measure	(Guimarães and de Carvalho, 2014)
	Measures labour productivity	(Thanki and Thakkar, 2014)
	Productivity calculation module for flexible workforce	(Saleeshya and Binu, 2019)
	Productivity linked to the personnel prosperity	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Asset productivity index above last measure	(Guimarães and de Carvalho, 2014)
	OEE calculation and improvement	(Maasouman and Demirli, 2016)

Resource cost effectiveness	Cost effectiveness guidelines (Labour)	(Saleeshya and Binu, 2019)
	Materials cost/patient treated below last measure	(Guimarães and de Carvalho, 2014)
Kaizen costing	Kaizen method of product pricing	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Reduction of non value-adding costs	
Costing system focusing on the identification of value adding and non-value adding activities	Costing system focusing on the identification of value adding and non-value adding activities	
Standardisation of work and operating procedures	Standardisation of components	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
	What employee tasks were most affected by product standardisation?	(Shetty, Ali and Cummings, 2010)
	Parts standardisation	(Doolen and Hacker, 2005)
	Work standardisation	
	Standard operating procedures are developed, published and readily available in all areas	(Pakdil and Leonard, 2014)
	Non-manufacturing operations are standardized	
	Work standardisation and effective scheduling	(Narayanamurthy and Gurumurthy, 2016a)
	Percentage of standard procedures adoption	(Guimarães and de Carvalho, 2014)
	Is the company ISO-9000 certified, and has it passed subsequent audits?	(Shetty, Ali and Cummings, 2010)
	Has standardisation increased the throughput and efficiency of the organisation?	
	Has standardisation generated better usage of tools/instruments?	
	The workstations contain posted and updated standard work procedures (yes or no)	
	ISO & SOPs	(Al-Aomar and Hussain, 2018)
	5s and work standards	
	Operational best practices standards	(Lemieux, Pellerin and Lamouri, 2013)
	TTM standards	
	Standardisation of daily maintenance activities	(Maasouman and Demirli, 2016)
	Roles and responsibilities standards	(Lemieux, Pellerin and Lamouri, 2013)
	Standardisation for flexibility -> Q: Does your company standardise skill sets for flexibility in resource management/staffing?	(Weloa, Tonninga and Rølvåga, 2013)

	Test and design procedure standards	(Lemieux, Pellerin and Lamouri, 2013)
	Communication standards/ Obeya	
	Standardisation of problem solving	(Weloa, Tonninga and Rølvåga, 2013)
	Design strategy -> Q: Is there a design strategy (reuse), and is it integrated as a part of the design practice?	
	Standard operation procedures	(Laoha and Sukto, 2015)
Standardisation of processes	Standardisation of process	(Almutairi, Salonitis and Al-Ashaab, 2019)
	Percentage of standard procedures development	(Guimarães and de Carvalho, 2014)
	Standardisation of production processes (Maybe more of an L2 - but no L3, see notes on 24)	(Maasouman and Demirli, 2016)
	What difficulties (technical, financial, personnel, production, and quality) were encountered in implementing process standardisation?	(Shetty, Ali and Cummings, 2010)
	Standardisation of the PD process -> Q: Assess the Product Development process from its focus on quality of deliverables?	(Weloa, Tonninga and Rølvåga, 2013)
	Standardised processes	(Saleeshya and Binu, 2019)
	Promote process standardisation	(Madhan and Suresh, 2017)
Standardisation of service provision	The customer complains about the differences between products from different jobs (A system with CI provides the same service. Changes are not seen as complaints)	(Martinez, 2018)
	What role has quality played in product standardisation?	(Shetty, Ali and Cummings, 2010)
	Standardised service	(Al-Aomar and Hussain, 2018)
Systemisation of processes	Systemisation of processes	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
Simplification of processes	Simplification of processes	
Flexible set-ups	Flexible set-ups	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
Setup time reduction	Less time for changing the machine set-ups	
	Setup time reduction	(Bon and Kee, 2015)

	What is the average overall setup time (in minutes) for major equipment?	(Taj, 2005)
	Redesigns equipment to shorten setup time	(Thanki and Thakkar, 2014)
	Uses special tools to shorten setup time	
	Redesigns jigs or fixtures to shorten setup times	
	Setup time	(Narayanamurthy and Gurumurthy, 2016a)
	Setup time reduction	(Doolen and Hacker, 2005)
	Setup time control system	(Saleeshya and Binu, 2019)
	What portion of machine operators have had formal training in rapid Setup techniques?	(Taj, 2005)
	To what extent are managers and workers measured and judges on setup performance?	
	Trains employees to shorten setup time	(Thanki and Thakkar, 2014)
Usage of automated tools used to enhance the production	Usage of automated tools used to enhance the production	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Automation (under technology)	(Yadav *et al.*, 2019)
	Automatic tool changing systems	(Saleeshya and Binu, 2019)
	Exploration of machine tool automation	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
Activity policy to help keep work environment clean, tidy, and uncluttered	Activity policy to help keep work areas clean, tidy, and uncluttered	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	"5s" shop-floor management	(Saleeshya and Binu, 2019)
	5S is integrated into the management system	(Pakdil and Leonard, 2014)
	Five S's	(Salem *et al.*, 2006)
	The percentage of the entire facility (administration, sales, shop floor, shipping/receiving, etc.) that have	(Shetty, Ali and Cummings, 2010)

	incorporated the 5S concept of sort, straighten, sanitise, sweep, sustain	
	5S	(Laoha and Sukto, 2015)
	5S methodology deployment for clean, safe, and ergonomic work environment	(Guimarães and de Carvalho, 2014)
	Work environment, cleanliness, and orderliness	(Gonçalves and Salonitis, 2017b)
	Cleanliness	(Oleghe and Salonitis, 2016)
	What does the workplace look like after working hours? (the question investigates the level of cleanness of the workplace after working hours. It is about finding evidence of 5S characteristics which provide information about how often the firm cares about the space they use for work)	(Martinez, 2018)
Workplace organisation and standardisation	Shop-floor organisation	(Doolen and Hacker, 2005)
	Layout (stacking pattern, aisle configuration, zoning, number and location of doors, number and location of docks, floors and yard pavement, roof systems and bay sizing, walls and landscaping, land coverage and future use)	(Sharma and Shah, 2016)
	Workplace standardisation	(Saleeshya and Binu, 2019)
	Groups equipment into product families	(Thanki and Thakkar, 2014)
	Proper allocation of tools	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
	Elimination of unnecessary tools	
	Equipment is grouped to produce a continuous flow of products	(Pakdil and Leonard, 2014)
Utilisation of advances MRPII systems	Utilisation of advances MRPII systems	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	The company plans and schedules production using MRP, MRP & Kanban, DBR, AVX business management system, Made 2 Manage ERP system	(Shetty, Ali and Cummings, 2010)
Usage of ERP systems	Usage of ERP systems	

Procurement policy based on time schedule	Company's procurement policy based on time schedule	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Processes of medical procurement	(Almutairi, Salonitis and Al-Ashaab, 2019)
Strategic network in SCM to exercise zero inventory system	Strategic network in SCM to exercise zero inventory system	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
Engage physicians in forecasting planning processes	Engage physicians in forecasting planning processes	(Almutairi, Salonitis and Al-Ashaab, 2019)
Execution of short range planning	Execution of short range planning	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Schedule effectiveness monitoring system	(Saleeshya and Binu, 2019)
	Production scheduling	(Doolen and Hacker, 2005)
	Service scheduling mechanism	(Saleeshya and Binu, 2019)
	Last planner (Reverse phase, scheduling, six-week look-ahead, weekly work plan, reasons for variance, PPC charts)	(Salem *et al.*, 2006)
	Scheduled activities	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
Worker scheduling	Shift calculation module	(Saleeshya and Binu, 2019)
	Worker monitoring cell	
	Crew selection rules (for selection from rosters)	
Workstation and equipment tasking system/scheduling	Equipment tasking system based on priority	
	Effective material handling system for optimal transfer time	

