Is the Hospital Lean?
A Mathematical Model for Assessing the Implementation of Lean Thinking in Healthcare Institutions

Abstract

Many academic and practice articles have been published in healthcare operations management literature documenting the experience of implementing lean thinking (LT) in healthcare institutions. But, none of them have developed a procedure for assessing the implementation of LT in healthcare institutions. Lack of assessment procedures make it difficult to evaluate the progress made during the implementation of LT. The current study attempts to address this gap by developing and demonstrating an assessment procedure to evaluate the extent of lean implementation in a healthcare institution. To begin with, different lean tenets and elements applied in healthcare institutions were identified through a literature review. Following it, a Fuzzy-Logic Input Based Healthcare Institution Lean Implementation Assessment (FLB-HLIA) was developed and deployed in an Indian case hospital to compute its "Healthcare Institution's Lean Implementation Index" (HLII). FLB-HLIA revealed that the case hospital has to focus on two lean tenets, namely establishing pull system, and seeking perfection, to improve its HLII. Assessment also revealed the lean elements that the case hospital can focus to upgrade its HLII. HLII can be used by practitioners to perform intra-benchmarking and inter-benchmarking of healthcare institutions. Results of FLB-HLIA provide a future action plan for the lean implementation journey of the healthcare institution by identifying the possible areas of improvement for future.

Keywords: Process improvement, healthcare institution, lean thinking, implementation, assessment, fuzzy-logic, lean implementation index.

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1. Introduction

In recent times, Lean Thinking (LT) is getting widely implemented in healthcare institutions with an objective to improve the efficiency and effectiveness of various processes by reducing the wastes and variability (Machado Guimarães & Crespo de Carvalho, 2012; Al-Balushi et al., 2014; McIntosh et al., 2014; Edaibat et al., 2017; etc.). Several experiences of implementing LT in healthcare institutions are documented in the form of case studies in literature (Ben-Tovim et al. 2007; Agnetis et al., 2012; Atkinson et al. 2012; Dankbar & Hayward, 2012; Diaz et al. 2012; Martin et al. 2012; Konrad et al., 2013; Pearson et al., 2013; Crop et al., 2015; Fortsch & Khapalova, 2016; etc.). Although, an adequate number of such case studies exist, none of them have addressed so far the issue of assessing the level of leanness attained by a healthcare institution (Kim et al., 2007). In particular, there is no robust mathematical procedure to assess and understand the degree of implementation of LT in a healthcare institution. Existence of an assessment procedure can facilitate the lean implementation journey by helping the implementing team to understand how good they have implemented different aspects of LT and provide inputs to suitably modify the future journey to improve further.

Narasimhan et al. (2006) defined leanness in the context of manufacturing as the accomplishment of production with minimal waste due to unneeded operations, inefficient operations, or excessive buffering in operations. But, this definition of leanness is based on the outcome that could be obtained after implementing LT. Moreover, such benefits can be obtained only if the various tools, techniques, procedures and practices (will be referred as 'elements' from now on) of LT are implemented properly. Hence, in this study, an attempt has been made to assess "how these elements were implemented by the lean implementation team that is tasked with transforming the healthcare institution through LT". As a result of assessment, healthcare institution's leanness will be computed based on the degree of implementation of various elements of LT. If the appropriate elements of LT are implemented in a structured and disciplined manner, the healthcare institution tends to achieve better performance and thereby have a high degree of leanness. Thus, Healthcare Institution's Leanness in this study is defined as the *"extent of implementation of lean elements by the implementation team for improving the processes in the healthcare institution to reduce the wastes prevailing due to non-value adding activities"*. Healthcare Institution's Leanness is quantified by developing a Healthcare Institution Lean Implementation Index (HLII), which is a numerical measure obtained by capturing the importance and degree of implementation of various elements of LT.

1.1 Need for Assessing the Implementation of LT

Womack et al. (1990) while defining lean manufacturing noted that on implementing LT, input dimensions such as human effort, manufacturing space, investment in tools, engineering hours for new product development, onsite inventory, etc. would reduce into half and output dimension would focus on delivering value with high quality and fewer defects in comparison to traditional manufacturing systems such as craft and mass production systems. Hence, it is very clear that LT implementation is itself defined by associating an assessment aspect to it. In addition, as LT implementation is both a process and journey without an end state, it is strongly recommended in literature that a firm implementing LT should continuously assess and monitor itself to identify the present level of leanness and future path of improvement (Liker, 1998). Even though assessment has theoretically been an integral part of lean implementation, it has been less studied in general (Pilkington and Fitzgerald, 2006) and has been seldom discussed in the context of healthcare (Narayanamurthy & Anand, 2016), where plenty of lean implementation studies have been published (refer to appendix 1 for the list of literature review papers on the topic "LT implementation in healthcare"). To be more precise, reasons motivating the development of leanness assessment method based on the degree of implementation of LT elements in a healthcare institution are highlighted below:

- Assessing the lean implementation will help in objectively convincing the healthcare institution's top management team or questioning the lean implementation team on the relationship between the amount of resources invested (man hours, manpower training, external consultants, etc.) and level of progress made in the lean implementation journey (Ker et al., 2014).
- Assessment method can help healthcare institutions in robustly measuring and quantifying the progress made in their lean implementation journey and compare them with their initially set targets to develop future action plans (Joseph, 2006).
- Structured assessment based on mathematical techniques can help in predicting the success/failure of lean implementation journey and can unbiasedly indicate the areas of improvement (such as employee training, reformulation of teams, involvement of consultants, etc. (Robinson et al., 2012))
- Assessment can assist healthcare institutions in benchmarking their leanness level (measured in terms of implementation of various elements) with other best-in-class partners and thereby motivate them to sustain continuous improvement (Pham et al., 2007).
- Financial indicators are mostly ineffective in capturing the benefits that may accrue due to implementation of LT in the initial few years. In addition, most of the healthcare institutions are hesitant to share the financial and performance data to external consultants for performing such assessments.

Since such an assessment method for lean implementation is not available in the literature, this study addresses the gap by answering the following questions in detail:

(1) Is the healthcare institution lean? What procedure can be adopted to numerically evaluate the extent of implementation of LT in a healthcare institution?
(2) Is it possible to identify how much the healthcare institution has achieved in terms of implementation of various elements of LT and how it can be improved further in future?

(3) How can healthcare institutions self-benchmark their present status of leanness with their past?

Rest of the article is arranged in the following sequence: section 2 details the review of recent literature in the domain of LT in healthcare. Based on the review, elements of LT implemented by healthcare institutions were identified. Section 3 develops a framework for leanness assessment specifically for healthcare institution and section 4 describes the fuzzy-logic input based leanness assessment model by applying to a case hospital. Section 5 discusses the interpretation of assessment results obtained. Finally, section 6 concludes the study by listing out the implications for research and practice.

2. Literature Review

An attempt was made to understand the previous works on assessment of leanness in the domain of healthcare. Since it is yet to be developed (Kim et al., 2007), no studies were available. Moreover, the objective of the proposed assessment methodology is to measure the degree of implementation of LT elements in healthcare institutions. So, it becomes necessary to understand the elements of LT, which are applicable in the healthcare setting. This can be accomplished by reviewing the case studies describing the implementation of LT in the healthcare setting. For example, studies by Alukal and Chalice (2007), Chalice (2007), Fine et al. (2009), Jones and Mitchell (2006), Joosten et al. (2009), Zidel (2006), etc. have documented the experience of various health care institutions that were transformed by implementing LT. From such published studies, various elements of LT were identified. Table 1 documents the review of case studies describing the implementation of LT in healthcare institutions.

"Insert Table 1 (a) & (b) here"

While reviewing such case studies on LT implementation, following research gaps was clearly revealed:

Gap 1: Not many studies have suggested a structured way of implementing LT. In particular, not many frameworks are available that explains a step-by-step approach for implementing and assessing LT.

Gap 2: Five tenets of LT proposed by Womack and Jones (2009) provide only a very broad and generic implementation guide. It fails to explain the different lean elements that need to be focussed by a firm to achieve the implementation of a tenet.

Gap 3: Review on "leanness assessment" literature carried out by Narayanamurthy & Anand (2016) clearly showed that none of the studies have developed an assessment procedure for evaluating the extent of implementation of LT in a healthcare institution.

This study addresses these gaps by building a framework on the five tenets of LT and lists the different lean elements that need to be implemented by a healthcare institution to achieve the tenets. Finally, this framework is used with fuzzy-logic input based method for assessing the implementation of LT in a case hospital.

3. Framework for Lean Assessment in Healthcare Institutions

Literature review in the previous section led to the identification of different elements of LT implemented by healthcare institutions. These elements were grouped under the "tenets of LT" (Womack and Jones, 1996) based on the literature to form a framework for implementing and assessing LT. The proposed framework serves the following purposes:

1. Help in suitably adapting the tenets within the domain of healthcare institution and in particular for hospitals.
2. Studies in the literature have discussed these tenets as a basis for implementing LT in healthcare (Bushell et al., 2002). However, none of the studies have linked the lean elements implemented in healthcare institutions to their corresponding tenet. Hence, in the proposed assessment framework, the five tenets and corresponding elements of LT in the context of healthcare are tied together.
3. Grouping the various elements of LT under each tenet will benefit the managers as it helps in reducing the confusion during the implementation.

Table 2 shows the proposed hierarchical five-tenet healthcare institution lean assessment framework (HLAF) with elements of LT clustered under each tenet.

"Insert Table 2 here"

The adaptation of the tenets of LT within a healthcare institution context is detailed below:

Step 1. Identify & Specify Value: Value is normally determined based on the needs of the patient visiting the healthcare institution to avail the services provided. Healthcare institutions like hospitals tend to have a variety of departments such as outpatient, gynecology, oncology, etc. and each of these departments would have processes/activities such as diagnostics, testing, and consulting (Bowen & Youngdahl, 1998; Bushell et al., 2002; Kim et al., 2006). A suitable department and a value stream within that department which is considered to be value-adding for patients should be selected for transformation through LT. Elements of LT that can be grouped together to help in specifying value are listed in Table 2.

Step 2. Evaluate Value Stream: Both value adding and non-value adding activities involved in healthcare delivery needs to be identified (Kim et al., 2007). It helps in the reduction or elimination of the non-value adding activities wherever possible. The elements listed under Step 2 progresses the LT implementation at healthcare institutions to next level by bringing in important elements such as waste identification, standardization, etc. Implementing the elements of LT listed under this step mostly builds on the implementation of LT elements grouped in Step 1. For instance, internal communication and teamwork (HLAF112) in Step 1 helps in achieving efficient waste identification system (HLAF23) in Step 2.

Step 3. Creating Continuous Flow: In any healthcare process, services need to flow smoothly towards the customer by adding value at every stage in a tight sequential manner (Kim et al., 2006). Most of the wastes that hinder flow as identified in Step 2 will be removed in this step by implementing relevant elements of LT such as reducing the queuing complexity, mistake proofing, etc.

Step 4. Establishing Pull System: Pull is defined as adding value only when requested or needed by the customers of the value stream. Healthcare institutions implementing pull system need to be open to stakeholders' feedback, especially to customers' feedback and comments for improving the system (Bowen & Youngdahl, 1998). Moreover, every process (such as treatment or testing) is initiated only depending upon the needs of the patient. Elements of LT that assist in achieving pull system in healthcare institutions are interaction and participation of stakeholders, patient satisfaction measurement, performance monitoring, supplier collaboration, etc.

Step 5. Seeking Perfection: The above cycle is repeated to continuously eliminate the waste prevailing in the healthcare institution. New goals are normally set for next improvement cycle, but it depends on the extent of meeting the goals in the previous cycle. Some of the elements of LT that can assist healthcare institutions in this phase are uninterrupted process evaluation, quality monitoring teams, etc.

The framework proposed is used to perform the leanness assessment of a healthcare institution based on the degree of implementation of various elements of LT using fuzzy-logic input based computations.

4. Mathematical Model: Fuzzy-Logic Input Based Healthcare Institution Lean Implementation Assessment (FLB-HLIA)

Since assessment studies related to LT in the context of healthcare institutions were not developed, the papers that dealt with leanness assessment in the context of manufacturing were relied upon to understand the assessment procedures and techniques adopted. Some of the assessment methodologies in the context of manufacturing were: fuzzy-logic (Vinodh and Balaji, 2011; Bayou and De Korvin, 2008; Singh et al., 2010; Behrouzi and Wong, 2011; Anvari et al., 2013), Mahalanobis distance (Srinivasaraghavan and Allada, 2006), data envelopment analysis (Wan and Chen, 2008), analytic network process (Wong et al., 2012), value stream mapping (Wan et al., 2007), negotiated order perspective (Pedersen and Huniche, 2011), analysis of variance (Arbos, 2002), if-then rule (Vimal and Vinodh, 2012), system dynamics (Krishnamurthy and Chan, 2013), set pair analysis (Niu et al., 2010), linear and logistic regression (Sanchez and Perez, 2001) and discrete event simulation (Detty and Yingling, 2000). Out of all these assessment methodologies, fuzzy-logic input based assessment method was chosen for the following reasons:

- Fuzzy-logic input based assessment method is less complex and therefore makes it easy to understand for both response providers and healthcare practitioners. The ease is also confirmed by larger number of studies adopting fuzzy methodology for leanness assessment in the context of manufacturing.
- As qualitative and ambiguous attributes are linked to the implementation of an element of LT in healthcare, leanness assessment cannot be handled effectively using assessment approaches involving quantitative responses.
- Most of the employees and managers, who might be providing the ratings on the extent of implementation of a given element of LT may not be sure of the true level of

implementation and therefore would be more realistic to capture the range in which the rating would fall. Owing to these “imprecise” and “vague” understanding, measuring the implementation of LT elements are characterized by multi-possibility.