	Machine uptime calculation module	
Understanding task dependencies and planning the precedence	Planning for precedence of task understanding task dependencies	(Madhan and Suresh, 2017)
	Task analysis module	(Saleeshya and Binu, 2019)
	Priority rules selection guidelines	
Maximise the concurrency of independent task	Maximise the concurrency of independent task	(Madhan and Suresh, 2017)
	Concurrent engineering	(Doolen and Hacker, 2005)
	Preliminary lean tools adoption such as, concurrent engineering	(Narayanamurthy and Gurumurthy, 2016a)
Process monitoring	Prioritise critical tasks and monitor	(Madhan and Suresh, 2017)
	Processes are controlled through measuring inside the process	(Pakdil and Leonard, 2014)
	Measuring is done after each process	
	Measuring is done only after product is complete	
Process variation reduction mechanism	Variation reduction mechanisms	(Saleeshya and Binu, 2019)
	Process variation average	(Guimarães and de Carvalho, 2014)
Resource planning and management	Resource planning and management	(Madhan and Suresh, 2017), (Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
	Work delegation and interchange-ability of personnel	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015), (Madhan and Suresh, 2017)
Utilisation of optimisation tool	Utilisation of optimisation tool	(Madhan and Suresh, 2017), (Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015), (Al-Aomar and Hussain, 2018)
Using ANDON device	Using ANDON device	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)

Introduction of Kanban system for material and patient flow	Introduction of card system	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
	Use Kanban system for material and patient flow	(Guimarães and de Carvalho, 2014)
	We use Kanban, squares, or containers of signals for production control.	(Pakdil and Leonard, 2014)
	Kanban system	(Laoha and Sukto, 2015)
KPI visibility	Visibility on project monitoring	(Lemieux, Pellerin and Lamouri, 2013)
	Visibility on results (cost/quality/delay)	
	Visibility on state of change and capacity	
	Visibility on deliverables quality	
	Visibility on return on investment (ROI)	
Visual controls (signs, pictures, procedures, etc.) in place for error and complexity	The company has visual controls (signs, pictures, procedure, etc.) in place at the workstations	(Shetty, Ali and Cummings, 2010)
	Information continuously is displayed in dedicated spaces	(Pakdil and Leonard, 2014)
	Preliminary lean tools adoption such as visual control	(Narayanamurthy and Gurumurthy, 2016a)
Implementation of TPM techniques	Implementation of TPM techniques	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015), (Bon and Kee, 2015), (Doolen and Hacker, 2005), (Narayanamurthy and Gurumurthy, 2016a), (Omogbai and Salonitis, 2016)
	Productive maintenance (with sub-techniques: schedule maintenance, preventive maintenance, corrective monitoring, and safety management)	(Al-Aomar and Hussain, 2018)
	TPM is applied throughout the firm	(Pakdil and Leonard, 2014)
	Percentage of process equipment currently covered by a total productive maintenance program	(Shetty, Ali and Cummings, 2010)
	Total productive maintenance framework	(Saleeshya and Binu, 2019)
	Total productive maintenance	
	Autonomous maintenance	(Maasouman and Demirli, 2016)
	Preventive, predictive and proactive maintenance	(Maasouman and Demirli, 2016)
	Total preventive maintenance	(Yadav *et al.*, 2019)

Maintenance management	How is maintenance performed? (Maintenance of tools and equipment is essential in a Lean system. These activities must be performed constantly to pursue perfection)	(Martinez, 2018)
	Maintenance of installed machine	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
	Identification and prioritisation of critical machines	
Equipment down-time reduction techniques	Measures equipment downtime	(Thanki and Thakkar, 2014)
	Machine down-time reduction techniques	(Saleeshya and Binu, 2019)
	Do equipment breakdowns limit or interrupt production?	(Taj, 2005)
	Describe equipment records and data. Include records of uptime, repair history, and spare parts. Include repair and parts manuals	
	What is the overall average availability of plant equipment?	
Inventory turns measured	What is the overall inventory turnover, including finished goods, WIP, and purchased/raw material?	(Taj, 2005)
	What is the ratio of inventory turnover to the industry average?	
	Measures inventory turns	(Thanki and Thakkar, 2014)
	Inventory turns ratio above last measure	(Guimarães and de Carvalho, 2014)
	The number of times inventory turns over per year	(Shetty, Ali and Cummings, 2010)
	For the categories of finished goods, WIP, and purchased/raw materials, what portion of middle and upper managers can state from memory the current turnover and purpose of each type?	(Taj, 2005)
Inventory and material logistics management rules	Inventory policy implementation guidelines	(Saleeshya and Binu, 2019)
	Logistics management rules	
	Cross docking/drop shipping	
Inventory control systems	Inventory control (with sub-techniques of EOQ model, holding & ordering cost, and forecasting system)	(Al-Aomar and Hussain, 2018)
	Effective lot size calculation module	(Saleeshya and Binu, 2019)
	Inventory classification scheme	
	Inventory status notification system	
	Work-in-progress monitoring system	

	Warehouse capacity monitoring system	
	Inventory performance measurement system	
Capacity management system	Capacity management system	
	Capacity management programme	
Layout flexibility	Flexibility in layout/ layout flexibility	(Vinodh and Vimal, 2012), (Matawale, Datta and Mahapatra, 2015)
Workforce flexibility	Workforce training for flexibility	(Saleeshya and Binu, 2019)
	Reliability monitoring mechanisms	
	Labour union-management agreements on skilled labour	
Flexibility of the offer	Product customisation	(Doolen and Hacker, 2005)
	Does it happen that the agreed parameters of the product are impossible to make? (This question focusses on flexibility of the offer)	(Martinez, 2018)
	Does the standard offer of your services change based on customer requirements?	
Machine flexibility	Flexible manufacturing systems	(Saleeshya and Binu, 2019)
	Machine flexibility	(Yadav *et al.*, 2019)
	Machine change over cost evaluation module	(Saleeshya and Binu, 2019)
	Machine reliability control systems	
	Productivity calculation modules for flexible machines	
Management interest towards investment on FMS concepts	Management interest towards investment on FMS concepts	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
Formal and informal “Voice of customer” system	Formal and informal "customer voice" system	(Guimarães and de Carvalho, 2014)
	Voice of customer cells/ A well-defined voice of consumer (physicians/patients) (VOC)	(Saleeshya and Binu, 2019), (Almutairi, Salonitis and Al-Ashaab, 2019)
	To what extent is it possible to adapt the standardised requirements of customers to your products?	(Martinez, 2018)
	Customer feedback system	(Saleeshya and Binu, 2019)
	Feedback assessment and implementation guidelines	
	Physician/patient feedback on quality, cost, time, and delivery performance	(Almutairi, Salonitis and Al-Ashaab, 2019)

	Can you determine the frequency of customer complaints? (The question explores the ability of the organisation to capture customer complaints)	(Martinez, 2018)
	We have frequent follow-up with our customer for quality/service feedback	(Pakdil and Leonard, 2014)
	How is the job specified technically? Or how do you get to know customer requirements? (The fulfilment of customer requirements is quality. Then, the firm should have mechanisms and practices that allow firm to provide these requirements)	(Martinez, 2018)
Customer requirement, needs, and preferences are prioritised and adopted	Customer involvement and their requirement adoption	(Narayanamurthy and Gurumurthy, 2016a)
	Customer requirements analysis	(Doolen and Hacker, 2005)
	Our customers are directly involved in current and future product offerings	(Pakdil and Leonard, 2014)
	Perceived role of customer	(Weloa, Tonninga and Rølvåga, 2013)
Patients/physicians involved with continuous improvement efforts	Physicians/patients participate in continuous improvement initiatives	(Almutairi, Salonitis and Al-Ashaab, 2019)
	Integration of customer in continuous improvement of product quality	(Weloa, Tonninga and Rølvåga, 2013)
Close cooperation and collaboration with customer	Customer relationship	(Yadav *et al.*, 2019)
	Long-term relationship	(Duarte and Cruz Machado, 2017)
	Close cooperation	
	Collaboration with customer in NPD	(Weloa, Tonninga and Rølvåga, 2013)
	Customer interaction teams	(Saleeshya and Binu, 2019)
Information sharing	Information sharing	(Duarte and Cruz Machado, 2017)
Market analysis and forecasting	Market analysis cell	(Saleeshya and Binu, 2019)
	Advanced forecasting cell	
Demand management and stabilisation	Demand stabilisation	(Doolen and Hacker, 2005)
	Demand stabilisation with allowable variety through standard/ modular/ platform components, sub-assembly, and products	(Narayanamurthy and Gurumurthy, 2016a)
	Demand management system	(Saleeshya and Binu, 2019)
	Unpredictable patient demand	(Almutairi, Salonitis and Al-Ashaab, 2019)