- Fuzzy methodology also accounts for the marginal variation in the implementation ratings provided by the hospital employees due to the difference in initially expected outcome and individual judgments on implementing LT.
- Martin et al. (2013) while collecting data on lean implementation observed that the environment in which the questionnaire is being filled can also have an impact on the responses to the questionnaire. By adopting fuzzy-logic input such minor variations can be nullified.
- Fuzzy-logic, by making no global assumptions regarding independence, exhaustiveness, and exclusiveness, can tolerate a blurred boundary in definitions (Lin and Chen, 2004).
- Moreover, fuzzy concepts enable assessors to use linguistic terms to assess indicators in natural language expressions.
- Lastly, Abbod et al. (2001) conducted a literature survey to understand the application of fuzzy-logic in healthcare and reported no application of fuzzy methodology for leanness assessment in the domain of healthcare.

FLB-HLIA technique can assess the extent of lean implementation based on the subjective input provided by the members of the implementing team on the “importance of an element of LT for the given healthcare institution” and “the degree of implementation of that particular element”. The fuzzy-logic input based assessment method in this study has been adapted from Lin et al. (2006). FLB-HLIA technique for a healthcare institution is as shown in Figure 1.

“Insert Figure 1 here”

4.1. Case hospital

As prescribed by Eisenhardt (1989), Glaser and Strauss (1967), and Siggelkow (2007), case organization for this current study is not randomly sampled. It was selected based on how it would help in answering the research questions raised. Best-fit hospital for this study would be the one that is implementing various process improvement initiatives by borrowing from the elements of LT. Case hospital chosen for this study is a multi-specialty hospital operating in Southern India for more than three decades. Case hospital chosen continuously works on creating new process improvement initiatives. Case hospital with over twenty clinical departments comprises of 256 employees. Distribution of the employees in the case hospital is provided in Table 3.

“Insert Table 3 here”

Motivated by the quantum of benefits harvested by several hospitals in US and UK after implementing LT, the case hospital was incrementally implementing process improvements using elements of LT. A detailed account of LT implementation journey of the case hospital is not reported in this study as the objective of this paper is to compute HLII based on the degree of implementation of LT elements in the case hospital. However, assessment results obtained are inferred by providing supporting evidence and snapshots of LT implementation experience in the case hospital.

A team of employees who played a key role in this process improvement initiative of the case hospital (composition of the implementing team is shown in Table 4) were interviewed by the research team. The research team comprised of members with a diverse background, from researchers working on LT to a physician with a management degree. Snowballing technique was used to ensure that all key members who played a key role in the implementation of process improvement were interviewed. Based on the expertise, knowledge, involvement, and also the time availability of interviewed members of lean implementation team, a five member lean assessment team was formed comprising of a physician, quality manager, HR manager, assistant nursing superintendent, and nursing assistant. Team comprised of employees from diverse departments to ensure complete domain coverage and equal emphasis for all areas of business. Before assessing the leanness of the case hospital, the assessment committee surveyed and studied the related data/information on leanness implementation with an aim to understand the case hospital's journey of lean implementation. The lean assessment team members had complete knowledge about the case hospital in terms of the efficiency of the hospital before implementing LT, implementation status of different elements of LT, future plans for LT implementation, the extent of wastes prevailing in different processes, etc.

"Insert Table 4 here"

4.2. Hospital leanness assessment

Employees interviewed in the case hospital also unanimously felt the need for a technique to assess the extent of lean implementation. Based on the interviews conducted, the research team evaluated the extent of implementation of different elements of LT using the step-by-step approach described below:

4.2.1. Linguistic terms and its corresponding preference scale

Linguistic terms and corresponding membership functions have been proposed for linguistic assessment in literature (Karwowski and Mital, 1986; Chen and Hwang, 1992). For convenience, as a substitute for assessor elicitation, linguistic terms and corresponding membership functions can be obtained directly from previous studies. Otherwise, based on the needs of cognitive perspectives and data characteristics, linguistic terms can be customized to meet individual situations and requirements. In this case, the research team discussed with the assessment team of the case hospital to arrive at a linguistic scale. The research team explained in detail the meaning of each linguistic terms and how it would be used for evaluation. The linguistic scale used for measuring the degree of implementation (also called as ratings in "fuzzy-logic" literature) and degree of importance (also called as weights in "fuzzy-logic" literature) of LT practices to perform assessment is shown in Table 5.

"Insert Table 5 here"

4.2.2. Data collection

Based on the repeated site visits, direct observations, and discussions with the lean assessment team, ratings and weights of different lean elements were obtained. These rating and weight values were discussed with the implementation team to attain consensus. A snapshot of the final linguistic data on degree of implementation and degree of importance after attaining consensus for HLAF1 is shown in Table 6.

"Insert Table 6 here"

4.2.3. Fuzzy conversion

Based on the corresponding relation between the linguistic terms and fuzzy numbers, as listed in Table 5, the linguistic terms of ratings and weights were approximated and averaged with fuzzy numbers. For example, consider the conversion of degree of implementation and degree of importance for the lean element '5S' (HLAF15) into fuzzy number as shown in Table 7.