Minimum delivery lead time and on-time delivery	Minimum delivery lead time and on-time delivery	(Narayanamurthy and Gurumurthy, 2016a)
	The percentage of on-time delivery from major suppliers	(Shetty, Ali and Cummings, 2010)
	Delivery performance improvement	(Doolen and Hacker, 2005)
	Measures vendor performance - on-time delivery	(Thanki and Thakkar, 2014)
	Minimise delivery lead times of medical supplies	(Almutairi, Salonitis and Al-Ashaab, 2019)
	Medical supplies arrive on time and in the correct amounts	
	What is the on-time delivery performance?	(Taj, 2005)
	Measures on-time delivery	(Thanki and Thakkar, 2014)
Key suppliers deliver to plant on JIT basis	Key suppliers deliver to plant on JIT basis	(Pakdil and Leonard, 2014)
Deliver urgent medicine when needed or in emergency cases	Deliver urgent medicine when needed or in emergency cases	(Almutairi, Salonitis and Al-Ashaab, 2019)
Quality of source considered when selecting suppliers	Quality at source	(Al-Aomar and Hussain, 2018)
	Quality of source (Prioritising quality of source when selecting suppliers)	
	We consider quality as our number one criterion in selecting suppliers	(Pakdil and Leonard, 2014)
Formal supplier certification program	We have a formal supplier certification program	
	Documented quality standards	(Saleeshya and Binu, 2019)
	Supplier's ISO 9001 and ISO 14001 implementation	(Duarte and Cruz Machado, 2017)
	"Quality at source" guidelines	(Saleeshya and Binu, 2019)
Supplier quality inspection and improvement programmes	Standardised quality inspection system	
	What portion of raw material and purchased parts comes from qualified suppliers with no need for incoming inspection?	(Taj, 2005)
	What portion of raw material and purchased items is delivered directly to the point of use without incoming inspection or storage?	
	Does the company certify suppliers?	(Shetty, Ali and Cummings, 2010)
	The company tracks and analyses defects on items and materials purchased from suppliers.	
	Measures vendor performance - product quality	(Thanki and Thakkar, 2014)

	Supplier quality improvement programmes	(Saleeshya and Binu, 2019)
	We have helped our suppliers to improve their product quality	(Pakdil and Leonard, 2014)
Providing training in quality issues to the supplier personnel	Providing training in quality issues to the supplier personnel	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
	Combined training programmes	(Saleeshya and Binu, 2019)
Total cost evaluation	Total cost evaluation	(Doolen and Hacker, 2005)
	Incurred costs due to shortage of medicine	(Almutairi, Salonitis and Al-Ashaab, 2019)
Cost control measures	Cost control measures	(Saleeshya and Binu, 2019)
Competitive pricing mechanism	Competitive pricing mechanism	
Flexible payment methods	Flexible payment methods	
Suppliers involved with continuous improvement, quality, and problem solving	What role have the suppliers played in the quality function?	(Shetty, Ali and Cummings, 2010)
	What resources were necessary to effectively use suppliers in the quality function?	
	What quality assurance tasks have been delegated to suppliers?	
	We have continuous improvement programs that include our key suppliers	(Pakdil and Leonard, 2014)
	We regularly solve problems jointly with our suppliers	
Suppliers are seen as a partner of the firm and included in planning and goal-setting activities	We include our key suppliers in our planning and goal-setting activities	
	Suppliers are perceived as a partner of the firm	
	Extended organisation	(Saleeshya and Binu, 2019)
Technological assistance to and from suppliers	Technological assistance to and from the suppliers	(Narayanamurthy and Gurumurthy, 2016a)
	Providing technological assistance to the suppliers	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)

	Technological support systems	(Saleeshya and Binu, 2019)
Providing financial assistance to the suppliers	Providing financial assistance to the suppliers	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
Information and profit sharing with suppliers	Information and profit sharing with suppliers	(Narayanamurthy and Gurumurthy, 2016a)
	Information exchange	(Doolen and Hacker, 2005)
	Information sharing	(Duarte and Cruz Machado, 2017)
	Suppliers have access to the company's production and inventory database.	(Shetty, Ali and Cummings, 2010)
	Information exchange/sharing across the hospital supply chain	(Almutairi, Salonitis and Al-Ashaab, 2019)
	We and our trading partners exchange information that helps establishment of business planning	(Pakdil and Leonard, 2014)
Supplier feedback system	Supplier feedback system	(Saleeshya and Binu, 2019)
	We give our suppliers feedback on quality and delivery performance	(Pakdil and Leonard, 2014)
Transparent communication systems	Transparent communication systems	(Saleeshya and Binu, 2019)
Proactive and long-term relationship established with suppliers	Long-term relationship	(Duarte and Cruz Machado, 2017), (Doolen and Hacker, 2005)
	We strive to establish long-term relationship with our suppliers	(Pakdil and Leonard, 2014)
	Proactive relationships with key stakeholders	(Guimarães and de Carvalho, 2014)
	Close cooperation	(Duarte and Cruz Machado, 2017)
	Supplier relations cell	(Saleeshya and Binu, 2019)
Supplier monitoring and evaluation framework	Supplier evaluation	(Doolen and Hacker, 2005)
	Supplier evaluation frameworks	(Saleeshya and Binu, 2019)
	Supplier evaluation	(Duarte and Cruz Machado, 2017)
	Supply monitoring system	

Supplier selection frameworks	Supplier selection frameworks	(Saleeshya and Binu, 2019)
Vendor management system	Vendor management system	
IT application to exercise better vendor and supplier management	IT application to exercise better vendor and supplier management	(Vinodh and Chintha, 2011), (Vinodh and Vimal, 2012), (Azadeh *et al.*, 2011), (Vimal and Vinodh, 2013), (Matawale, Datta and Mahapatra, 2015)
Supply variability monitoring module	Supply variability monitoring module	(Saleeshya and Binu, 2019)

Appendix D Approach to leanness assessment of considered studies

This appendix provides a summary of the assessment methodology and leanness computation method used by the studies considered for their approaches after being filtered in Section 6.2.2 in Table D.1.

Table D.1 Approach to leanness assessment of considered studies

Author	Assessment methodology	Leanness computation method
(Vinodh and Chintha, 2011)	Fuzzy-based leanness assessment	Fuzzy logic computation method
(Vinodh and Balaji, 2011)	Fuzzy-based leanness assessment	Fuzzy logic computation method
(Vinodh and Vimal, 2012)	30 criteria-based leanness assessment methodology using fuzzy logic	Fuzzy logic computation method
(Taj, 2005)	Survey	Averages indicator scores & weights sub-elements for a score for each sub-element No overall score
(Wan and Chen, 2009)	Adaptive assessment approach	Unclear
(Shetty, Ali and Cummings, 2010)	Survey using a Lean Relative Weight table. Weight is applied from 10 to 100% indicating the relevant weight particular aspects of lean thinking methods or culture have on the makeup of successful lean manufacturing acceptance & implementation. The view of how much weight each lean component contributes to a successful lean	Information provided by respondent was used to derive weighting factors to associate answers to questions in the questionnaires.

	environment was provided through a check-list of the relevant view.	
(Vimal and Vinodh, 2013)	ANN & fuzzy approach	Artificial neural network (ANN) has been used for performing fuzzy logic-based leanness assessment along with triangular fuzzy numbers
(Vinodh and Dinesh Kumar, 2012)	Fuzzy-based leanness assessment	Decision support system (DSS) for multi grade fuzzy leanness assessment (MGFLA) (DSS-MGFLA)
(Matawale, Datta and Mahapatra, 2015)	Fuzzy-based leanness assessment	Fuzzy-based leanness assessment system using generalised interval-valued (IV) trapezoidal fuzzy numbers set
(Al-Ashaab *et al.*, 2016)	Adopted Balanced scorecard.	Authors weighted importance of the 4 lean perspectives. Each perspective has a given number of questions; however, they were not weighted at that level
(Duarte and Cruz Machado, 2017)	Criterion scale and calculation method were based on EFQM evaluation. Green-lean assessment method used.	Scoring weight technique was based on the awards MBNQA, EFQM, & SP. Level 2 indices were weighted equally. Weighted average of scores provided was used to determine leanness.
(Guimarães and de Carvalho, 2014)	Survey (Assessment scale).	The different dimensions (elements) are weighted differently, with the last dimensions having sub-dimensions that are equally weighted. The lowest level of indices are not weighted by respondent, weights pre-determined.
(Matawale, Datta and Mahapatra, 2015)	Fuzzy-based leanness assessment.	Fuzzy-based leanness assessment.