"Insert Table 7 here"

To generalize the same, assume that a committee of *m* evaluators, i.e., E_t, t = 1, 2, ..., m, conduct the hospital leanness evaluation. Let F_j, j = 1, 2, . . ., n; be set of lean practices within a lean tenet which need to be evaluated for assessing the hospital leanness. Let $R_{tj} = (a_{jt}, b_{jt}, c_{jt})$ be the fuzzy numbers approximating the linguistic implementation ratings given to F_j by the assessor E_t, and let $W_{tj} = (x_{jt}, y_{jt}, z_{jt})$ be the fuzzy numbers approximating the linguistic importance weights assigned to F_j by the assessor E_t. Using the average fuzzy implementation rating R_j and average fuzzy importance weight W_j, aggregation of the opinions of experts is calculated as

$$R_j = (a_j, b_j, c_j) = (R_{j1} (+) R_{j2} (+) \ldots (+) R_{jm})/m \quad (1)$$

$$W_j = (x_j, y_j, z_j) = (W_{j1} (+) W_{j2} (+) \ldots (+) W_{jm})/m \quad (2)$$

Fuzzy average implementation rating and importance weighing in the last row of Table 7 is obtained by following the procedure shown in eq. (1) and (2). Similarly, 'implementation rating' and 'importance weight' fuzzy numbers were averaged for all the lean elements. Other methods can also be adopted to aggregate the assessments of multiple decision-makers, such as arithmetic mean, median, and mode. Since the arithmetic mean operation is the most widespread aggregation method, it is used to pool the opinions of the lean assessment team.

4.2.4. Fuzzy evaluation

In this step, fuzzy average implementation ratings and fuzzy average importance weights of all the elements of LT are aggregated to obtain the HLII. HLII determines the extent of leanness attained by the hospital. As HLII increases with increase in the degree of implementation of elements of LT, the membership function of HLII can be used to determine the leanness level of the case hospital. Let R_j and W_j, j = 1, 2, . . ., n, respectively, denote the average fuzzy implementation rating and average fuzzy importance weight given to an LT element 'j' by the evaluation committee. The HLII is defined as

$$HLII = \frac{\sum_{j=1}^{n}(Wj(.)Rj)}{\sum_{j=1}^{n} Wj} \quad (3)$$

The membership function of HLII can be calculated using the fuzzy weighted average operation whose description can be obtained from Kao and Liu (2001). Using eq. (3), the integrated fuzzy implementation rating of all the five lean tenets was calculated.

HLAF1 = (0.578, 0.710, 0.838)
HLAF2 = (0.453, 0.607, 0.759)
HLAF3 = (0.187, 0.326, 0.468)
HLAF4 = (0.246, 0.400, 0.554)
HLAF5 = (0.245, 0.401, 0.557)

Finally, by applying eq. (3) again, the HLII of the case hospital was obtained as (0.338, 0.486, 0.633).

4.2.5. Linguistic conversion

HLII needs to be translated into an appropriate linguistic level for easy interpretation. To identify the linguistic equivalent of HLII, the assessment committee needs to approximate a linguistic label with a meaning identical or close to the meaning of HLII from the natural-language expression set of Healthcare Institution Leanness (HL). HL set consists of the following levels for labeling:

HL = *{Completely Lean [CL], Almost Lean [AL], Reaching Lean [RL], Growing Lean [GL], Semi Lean [SL], Fairly Lean [FL], Developing Lean [DL], Beginning Lean [BL], Not Lean [NL]}*

These linguistics and corresponding membership functions are as shown in Figure 2. Several methods such as the Euclidean distance, successive approximation, and piecewise decomposition have been proposed in literature for matching the membership function with linguistic terms (Lin et al., 2006). This study uses the Euclidean distance method since it is the most intuitive method for humans to use in perceiving proximity (Guesgen and Albrecht, 2000; Lin et al. 2006). Assuming the natural-language leanness level expression set to be HL, U_{HLII} and U_{HLi} represent the membership functions of the HLII and of the natural-language leanness i, respectively. The distance between U_{HLII} and U_{HLi} can be calculated as

$$d\,(\text{HLII, HL}i) = \{\sum_{x \in p}(U_{HLII}(x) - U_{HLi}(x))^2\}^{1/2} \quad (4)$$

where p={$x_0, x_1, \ldots\ldots, x_m$} Є [0, 1] so that $0 = x_0 < x_1 < \ldots < x_m = 1$

For simplicity, assume p = *{0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1}*

"Insert Figure 2 here"

The distance between the HLII and natural-language leanness level *i* is then calculated, and the closest natural expression with the smallest distance between U_{HLII} to U_{HLi} is identified. Using eq. 4, Euclidean distance 'd' is calculated between the HLII and each member in set HL:

D(HLII, CL) = 0.721	D(HLII, AL) = 0.549	D(HLII, RL) = 0.377
D(HLII, GL) = 0.209	**D(HLII, SL) = 0.072**	D(HLII, FL) = 0.163
D(HLII, DL) = 0.329	D(HLII, BL) = 0.499	D(HLII, NL) = 0.671

From Figure 3, it can be clearly inferred that the equivalent linguistic label that is close to the case hospital's leanness is "Semi Lean" (SL).

"Insert Figure 3 here"

4.2.6. Status of the lean implementation in the case hospital

FLB-HLIA not only determines the extent of leanness attained by a healthcare institution but also helps to identify the elements of LT that needs to be focused in future. Thereby it provides an appropriate action plan to improve the leanness level of the healthcare institution. To arrive at this action plan, a ranking of aggregated fuzzy values of each of the LT element and tenet needs to be performed.

(i) Fuzzy performance-importance indexes of the case hospital

Fuzzy performance-importance index (FPII) combines the implementation rating and importance weighting of each of the element of LT. Higher the value of FPII, higher is the degree of contribution of that particular element of LT towards the leanness level of the healthcare institution. Thus, FPII of elements of LT can be used for identifying the future focus areas for improving the leanness level of assessed healthcare institution. $FPII_i$ indicating the contribution of each element of LT to case hospital's leanness is defined as:

$$FPII_i = R_i(.)[(1, 1, 1)(-)W_i] \quad (5)$$

Applying Eq. (5), 43 FPIIs for each element of LT and 5 FPIIs for each of the lean tenet are obtained as listed in Table 8 and Table 9 respectively. Although the HLII of the case hospital is equivalent to the linguistic level of "Semi-Lean" (according to the evaluation), it is much away from '"Completely Lean" (the leanness level aimed by the case hospital). Obstacles that could act as barriers for improvements in HLII of the case hospital were identified through ranking FPII values.

"Insert Table 8 & Table 9 here"

(ii) Ranking Fuzzy performance-importance indexes

Since fuzzy numbers do not always yield a totally ordered set as it can be obtained in the case of real numbers, the FPII's must be ranked. Numerous methods have been devised for ranking fuzzy numbers (Chen and Hwang, 1992; Lee-Kwang and Lee, 1999). In this study, fuzzy numbers were ranked using the method proposed by Wang and Lee (2008) which is based on the area between the centroid and original points. This method was chosen as it identified the disadvantages in the existing fuzzy ranking methods such as those proposed by Chu and Tsao (2002). In addition, this method was computationally simpler and the ranking order obtained was more consistent with the intuition.

In this study, the ranking score of triangular FPII fuzzy numbers is calculated by evaluating the centroid of that particular fuzzy number. The scores represent the effect/contribution of each element of LT towards overall HLII. Table 8 and Table 9 ranks the FPII's of 43 elements of LT and five tenets of LT respectively. To identify the most critical factors, Pareto principle was adopted by the research team. The threshold for ranking score was intuitively set to less than 0.05 for filtering the elements of LT that requires future focus (Vinodh and Balaji, 2011; Vinodh and Aravindraj, 2013). Elements of LT which were ranked more than 36 (last seven practices) had ranking score less than 0.05.

5. Results and Discussion

In the subsequent paragraphs, the process improvement achieved by the case hospital through lean implementation is documented. This helps in validating and triangulating the assessment results obtained. Case hospital has achieved successful implementation of first three lean tenets beyond the set threshold of 0.05. It needs to focus on the remaining two tenets namely, establishing pull system (HLAF4), and seeking perfection (HLAF5). But, it was also observed that nearly 3 lean elements within first 3 tenets were below the set threshold value of 0.05 which needs to be revisited by the implementation team.

a) "Identify & Specify Value" (HLAF1)

Contributors: Tenet 1 ranks second among other five tenets. But, difference in the ranking score of first (tenet 2) and second (tenet 1) ranked tenet is negligible (magnitude of 0.003) and hence the progress made in the implementation of these two top ranked tenets (tenet 1 and tenet 2) can be considered to be equal. Elements of LT that are highly contributing towards the rank of this lean tenet are top management and leadership support (HLAF12), 5S (HLAF15), employee and supplier feedback (HLAF17), checklist maintenance (HLAF111), and information transparency across the supply chain (HLAF113).

- The top management in the case hospital demonstrated and emphasized its support for lean implementation through the following practices: installing a register for gathering the complaints from both internal employees and external customers, daily rounds at clinical and non-clinical areas, listen to the day to day grievances of the employees and customers and ensure that the requisite action is taken within next three days, suggestion box at different locations of the hospital (which will be checked every week), recognition of employees who suggested the best improvement solution to reduce the wastes prevailing in the process, etc.
- 5S led to various process level changes in the case hospital. Some of the changes implemented were standard coding scheme for medical records which were earlier tracked in the repository using staff's tacit experience, and the introduction of index

cards for assisting in the faster identification of exact shelf from where the medical files were taken for physician consultation.

Challenges: "Value stream identification" (HLAF11) and "A3 problem solving" (HLAF18) contributes the least for tenet 1. Hospital has started training its employees towards implementation of these lean elements and will begin implementing them in the immediate future.

- Low score for "Value stream identification" can be because the case hospital has started implementing elements of LT recently and is targeting problems that are of an immediate priority than structurally proceeding as prescribed in the five tenets of LT.
- A3 problem solving was not practiced by the case hospital as its successful adoption requires training from a consultant. At the starting, the implementation committee was only focusing on those elements of LT which can be easily implemented by the grass root level employees with minimal training and financial investment.

b) "Evaluate Value Stream" (HLAF2)

Contributors: Tenet 2 score is close to tenet 1 and higher than the remaining three tenets. The lean element that is highly contributing towards this tenet is "waste identification" (HLAF23).

- Waste identification is one of the elements that would motivate the top management of healthcare institutions as it clearly reveals the potential benefits and monetary savings that can be obtained. Case hospital conducted several audits to understand the flow of patients. They studied the processes prevailing within, relationships between the processes, value adding and non-value adding activities from the perspective of patients and visitors to identify the wastes. For instance, during hospital visits, implementation team found several medicines to be "out of stock" in the outpatient department storage room but found them to be available in the storage rooms of inpatient department. Reason for maintaining two different storage rooms were stated to be the built-in layout of the hospital and also for ensuring the accountability of the in-charge of these two departments. To overcome this inventory and waiting waste, the lean implementation team streamlined and centralized the procurement process for both the departments and appointed a single-in-charge to monitor the reorders and availability of stock. Moreover, stocks at both these storage rooms were linked and tracked through IT system.

Challenges: The elements of LT that are least contributing towards the rank of this lean tenet are value stream mapping (HLAF21), and efficient scheduling (HLAF24). The reason for least implementation of value stream mapping was found to be similar to that of A3 problem solving, i.e. the guidance and training from a consultant for implementation of these complex tools is mandatory. Implementation team in the hospital also indicated in the interview that the reason for the minimal implementation of "efficient scheduling" to be the resistance of physicians towards standardizing the scheduling procedure. They also mentioned that this change was perceived by physicians to reduce their autonomy.

c) 'Creating Continuous Flow' (HLAF3)

Contributors: This tenet ranks third among other lean tenets. Elements of LT that are highly contributing towards this tenet are "patient waiting time reduction" (HLAF32), "load leveling (through patient family grouping and demand-based scheduling)" (HLAF37), and "medical device preparation and downtime reduction" (HLAF39).

- Waiting time reduction was achieved by implementing token and online booking systems at different departments. In an attempt to reduce the waiting time and level the load at a process, layout changes were implemented in the hospital by studying the movement of patients. For instance, the pathological laboratory was shifted to the 4th floor of the hospital as its earlier location was hindering the smooth flow of patients without adding much value. Future plans have been made for renovating the operation theaters (OT) and casualty department to improve process flow and reduce the waiting time.
- Case hospital started separate inpatient and outpatient pharmacy counters to distribute and level the load at the counters.

Challenges: Elements of LT that are least contributing to this tenet are "minimizing complex queuing" (HLAF31), "patient flow streamlining & transfer minimization" (HLAF33), "reports & procedural delay reduction" (HLAF35), and "standardized work sequencing for physicians" (HLAF38).