(Saleeshya and Binu, 2019)	Neuro-fuzzy hybrid modelling (Stage 1: fuzzy modelling. Stage 2: neural network modelling).	Artificial neural network (ANN) has been used for performing fuzzy logic-based leanness assessment along with triangular fuzzy numbers.
(Almutairi, Salonitis and Al-Ashaab, 2019)	Multi-grade (multi-attributes) fuzzy logic.	Judgement of experts and stakeholders are used to weight the effect of alternatives and categories. Fuzzy logic computation method used to determine leanness.
(Rakhmanhuda and Karningsih, 2018)	Fuzzy logic and aggregate scoring.	Weighted with Brown-Gibson method.
(Madhan and Suresh, 2017)	Multigrade fuzzy approach.	Fuzzy logic computation method.
(Gomez, 2009)	Lean Excellence Assessment Framework Web-based tool, requiring participant to indicate the level of implementation for a check list of practices.	Detail not provided.

Appendix E Preliminary SLAT landing page

This appendix shows the landing page of the preliminary SLAT developed in Chapter 6 in Figure E.1.

INTRODUCTION

The sustainable lean assessment tool (SLAT) presented is a self-assessment tool developed for hospitals that can be used to ascertain the degree to which practices that enable the sustainable implementation of lean have been implemented at the facility. It thus determines how capable the hospital is to sustain lean and prioritises practices in need for better implementation to improve this capability. The purpose of the SLAT is thus to support a more successful and sustainable transition towards a lean hospital, so that more significant and long-term improvements can be realised.

GETTING STARTED

This page serves as an introduction to the tool contained. It explains the overall structure of the tool and how to go about using it, how to interpret the results, as well as providing a navigation index for easy navigation to any of the pages contained within the tool. Please carefully read this page before commencing with the assessment.

STRUCTURE OF THE TOOL

In order to ascertain how capable a hospital is of sustaining lean, this tool uses ratings indicating the degree to which a collection of practices supporting a long-term adoption of lean has been implemented at the facility. These ratings are provided by the user and are collected through the use of two different assessment forms, namely the *Lean Sustainability* and *Leanness* assessments. The *Lean Sustainability* form makes up the main assessment and is used to determine the hospital's capability to sustain lean, it includes 30 practices arranged into 10 overarching areas. Each of these practices is scored by the user for their level of implementation. For one of the practices, however, instead of providing a score directly, the *Leanness* assessment is used as a supplementary assessment form to provide more specific indicators used to determine the implementation level of that area.

Therefore, in order to obtain your results, implementation ratings in the form of linguistic terms must be provided for each of the leanness indicators and sustainability practices by making use of the drop-down lists provided. The implementation rating refers to the degree to which a given practice has been implemented in the hospital. This can be scored as worst, very poor, poor, fair, good, or excellent, in increasing degree of implementation. The provided scores will determine the weighted overall score for the hospital's capability to sustain lean, as well as a ranked list of sustainability practices that need to be prioritised for improvement. A leanness score from the leanness assessment is also provided and can be used to compare the scores across the different areas and to prioritise the

INSTRUCTIONS

1. When you have read the introduction page and are ready to proceed, click the button at the bottom of this page labelled "BEGIN ASSESSMENT". This will navigate you to the overarching *Lean Sustainability* assessment form. Alternatively, use the navigation panel on the top right of this page to navigate to the assessment.

2. Provide implementation scores for each of the sustainability practices by making use of the drop-down lists provided. For practice number S2, a button for the *Leanness* assessment form which provides more specific indicators for this practice is provided in place of a drop-down list. Click this button to navigate to the form.

3. Provide implementation scores for each of the leanness indicators by making use of the drop-down lists provided. When this is complete, you can use the back arrow at the top left of the page to navigate back to the *Lean Sustainability* form. Alternatively, the navigation panel can also be used to proceed to another section of the tool. When the *Leanness* form has successfully been completed, the implementation rating for practice number S2 in the *Lean Sustainability* form will reflect the appropriate rating. If the Leanness form has not been completed, it will state "Leanness assessment incomplete". Both forms will need to be completed to obtain your results.

4. Once both assessment forms have been completed, click the right arrow or the "RESULTS" button to navigate to the results.

Any of the scores given can be changed and any assessment forms can be revisited at any point during the assessment.

UNDERSTANDING THE RESULTS

The results page provides three forms of output: 1) overall leanness and capability to sustain scores, 2) an importance ranking of the sustainability practices in need of improvement, and 3) a radar chart comparing the leanness scores of the different lean areas. Each is explained below.

1. Capability and leanness score

The two scores provided are rated on a linguistic scale. Both scores are weighted according to the built-in weights for the degree to which a given practice or indicator contributes to the hospital's capability to sustain lean or leanness. The 'Hospital sustainability capability' score is the result of the overall assessment indicating the degree to which the hospital is capable to sustain lean, this can be either extremely capable, very capable, capable, fairly capable, or poorly capable, in decreasing levels of capability. Similarly, the leanness score is a result of the leanness sub-assessment and indicates the extent to which the hospital has implemented the lean philosophy as either extremely lean, very lean, lean, fairly lean, or poorly lean, where extremely lean represents a higher level of adoption of lean

2. Ranked priorities

All the sustainability practices are ranked according to the importance of their improvement in descending order, where improving the first practice shown will most significantly improve the overall capability of the hospital to sustain lean. This ranking takes into consideration both the implementation level of a given practice and the degree to which it contributes to the capability to sustain lean, which is based on the weights built into the tool.

3. Radar chart

The radar chart represents the 5 lean principles and the extent to which they are being practised in the hospital for an easy visualisation so that areas of improvement can be identified.

NOTES ON THE TOOL

This tool focuses specifically on leanness, and thus assesses only the extent to which lean practices have been adopted following the implementation of lean in the hospital, it is therefore intended to be used alongside assessment systems focusing on the improvements that have been realised as a result of this implementation, in order to comprise a full lean evaluation. It is also suggested that the user of the SLAT have a sufficient understanding of lean and their hospital's implementation practices.

BEGIN ASSESSMENT

Figure E.1 preliminary SLAT landing page

Appendix F Delphi Round 1 assessment responses

This appendix provides the detailed responses received for each question in the first assessment round of the Delphi study. Table F.1 shows the scores received for Question 1, Table F.2 shows those for Question 2, and Table F.3 includes the score for Questions 3 to 5.

Table F.1 Round 1 Question 1 responses

AREAS	PRACTICES		SME Responses					SUMMARY	
			1	2	3	4	5	Median	IQR
Measurement system	S_{11}	Measurement system	6	7	7	6	6	6	1
Lean tools and principles	S_{21}	Holistic implementation of lean philosophy	5	6	4	7	5	5	1
Knowledge and competency	S_{31}	Training doctors, staff, and management	5	7	5	7	5	5	2
	S_{32}	Training is tailored to the hospital's context	6	6	7	N/A	5	6	0.5
Communication and feedback	S_{41}	Visible communication of information	5	7	7	6	5	6	2
	S_{42}	Communicate reasons for change and improvement successes	5	7	5	7	6	6	2
Leadership	S_{51}	There is leadership buy-in	5	7	7	7	7	7	0
	S_{52}	Long-term committed and actively involved management	4	6	6	7	7	6	1
	S_{53}	Visible and stable support	4	7	5	7	7	7	2
	S_{54}	Availability of resources	5	5	4	6	5	5	0
Workforce empowerment	S_{61}	Participation	4	6	6	7	5	6	1
	S_{62}	Ownership	4	6	7	7	6	6	1
Culture	S_{71}	Long-term and continuous implementation	5	7	4	7	5	5	2
	S_{72}	There is a culture change	5	7	7	7	4	7	2
	S_{73}	Open, no-blame culture	4	7	4	7	6	6	3
	S_{74}	Patient-centred and process-driven	5	7	5	6	6	6	1

	S_{75}	A bottom-up approach is adopted	4	7	4	6	4	4	2
	S_{76}	Rewards and recognition	3	6	7	7	4	6	3
	S_{77}	Teamwork	4	7	5	7	4	5	3
Lean team	S_{81}	Clarity of roles and responsibilities	5	6	7	7	5	6	2
	S_{82}	Utilisation of internal resources	7	6	7	6	5	6	1
	S_{83}	Lean champion	7	7	5	7	5	7	2
	S_{84}	Teams are multi-professional and multi-disciplinary	5	4	4	6	5	5	1
Change management	S_{91}	Strategic planning	6	7	4	7	4	6	3
	S_{92}	Improvement program and organisational strategy integration	5	7	7	7	5	7	2
	S_{93}	Paced hospital-wide implementation	6	7	7	7	6	7	1
	S_{94}	Sustainability plan	4	6	4	7	6	6	2
	S_{95}	Gain stakeholder commitment and buy-in	5	7	7	7	5	7	2
	S_{96}	Contextual influence is understood	5	5	3	6	4	5	1
Organisation structure	S_{101}	There are no functional and professional silos	3	6	5	7	6	6	1

Table F.2 Round 1 Question 2 responses

PRACTICE RATINGS			SME Responses					SUMMARY	
Principles	Practices	Indicators	1	2	3	4	5	Median	IQR
Identify value	Define customer expectations	A formal and informal "voice of customer" system is in place for close cooperation, collaboration, and information sharing with the customer, allowing their requirements, needs, and preferences to be adopted and prioritised. (L1)	6	7	5	7	5	6	2
Map the value stream	Identify and eliminate wastes	Process and value streams are mapped and analysed to classify activities as value-added (VA), non-value added (NVA), or necessary	5	7	7	7	5	7	2

		but non-value added (NNVA). These activities identify wastes so that they can be minimised or eliminated where possible. Tools such as value stream mapping (VSM), 5 Whys, plan-do-check-act (PDCA) cycle, A3 report, DMAIC, and root cause analysis are used to map the value stream and identify and eliminate wastes. (L2)							
Create flow	Workload levelling (Heijunka)	The processing sequence is optimised, and its variation is reduced to level workload for smooth flow without interruptions, delays, or bottlenecks. (L3)	4	7	4	7	6	6	3
		Plans for resource management are drawn up for the short- and long-term, including worker, workstation, and equipment schedules. In these plans task precedence is organised to maximise concurrency. Physicians are engaged in forecasting the planning process. (L4)	4	7	7	7	6	7	1
	Process time improvement	Streamline processes to improve patient throughout. Cycle or lead time reduction techniques such as layout optimisation, quick changeover, set-up time reduction, etc., can be used. (L5)	5	7	7	7	5	7	2
		Usage of automated tools to enhance processing time. (L6)	3	4	3	6	2	3	1
		Productivity is measured, and optimisation tools are used to improve resource productivity. Quality is not infused at the cost of productivity. (L7)	5	5	1	7	4	5	1
	Reduce delays and interruptions	Maintenance techniques such as TPM are employed to reduce disruptions caused by tool and equipment downtime. Staff are also trained to maintain competency in providing uninterrupted care without error. (L8)	6	6	2	7	6	6	0
	Workplace organisation	Workplaces are organised and standardised with an activity policy	5	7	5	7	6	6	2

		(such as 5S) to help keep work areas clean, tidy, and uncluttered. (L9)							
	Quality	The hospital has a formal quality system and program that ensures the provided service exceeds customer expectations. Measurable quality objectives are set regularly to monitor quality status, and quality issues are tracked, reported, and communicated. (L10)	7	7	7	7	7	7	0
		Implementation of Total Quality Management (TQM) practices. (L11)	6	7	7	6	5	6	1
		Quality is built-in by preventing errors (implementing poka-yoke methods) and having visual controls (such as signs, pictures, or procedures) to identify errors. (L12)	N/A	7	N/A	7	5	7	1
		The Jidoka principle (autonomation) is implemented. (L13)	4	6	4	N/A	4	4	0.5
		The quality of materials received from suppliers is ensured through supplier selection and development activities, such as providing technical and financial assistance and training in quality issues. (L14)	6	5	3	7	5	5	1
	Flexibility	To quickly adapt to changes, there is flexibility and adaptability in the service provided, as well as flexibility in the workforce, layout, and set-up. (L15)	6	7	6	7	4	6	1
	Visual management	Visual management (such as Kanban) is used to manage inventory levels and patients as they move through the system so that inventory levels and overproduction waste is minimised for better material, patient, and workflow. (L16)	5	7	7	6	5	6	2
Establish pull	Pull system	A pull system is used to determine the supply of sundries and jobs. The hospital thus executes	4	6	1	7	4	4	2

		healthcare demand analysis and forecasting. It has a capacity management system/ programme to ensure new work is started only when there is demand for it and the staff has spare capacity. (L17)								
	Minimise inventory and patients waiting	Inventory and work-in-process (WIP) items must be limited while ensuring that the requisite materials and information are available for a smooth workflow. Therefore, inventory and material logistics are managed to monitor and reduce inventory and lot sizes, and just-in-time (JIT) techniques are employed. (L18)	4	6	4	7	4	4	2
		Techniques are employed to minimise the number of patients waiting in the system. (L19)	6	7	7	N/A	6	6.5	1
	Supplier delivery and responsiveness	A strategic network is utilised to exercise a zero inventory system. Suppliers must thus have minimum delivery lead time and on-time delivery to ensure hospital consumables are delivered when needed or in emergencies. (L20)	4	5	1	6	4	4	1
		Hospital-supplier integration. There is a proactive and long-term relationship established with suppliers. They are included in planning, goal-setting, continuous improvement, quality, and problem-solving activities. (L21)	3	5	5	7	4	5	1
		There are transparent communication systems between the hospital and supplier, where feedback is provided, and information is shared. (L22)	4	6	7	6	5	6	1
Seek perfection	Continuous improvement	Tools such as kaizen and Gemba walks are used to engage with employees and explore opportunities for continuous improvement. Employee suggestions are utilised when identifying possible improvements. (L23)	6	7	7	7	6	7	1

		Process and improvements are monitored, evaluated, and controlled to identify opportunities for improvement and allow data-based decision-making. (L24)	5	7	7	7	6	7	1
		Customers are involved in continuous improvement efforts to adapt the services to changing demands. (L25)	4	7	N/A	7	5	6	2.25
	Standardisation, systematisation, and simplification	Processes are continuously standardised, systematised, and simplified. (L26)	4	7	7	7	6	7	1

Table F.3 Round 1 Questions 3, 4, and 5 responses

QUESTIONS	RESPONSES				
	SME1	SME2	SME3	SME4	SME5
Question 3.1	4	5	5	4	4
Question 3.2	4	5	5	5	4
Question 3.3	4	5	4	5	4
Question 4.1	4	3	4	5	4
Question 4.2	4	3	2	4	4
Question 4.3	4	2	4	4	4
Question 4.4	4	3	4	4	3
Question 4.5	4	3	2	5	3
Question 4.6	4	1	4	3	3
Question 5.1	2	5	4	5	2
Question 5.2	4	5	5	5	4
Question 5.3	4	5	5	5	4
Question 5.4	4	1	3	4	3

Appendix G Delphi Round 1 summary report responses

This appendix provides the detailed responses received for each second summary report question of the first evaluation round. Table G.1 shows the scores received for Question 1,

Table G.2 shows those for Question 2, and Table G.3 includes the score for Questions 3 to 5. The full descriptions for the leanness indicator codes used in Table G.2 can be found in Table F.2.

Table G.1 Round 1 summary report Question 1 responses

AREAS	PRACTICES		SME Responses					SUMMARY	
			1	2	3	4	5	Median	IQR
Measurement system	S_{11}	Measurement system	6	6	7	6	6	6	0
Lean tools and principles	S_{21}	Holistic implementation of lean philosophy	5	5	5	6	5	5	0
Knowledge and competency	S_{31}	Training doctors, staff, and management	5	7	5	6	5	5	1
	S_{32}	Training is tailored to the hospital's context	6	6	7	6	5	6	0
Communication and feedback	S_{41}	Visible communication of information	6	6	7	6	6	6	0
	S_{42}	Communicate reasons for change and improvement successes	6	6	6	7	6	6	0
Leadership	S_{51}	There is leadership buy-in	7	7	7	7	7	7	0
	S_{52}	Long-term committed and actively involved management	6	6	6	7	7	6	1
	S_{53}	Visible and stable support	7	7	7	7	7	7	0
	S_{54}	Availability of resources	5	5	5	5	5	5	0
Workforce empowerment	S_{61}	Participation	6	6	6	6	5	6	0
	S_{62}	Ownership	6	6	7	7	6	6	1
Culture	S_{71}	Long-term and continuous implementation	6	5	6	7	6	6	0
	S_{72}	There is a culture change	7	7	7	7	5	7	0
	S_{73}	Open, no-blame culture	6	7	6	6	6	6	0