- Physicians resisted the implementation of "standardized work sequencing" fearing the loss of autonomy in flexibly scheduling their activities based on the needs of the patient being treated. Physicians interviewed mentioned that every patient is unique and it is nearly impossible to standardize the amount of time for each task.
- Management would encourage creating standardized schedules and processes for increasing the efficiency of the process and utilization of scarce resources such as OT. Implementation team stated that the management and physicians are discussing to strike a balance by identifying the set of tasks that can be standardized.

d) Other tenets: 'Establishing Pull' (HLAF4) and 'Seeking Perfection' (HLAF5) tenets are the least ranked. According to the assessment, case hospital needs to focus on these tenets to improve its HLII. None of the elements of LT within these tenets are sufficiently implemented to contribute towards the leanness. "Just-in-time" (HLAF45), "resource overcapacity and under capacity minimization" (HLAF46), "U-shaped OT and laboratory design" (HLAF55), and "quality monitoring teams" (HLAF56) are some of the lean elements that the case hospital can implement in future to improve their lean performance under these two tenets. Research team proposed the following measures to the case hospital for improving its lean elements implementation under HLAF 4 and HLAF5 tenets:

- Involving employees in the process to ensure that medical devices are prepared well before starting the next task
- Training employees (especially nurses in the out-patient department and wards) for multi-skilling through job rotation would help in achieving optimal capacity utilization in long run by moving employees to the bottleneck process whenever necessary

- Formation of health care quality committees at different hospital departments to conduct regular meetings for identifying continuous improvement projects
- Lean implementation team can apply for national and international level quality certifications, accreditations and awards

6. Conclusion

Leanness of a healthcare institution has been defined to capture the importance and degree of implementation of lean elements. The importance of leanness assessment in healthcare institutions has also been discussed by documenting different leanness assessment techniques existing in literature and its absence in the context of healthcare institutions. A framework for assessment of LT and the associated FLB-HLIA have been developed and demonstrated in this study. FLB-HLIA incorporated linguistic approximation and fuzzy arithmetic for measuring HLII, stressing the multiplicity of meaning and ambiguity of attribute measurement. FLB-HLIA not only provides a holistic picture of leanness attained but also computes the individual score attained by the healthcare institution in five tenets and 43 lean elements. Leanness values can assist the implementation team in understanding the barriers prevailing in the healthcare institution and in turn provide necessary inputs for overcoming them. Therefore, FLB-HLIA technique facilitates continuous improvement of a healthcare institution for pursuing perfection through the implementation of lean elements.

The current study has answered all the three research questions raised at the beginning of this study. In answer to the first research question, a framework for assessing LT based on its five tenets has been developed by listing the elements that can be implemented by a healthcare institution under each tenet. The procedure for measuring leanness using FLB-HLIA has been demonstrated using a case hospital. To answer the second research question, FLB-HLIA is capable of revealing the level of implementation of different LT elements under the corresponding tenet at the healthcare institution. Assessment procedure also delivers the future action plan for carrying out further process improvements in the healthcare institution. Finally, the assessment technique demonstrated in this study can be used to answer the third research question as it proposes HLII which can encourage comparison with other healthcare institutions (inter-benchmarking) in the market or with itself (intra-benchmarking) in the past.

6.1. Research Implications

Assessment framework developed in this study is grounded in literature and hence is theoretically generalizable across healthcare institutions. Even though the demonstrated FLB-HLIA is specific to a case hospital, the documented assessment procedure for inferring and interpreting the results is transferrable to lean assessment in other healthcare institutions. Our research is unique in developing an assessment procedure to assist the application of widely adopted operations research tool, namely lean (Dankbar & Hayward, 2012), to improve the processes of healthcare institutions. Similar to operations research tool, the FLB-HLIA tool developed in our study helps the lean consultants and healthcare practitioners in making decisions on where to focus and invest resources in future for furthering the lean journey.

Studies in future can attempt to empirically validate the developed framework by conducting large-scale surveys. In addition, to overcome the subjectivity associated with perception based ratings of implementation, future studies can assess how the implementation of different lean practices impacts the objective operational performance measures such as inventory level, patient flow time, etc. of the healthcare institution. Studies in future can also develop an assessment technique to evaluate the readiness of a hospital before proceeding with the implementation of LT.

6.2. Managerial Implications

Five lean tenets will be achieved one after the other as the healthcare institution moves forward in its lean implementation journey. The choice of LT element within a tenet to be implemented depends on the availability of different resources such as financial, human, infrastructure, etc. at the healthcare institution. Post-achieving the targeted implementation of all the five tenets, healthcare institution can assess the extent of implementation of LT. FLB-HLIA assists practitioners by offering a literature grounded implementation framework and assessment technique for measuring healthcare institution's leanness. This technique also reveals the areas for future focus by understanding which elements of LT were fairly implemented and which needs further improvement. If the healthcare institution has achieved the initially set objective, it may revise its objective or formulate a new objective and start with a new/modified lean cycle. On the other hand, if the healthcare institution's achievements are incomplete in its previous lean cycle, then it would follow the future action plan that will be developed as a result of FLB-HLIA. Post implementing the future action plan, the healthcare institution can repeat its assessment using FLB-HLIA technique to evaluate the improvement in leanness in comparison to the earlier cycle. Lean implementation team of the case hospital was convinced with the results obtained from FLB-HLIA. They consented to implement the recommendations made by the assessment as it revealed the barriers that they were experiencing in their lean implementation journey. Proposed assessment procedure also takes care of the uncertainty in evaluating the degree of implementation of each LT element for assuring realistic and informative assessment. FLB-HLIA technique would help lean practitioners and consultants to understand where the healthcare institution stands in its lean implementation journey. Lean assessment team of the case hospital felt the assessment procedure to be very practitioner friendly as it requires only the input of linguistic values to deliver HLII and future areas for improvement. These characteristics of FLB-HLIA can be expected to encourage its adoption by healthcare professionals.

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Figures

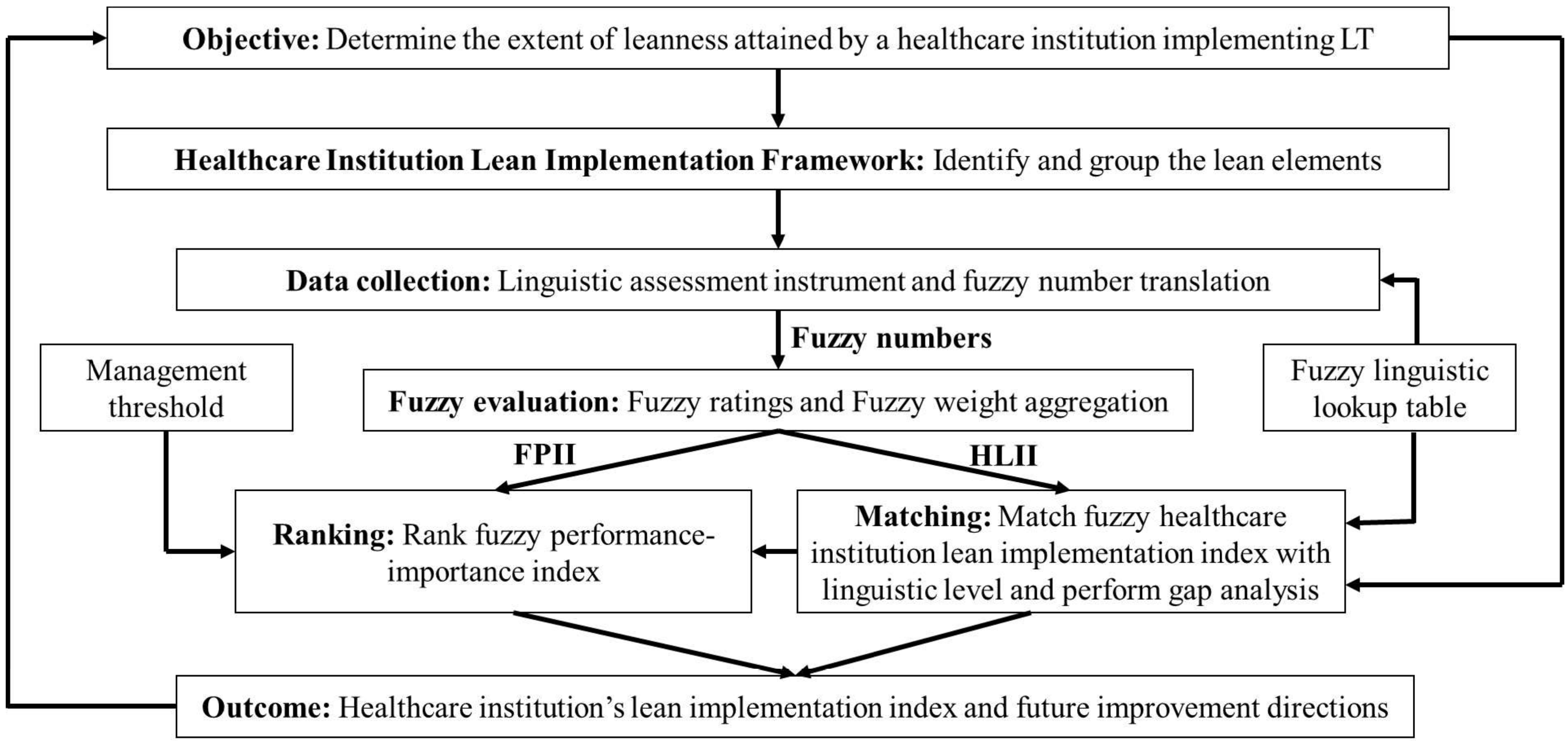

Figure 1 - Fuzzy Logic based leanness assessment framework for healthcare institution

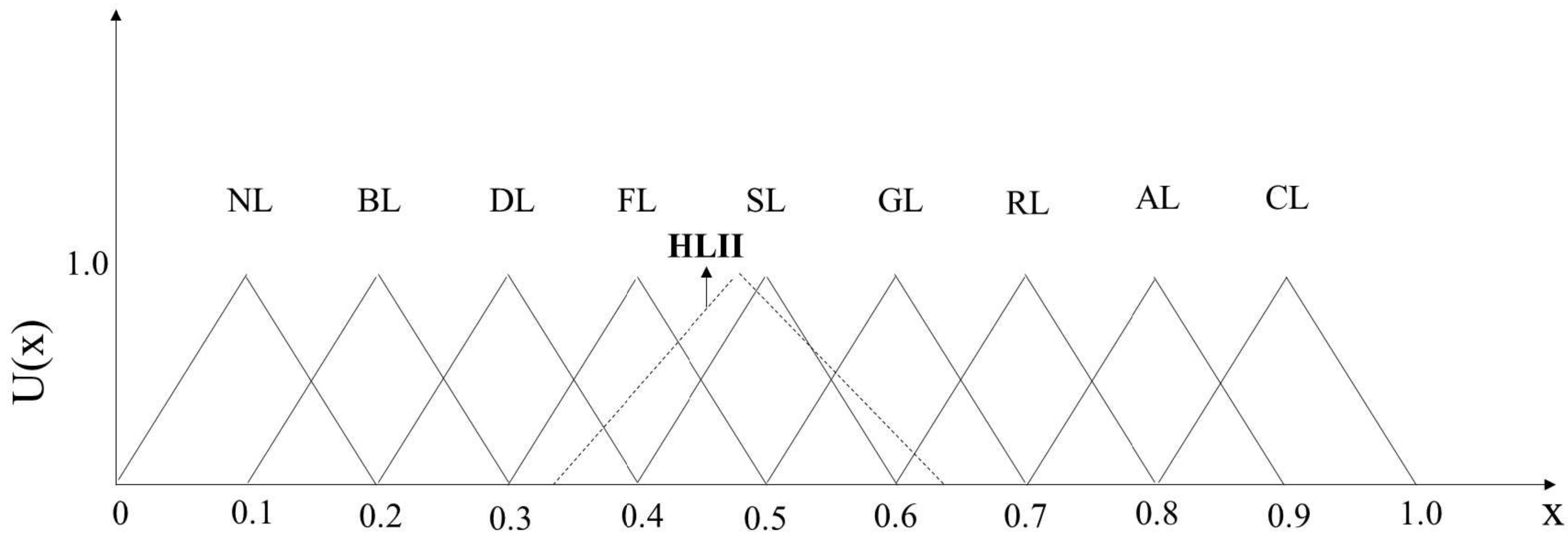

Figure 2 - Linguistic levels for matching HLII. [(NL (0.0, 0.1, 0.2); BL (0.1, 0.2, 0.3); DL (0.2, 0.3, 0.4); FL (0.3, 0.4, 0.5); SL (0.4, 0.5, 0.6); GL (0.5, 0.6, 0.7); RL (0.6, 0.7, 0.8); Al (0.7, 0.8, 0.9); CL (0.8, 0.9, 1.0)]