	S_{74}	Patient-centred and process-driven	6	6	5	6	6	6	0
	S_{75}	A bottom-up approach is adopted	5	6	4	5	4	5	1
	S_{76}	Rewards and recognition	6	6	7	6	4	6	0
	S_{77}	Teamwork	6	7	5	6	5	6	1
Lean team	S_{81}	Clarity of roles and responsibilities	6	6	7	7	6	6	1
	S_{82}	Utilisation of internal resources	6	6	7	6	6	6	0
	S_{83}	Lean champion	7	7	5	7	6	7	1
	S_{84}	Teams are multi-professional and multi-disciplinary	5	5	4	6	5	5	0
Change management	S_{91}	Strategic planning	6	6	4	7	5	6	1
	S_{92}	Improvement program and organisational strategy integration	6	7	7	7	5	7	1
	S_{93}	Paced hospital-wide implementation	7	7	7	7	6	7	0
	S_{94}	Sustainability plan	6	6	4	7	6	6	0
	S_{95}	Gain stakeholder commitment and buy-in	7	7	7	7	5	7	0
	S_{96}	Contextual influence is understood	5	5	3	6	4	5	1
Organisation structure	S_{101}	There are no functional and professional silos	6	6	6	6	6	6	0

Table G.2 Round 1 summary report Question 2 responses

PRACTICE RATINGS			SME Responses					SUMMARY	
Principles	Practices	Indicators	1	2	3	4	5	Median	IQR
Identify value	Define customer expectations	L1	6	7	5	7	5	6	2
Map the value stream	Identify and eliminate wastes	L2	5	7	7	7	5	7	2
Create flow	Workload levelling (Heijunka)	L3	4	7	4	7	6	6	3
		L4	4	7	7	7	6	7	1

	Process time improvement	L5	5	7	7	7	5	7	2
		L6.	3	4	3	6	2	3	1
		L7	5	5	1	7	4	5	1
	Reduce delays and interruptions	L8	6	6	2	7	6	6	0
	Workplace organisation	L9	5	7	5	7	6	6	2
	Quality	L10	7	7	7	7	7	7	0
		L11	6	7	7	6	5	6	1
		L12	N/A	7	N/A	7	5	7	1
		L13	4	6	4	N/A	4	4	0.5
		L14	6	5	3	7	5	5	1
	Flexibility	L15	6	7	6	7	4	6	1
	Visual management	L16	5	7	7	6	5	6	2
Establish pull	Pull system	L17	4	6	1	7	4	4	2
	Minimise inventory and patients waiting	L18	4	6	4	7	4	4	2
		L19	6	7	7	N/A	6	6.5	1
	Supplier delivery and responsiveness	L20	4	5	1	6	4	4	1
		L21	3	5	5	7	4	5	1
		L22	4	6	7	6	5	6	1
Seek perfection	Continuous improvement	L23	6	7	7	7	6	7	1
		L24	5	7	7	7	6	7	1
		L25	4	7	N/A	7	5	6	2.25

	Standardisation, systematisation, and simplification	L26	4	7	7	7	6	7	1

Table G.3 Round 1 summary report Questions 3, 4, and 5 responses

QUESTIONS	RESPONSES				
	SME1	SME2	SME3	SME4	SME5
Question 3.1	4	4	5	4	4
Question 3.2	4	5	5	5	4
Question 3.3	5	5	4	5	4
Question 4.1	4	4	4	4	4
Question 4.2	4	4	4	4	4
Question 4.3	4	2	4	4	4
Question 4.4	4	3	4	4	3
Question 4.5	4	3	4	5	3
Question 4.6	4	2	4	3	3
Question 5.1	3	4	4	5	2
Question 5.2	4	5	5	5	4
Question 5.3	4	5	5	5	4
Question 5.4	4	2	3	4	3

Appendix H Delphi Round 2 assessment results

This appendix provides the detailed responses received for each question in the first assessment round of the Delphi study. Table H.1 shows the scores received for Question 1, Table H.2 shows those for Question 2, and Table H.3 includes the score for Questions 3 to 5.

Table H.1 Round 2 Question 1 responses

AREAS	PRACTICES		SME Responses					SUMMARY	
			1	2	3	4	5	Median	IQR
Measurement system	S_{11}	Measurement system	6	6	7	6	6	6	0
Lean tools and principles	S_{21}	Holistic implementation of lean philosophy	5	5	5	6	5	5	0
Knowledge and competency	S_{31}	Ongoing training	5	6	5	6	5	5	1
	S_{32}	Training is tailored to context	6	6	7	6	5	6	0
Communication and feedback	S_{41}	Visible communication of information	6	6	7	6	6	6	0
	S_{42}	Communicate reasons for change and improvement successes	6	6	6	7	6	6	0
Leadership	S_{51}	There is leadership buy-in	7	7	7	7	7	7	0
	S_{52}	Long-term committed and actively involved management	6	6	6	7	7	6	1
	S_{53}	Visible and stable support	7	7	7	7	7	7	0
	S_{54}	Availability of resources	5	5	5	5	5	5	0
Workforce empowerment	S_{61}	Participation	6	6	6	6	6	6	0
	S_{62}	Ownership	6	6	7	7	6	6	1
Culture	S_{71}	Long-term and continuous implementation	6	5	6	7	6	6	0
	S_{72}	Lean is part of daily work	7	6	7	7	7	7	0
	S_{73}	Willing to change	5	6	7	7	5	6	2
	S_{74}	Open, no-blame culture	6	7	6	6	6	6	0
	S_{75}	Patient-centred and process-driven	6	6	5	6	6	6	0

	S_{76}	A bottom-up approach is adopted	5	6	4	5	4	5	1
	S_{77}	Rewards and recognition	6	6	7	6	4	6	0
	S_{78}	Teamwork	6	7	5	6	5	6	1
Lean team	S_{81}	Clarity of roles and responsibilities	6	6	7	7	6	6	1
	S_{82}	Utilisation of internal resources	6	6	7	6	6	6	0
	S_{83}	Lean champion	7	7	7	7	6	7	0
	S_{84}	Teams are multi-professional and multi-disciplinary	5	5	4	6	5	5	0
Change management	S_{91}	Clear vision and goals	7	6	6	6	6	6	0
	S_{92}	Improvement program and organisational strategy integration	7	7	7	7	7	7	0
	S_{93}	Paced hospital-wide implementation	7	7	7	7	6	7	0
	S_{94}	Gain stakeholder commitment and buy-in	7	7	7	7	5	7	0
	S_{96}	Contextual influence is understood	5	5	6	6	4	5	1
Organisation structure	S_{101}	There are no functional and professional silos	6	6	6	6	6	6	0

Table H.2 Round 2 Question 2 responses

PRACTICE RATINGS			SME Responses					SUMMARY	
Principles	Practices	Indicators	1	2	3	4	5	Median	IQR
Identify value	Define customer expectations	Feedback on quality/service from customers are used in order to prioritise and adopt care to patient requirements, needs, and preferences. (L1)	6	6	6	7	5	6	0
Map the value stream	Identify and eliminate wastes	Process and value streams are mapped and analysed in order to classify activities as value-added (VA), non-value added (NVA), or necessary but non-value added (NNVA). This allows wastes to be identified so that they can be minimised, or eliminated,	7	7	7	7	6	7	0

		where possible. Tools such as value stream mapping (VSM), 5 Whys, plan-do-check-act (PDCA) cycle, A3 report, DMAIC, root cause analysis are used to map the value stream and identify and eliminate wastes. (L2)							
Create flow	Workload levelling (Heijunka)	Equalise work distribution among employees, or better match staffing to demand in areas where the demand cannot be managed (such as the ED), in order to ensure smooth flow through the process with no interruptions, delays, or bottlenecks. This can be done by cross-training employees (where possible), ensuring a flexible workforce, and standardising processes between floors and departments. (L3)	6	6	5	6	6	6	0
		Execution of short- and long-term planning for resource management. This includes scheduling workers, workstations and equipment, and planning task precedence in order to maximise concurrency. Physicians are engaged in forecasting the planning process. (L4)	7	7	7	7	6	7	0
	Process time improvement	Streamline processes by reducing cycle or lead time through practices such as layout optimisation, quick changeover, setup time reduction, etc. to reduce patient throughput. (L5)	5	7	7	7	5	7	2
		Productivity is measured and improved through the use of lean tools (such as VSM, 5S, Kanban, Kaizen, etc.), but not at the cost of quality. (L6)	5	5	5	5	5	5	0
	Reduce delays and interruptions	Effective asset management processes to prevent disruptions in flow. TPM can	6	6	6	6	6	6	0

		be used for to prevent tool and equipment breakdowns, while Andon and competency training of staff can be used to ensure uninterrupted care without error is provided. (L7)							
	Workplace organisation	Workplaces are organised and standardised with the application of an activity policy (such as 5S) to help keep work areas clean, tidy, and uncluttered. (L8)	6	6	5	7	7	6	1
	Quality	The hospital has a formal quality system and program that ensures the service provision is exceeding the customer expectations. Measurable quality objectives are set on a regular basis to monitor quality status, and quality issues are tracked, reported, and communicated on a regular basis. (L10)	7	7	7	7	7	7	0
		Implementation of Total Quality Management (TQM) practices. (L11)	6	6	6	6	5	6	0
		Quality is built-in by preventing errors (implementation of poka-yoke methods) and having visual controls (such as signs, pictures, or procedures) to identify errors. (L12)	6	7	6	6	6	6	0
		Implementation of the Jidoka principle (autonomation). (L13)	4	5	4	4	4	4	0
	Flexibility	Flexibility and adaptability of the service provided, as well as flexibility in the workforce, layout, and set-up in order to easily adapt to changes.(L14)	6	6	6	6	5	6	0
	Visual management	Visual management (such as Kanban) is used to provide timeous feedback on key parameters to manage improvements, as well as to manage inventory levels and	6	6	7	6	5	6	0

		patients as they move through the system so that continuous improvements can be made and inventory levels and overproduction waste can be minimised for better material, patient, and workflow. (L15)							
Establish pull	Pull system	A pull system is used to determine where care providers spend their time and where patients move in the system. The hospital thus executes healthcare demand analysis and forecasting and has a capacity management system/ programme to ensure new work is started only when there is demand for it (when the patient needs it) and the staff has spare capacity. (L16)	4	5	3	5	4	4	1
	Minimise inventory and patients waiting	Work in process (WIP) items must be limited while ensuring that the requisite materials and information are available for a smooth flow of work. Material logistics are therefore managed to monitor and reduce items waiting. (L17)	4	5	4	5	4	4	1
		Number of patients waiting in the system is minimised. (L18)	6	7	7	6	6	6	1
	Supplier delivery and responsiveness	Hospital-supplier integration. There is a proactive and long-term relationship established with suppliers. They are included in planning and goal-setting activities and involved with continuous improvement, quality, and problem-solving activities. (L19)	5	5	5	5	5	5	0
		There are transparent communication systems between the hospital and supplier, where feedback is	6	6	7	6	6	6	0

		provided and information is shared. (L20)							
Seek perfection	Continuous improvement	Tools such as kaizen and Gemba walks are used to engage with employees and explore opportunities for continuous improvement. Employee suggestions are utilised when identifying possible improvements. (L21)	7	7	7	7	7	7	0
		Monitoring, evaluation, and control of processes and their improvement, to identify opportunities for improvement and to allow data-based decision making. (L22)	7	7	7	7	7	7	0
		Involve customers in continuous improvement efforts in order to adapt the services to changing demands. (L23)	6	6	5	7	5	6	1
	Standardisation, systematisation, and simplification	Continuous standardisation, systematisation, and simplification of processes. (L24)	7	7	7	7	6	7	0

Table H.3 Round 1 Question 3, 4, and 5 responses

QUESTIONS	RESPONSES				
	SME1	SME2	SME3	SME4	SME5
Question 3.1	4	4	5	4	4
Question 3.2	4	5	5	5	4
Question 3.3	5	5	4	5	4
Question 4.1	4	4	4	4	4
Question 4.2	4	4	4	4	4
Question 4.3	4	4	4	4	4
Question 4.4	4	3	4	4	3

Question 4.5	4	3	4	5	3
Question 4.6	5	4	5	5	4
Question 5.1	5	4	4	5	2
Question 5.2	4	5	5	5	4
Question 5.3	4	5	5	5	4
Question 5.4	4	4	3	4	3

Appendix I Delphi Round 2 summary report results

This appendix provides the detailed responses received for each second summary report question of the first evaluation round. Table I.1 shows the scores received for Question 1, Table I.2 shows those for Question 2, and Table I.3 includes the score for Questions 3 to 5. The full descriptions for the leanness indicator codes used in Table I.2 can be found in Table H.2.

Table I.1 Round 2 summary report Question 1 responses

AREAS	PRACTICES		SME Responses					SUMMARY	
			1	2	3	4	5	Median	IQR
Measurement system	S_{11}	Measurement system	6	6	7	6	6	6	0
Lean tools and principles	S_{21}	Holistic implementation of lean philosophy	5	5	5	6	5	5	0
Knowledge and competency	S_{31}	Ongoing training	5	6	5	6	5	5	1
	S_{32}	Training is tailored to context	6	6	7	6	5	6	0
Communication and feedback	S_{41}	Visible communication of information	6	6	7	6	6	6	0
	S_{42}	Communicate reasons for change and improvement successes	6	6	6	7	6	6	0
Leadership	S_{51}	There is leadership buy-in	7	7	7	7	7	7	0
	S_{52}	Long-term committed and actively involved management	6	6	6	7	7	6	1
	S_{53}	Visible and stable support	7	7	7	7	7	7	0
	S_{54}	Availability of resources	5	5	5	5	5	5	0
Workforce empowerment	S_{61}	Participation	6	6	6	6	6	6	0
	S_{62}	Ownership	6	6	7	7	6	6	1
Culture	S_{71}	Long-term and continuous implementation	6	5	6	7	6	6	0
	S_{72}	Lean is part of daily work	7	6	7	7	7	7	0
	S_{73}	Willing to change	5	6	7	7	6	6	1

	S_{74}	Open, no-blame culture	6	7	6	6	6	6	0
	S_{75}	Patient-centred and process-driven	6	6	5	6	6	6	0
	S_{76}	A bottom-up approach is adopted	5	6	4	5	4	5	1
	S_{77}	Rewards and recognition	6	6	7	6	5	6	0
	S_{78}	Teamwork	6	7	5	6	5	6	1
Lean team	S_{81}	Clarity of roles and responsibilities	6	6	7	7	6	6	1
	S_{82}	Utilisation of internal resources	6	6	7	6	6	6	0
	S_{83}	Lean champion	7	7	7	7	6	7	0
	S_{84}	Teams are multi-professional and multi-disciplinary	5	5	4	6	5	5	0
Change management	S_{91}	Clear vision and goals	7	6	6	6	6	6	0
	S_{92}	Improvement program and organisational strategy integration	7	7	7	7	7	7	0
	S_{93}	Paced hospital-wide implementation	7	7	7	7	6	7	0
	S_{94}	Gain stakeholder commitment and buy-in	7	7	7	7	5	7	0
	S_{96}	Contextual influence is understood	5	5	6	6	4	5	1
Organisation structure	S_{101}	There are no functional and professional silos	6	6	6	6	6	6	0

Table I.2 Round 2 summary report Question 2 responses

PRACTICE RATINGS			SME Responses					SUMMARY	
Principles	Practices	Indicators	1	2	3	4	5	Median	IQR
Identify value	Define customer expectations	L1	6	6	6	7	6	6	0
Map the value stream	Identify and eliminate wastes	L2	7	7	7	7	6	7	0
Create flow		L3	6	6	5	6	6	6	0

	Workload levelling (Heijunka)	L4	7	7	7	7	6	7	0
	Process time improvement	L5	5	7	7	7	6	7	1
		L6	5	5	5	5	5	5	0
	Reduce delays and interruptions	L7	6	6	6	6	6	6	0
	Workplace organisation	L8	6	6	5	7	7	6	1
	Quality	L9	7	7	7	7	7	7	0
		L10	6	7	7	6	5	6	1
		L11	6	7	6	6	6	6	0
		L12	4	5	4	4	4	4	0
	Flexibility	L13	6	6	6	6	5	6	0
	Visual management	L14	6	6	7	6	6	6	0
Establish pull	Pull system	L15	4	5	3	5	4	4	1
	Minimise inventory and patients waiting	L16	4	5	4	5	4	4	1
		L17	6	7	7	6	6	6	1
	Supplier delivery and responsiveness	L18	5	5	5	5	5	5	0
		L19	6	6	7	6	6	6	0
Seek perfection	Continuous improvement	L20	7	7	7	7	7	7	0
		L21	7	7	7	7	7	7	0
		L22	6	6	5	7	5	6	1
	Standardisation, systematisation, and simplification	L23	7	7	7	7	6	7	0

Table I.3 Round 2 summary report Question 3, 4, and 5 responses

QUESTIONS	RESPONSES				
	SME1	SME2	SME3	SME4	SME5
Question 3.1	4	4	5	4	4
Question 3.2	4	5	5	5	4
Question 3.3	5	5	4	5	4
Question 3.4	5	3	4	N/A	5
Question 4.1	4	4	4	4	4
Question 4.2	4	4	4	4	4
Question 4.3	4	4	4	4	4
Question 4.4	4	3	4	4	3
Question 4.5	4	3	4	5	3
Question 4.6	5	4	5	5	5
Question 5.1	5	4	4	5	N/A
Question 5.2	4	5	5	5	4
Question 5.3	4	5	5	5	4
Question 5.4	4	4	3	4	3

Appendix J Final sustainable lean assessment tool

This appendix shows the landing page of the final SLAT developed in Figure J.1.

INTRODUCTION

The sustainable lean assessment tool (SLAT) presented is a self-assessment tool developed for hospitals that can be used to ascertain the degree to which practices that enable the sustainable implementation of lean have been implemented at the facility. It thus determines how capable the hospital is to sustain lean and prioritises practices in need for better implementation to improve this capability. The purpose of the SLAT is thus to support a more successful and sustainable transition towards a lean hospital, so that more significant and long-term improvements can be realised.

GETTING STARTED

This page serves as an introduction to the tool contained. It explains the overall structure of the tool and how to go about using it, how to interpret the results, as well as providing a navigation index for easy navigation to any of the pages contained within the tool. Please carefully read this page before commencing with the assessment.

STRUCTURE OF THE TOOL

In order to ascertain how capable a hospital is of sustaining lean, this tool uses ratings indicating the degree to which a collection of practices supporting a long-term adoption of lean has been implemented at the facility. These ratings are provided by the user and are collected through the use of two different assessment forms, namely the *Lean Sustainability* and *Leanness* assessments. The *Lean Sustainability* form makes up the main assessment and is used to determine the hospital's capability to sustain lean, it includes 30 practices arranged into 10 overarching areas. Each of these practices is scored by the user for their level of implementation. For one of the practices, however, instead of providing a score directly, the *Leanness* assessment is used as a supplementary assessment form to provide more specific indicators used to determine the implementation level of that area.

Therefore, in order to obtain your results, implementation ratings in the form of linguistic terms must be provided for each of the leanness indicators and sustainability practices by making use of the drop-down lists provided. The implementation rating refers to the degree to which a given practice has been implemented in the hospital. This can be scored as worst, very poor, poor, fair, good, or excellent, in increasing degree of implementation. The provided scores will determine the weighted overall score for the hospital's capability to sustain lean, as well as a ranked list of sustainability practices that need to be prioritised for improvement. A leanness score from the leanness assessment is also provided and can be used to compare the scores across the different areas and to prioritise the practices that need improvement.

Furthermore, if there is a particular sustainability practice of interest that the user would like further information on, it can be selected using the drop-down list provided on the results page. The tool will then provide more detail on how to improve the selected practice.

INSTRUCTIONS

1. When you have read the introduction page and are ready to proceed, complete the "hospital information" section and click the button at the bottom of this page labelled "BEGIN ASSESSMENT". This will navigate you to the overarching *Lean Sustainability* assessment form. Alternatively, use the navigation panel on the top right of this page to navigate to the assessment.

2. Provide implementation scores for each of the sustainability practices by making use of the drop-down lists provided. For practice number S21, a button for the *Leanness* assessment form which provides more specific indicators for this practice is provided in place of a drop-down list. Click this button to navigate to the form.

3. Provide implementation scores for each of the leanness indicators by making use of the drop-down lists provided. When this is complete, you can use the back arrow at the top left of the page to navigate back to the *Lean Sustainability* form. Alternatively, the navigation panel can also be used to proceed to another section of the tool. When the *Leanness* form has successfully been completed, the implementation rating for practice number S2 in the *Lean Sustainability* form will reflect the appropriate rating. If the Leanness form has not been completed, it will state "Leanness assessment incomplete". Both forms will need to be completed to obtain your results.

4. Once both assessment forms have been completed, click the right arrow or the "RESULTS" button to navigate to the results.

5. If you wish to obtain more information about the ranked sustainability practices, select the practice of interest on the drop-down list labelled "More information".

Any of the scores given can be changed and any assessment forms can be revisited at any point during the assessment.

UNDERSTANDING THE RESULTS

The results page provides four forms of output: 1) overall leanness and capability to sustain scores, 2) an importance ranking of the sustainability practices in need of improvement, 3) a radar chart comparing the leanness scores of the different lean areas, and 4) a list of sustainability practices prioritised for improvement. Each is explained below.

1. Capability and leanness score

The two scores provided are rated on a linguistic scale. Both scores are weighted according to the built-in weights for the degree to which a given practice or indicator contributes to the hospital's capability to sustain lean or leanness. The 'Hospital sustainability capability' score is the result of the overall assessment indicating the degree to which the hospital is capable to sustain lean, this can be either extremely capable, very capable, capable, fairly capable, or poorly capable, in decreasing levels of capability. Similarly, the leanness score is a result of the leanness sub-assessment and indicates the extent to which the hospital has implemented the lean philosophy as either extremely lean, very lean, lean, fairly lean, or poorly lean, where extremely lean represents a higher level of adoption of lean practices, and poorly

2. Ranked practices

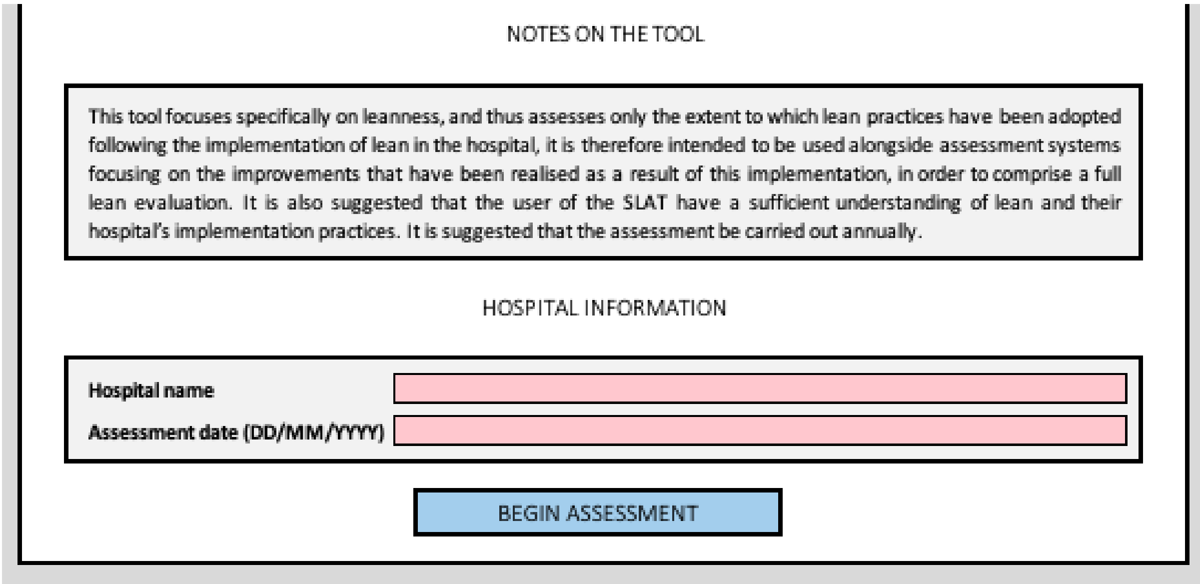
All the sustainability practices are ranked according to the importance of their improvement in descending order, where improving the first practice shown will most significantly improve the overall capability of the hospital to sustain lean. This ranking takes into consideration both the implementation level of a given practice and the degree to which it contributes to the capability to sustain lean, which is based on the weights built into the tool.

3. Radar chart

The radar chart represents the 5 lean principles and the extent to which they are being practised in the hospital for an easy visualisation so that areas of improvement can be identified.

4. Practice information

If a sustainability practice was selected on the drop-down list, more information for that practice is provided.



NOTES ON THE TOOL

This tool focuses specifically on leanness, and thus assesses only the extent to which lean practices have been adopted following the implementation of lean in the hospital, it is therefore intended to be used alongside assessment systems focusing on the improvements that have been realised as a result of this implementation, in order to comprise a full lean evaluation. It is also suggested that the user of the SLAT have a sufficient understanding of lean and their hospital's implementation practices. It is suggested that the assessment be carried out annually.

HOSPITAL INFORMATION

Hospital name

Assessment date (DD/MM/YYYY)

BEGIN ASSESSMENT

Figure J.1 Final SLAT introduction page