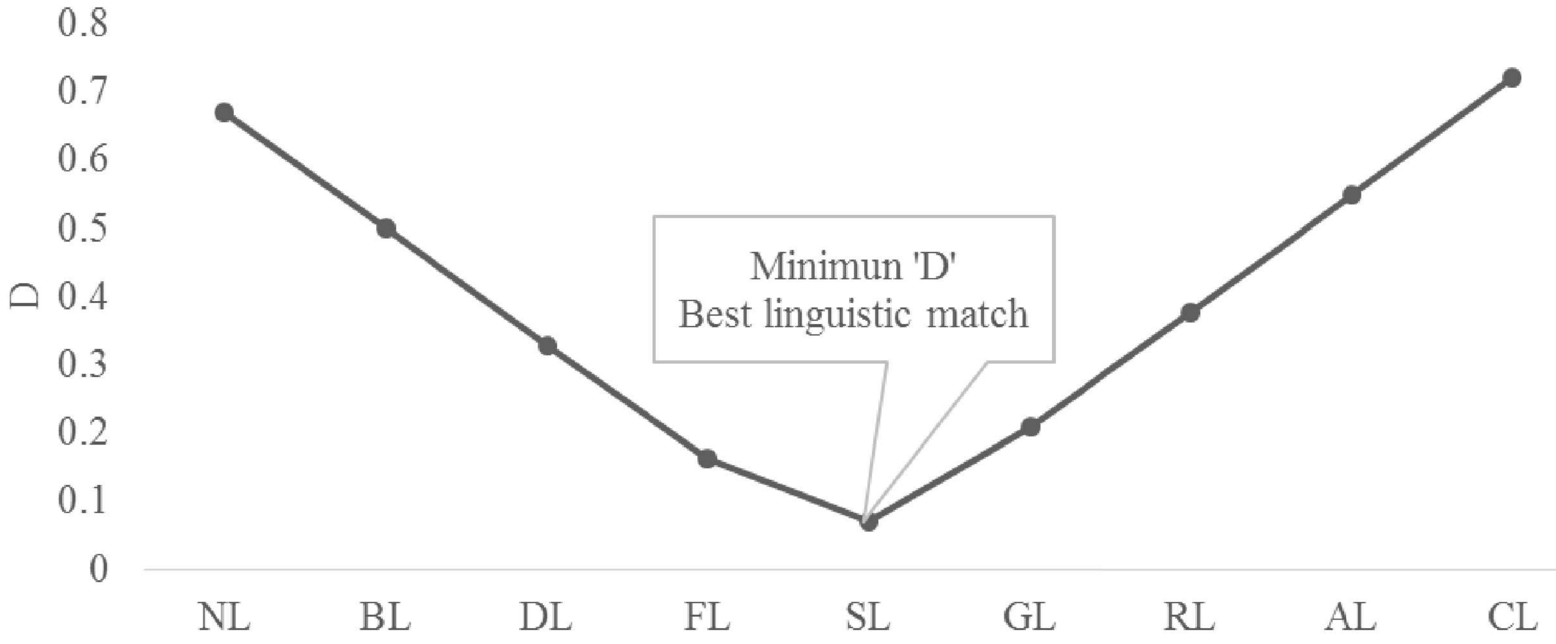

Figure 3 - HLII Euclidean distance (D) from each member of HL set

Tables

Table 1 (a): LT implementation in healthcare

Authors	Country	Problem	Process
Heinbuch (1995)	USA	To remain viable and competitive in the new cost-conscious environment.	Hospital purchasing and materials management function
Bowen & Youngdahl (1998)	Canada	To improve the service delivery to become acclaimed service role model in healthcare industry	Diagnosis
Bushell et al. (2002)	USA	To improve the patient experience and care delivery	Diagnosis
Kim et al. (2006)	USA	To enhance the care of patients across various venues of hospitalization and flow toward discharge.	Processes from hospitalization to discharge
Jimmerson et al. (2005)	USA	Poorly specified activity and a complex pathway	Multiple processes
King et al. (2006)	Australia	To establish streams for patient flows in a teaching general hospital ED.	Emergency department
Weber (2006)	USA	Improve process efficiency	General processes
Ben-Tovim et al. (2007)	Australia	Redesigning of care	Multiple processes
Pham et al. (2007)	USA	Redesigning care delivery	Multiple processes
Balle & Regnier (2007)	Paris	Teaching LT	Nursing
Kim et al. (2007)	USA	Improve patient care access and reduce excess work	Multiple processes
Smith et al. (2011)	U.S.	To decrease non-value-added time (time a patient spends alone in an examination room) without altering the time providers spend caring for a patient and improve the timely coordination of care in clinics	Cystic fibrosis centers
Toussaint & Berry (2013)	USA	Multiple problems in the healthcare processes	Scheduling in radiology

Table 1 (b): LT principles and practices in healthcare

Authors	**Lean Tenet**	**Lean Element**
Heinbuch (1995)	Waste reduction & flow establishment	Just-in-time (JIT) inventory management system, no employee lay-off, consolidation of vendors, and weekly operational meetings between purchasing, materials management, distribution and central sterile.
Bowen & Youngdahl (1998)	Absolute perfection, flow achievement, continuous value addition, and patient pull	Focussed factory, back-office standardization, patient involvement in processes like screening and shaving, medical application over email, production capacity leveling, surgeons working as a team, surgeons assignment rotation, U-shaped operating rooms configuration, and loving care in service encounters.
Bushell et al. (2002)	Value addition and flow	VSM, smartcard based automatic check-in, walking the process, information sharing between representatives across functional areas, consultant involvement, standardization of supplies for all exam rooms, and locations of nurse/provider teams.
Kim et al. (2006)	Waste reduction and Flow establishment	VSM, Plan–do–check–act cycle, standardization of surgical instrument use, mistake proofing, utilization of skilled individuals, standardization of order processing, no fire policy, and no autonomous 'silos' operation.
Jimmerson et al. (2005)	Defect free and no waste	VSM and one-page problem-solving A3 report.
King et al. (2006)	Waste reduction and flow establishment	Process mapping with staff, identification of value streams, and minimizing complex queuing in ED.
Weber (2006)	Waste reduction	U-shaped cell, standardized work sequencing for physicians, and no-layoff policy
Ben-Tovim et al. (2007)	Establishing flow and eliminating waste	Work prioritization, production cells aligned with value streams, plan-do-study-act, employee training programs, visual management, and load leveling.
Pham et al. (2007)	Waste reduction	Cost and inappropriate service volume reduction, staff education and reorganization, VSM for different disorders, documentation of treatment guidelines, feedback on cost performance, and collaboration among purchasers.
Balle & Regnier (2007)	Waste reduction and zero defects	5S, systematic audit, zero out-of-date practice, supermarket arrangement, daily ward tour, standardization, and A3 report.
Kim et al. (2007)	Waste reduction and to create flow	VSM, one piece flow, and standardization.
Toussaint & Berry (2013)	Create value and reduce waste	Voice of the customer, voice of the business, trained clinic staff, and checklist to screen records during the weekly team meeting.
Heinbuch (1995)	Waste reduction	Respect for front-line workers, visual tracking, flexible regimentation, internal communication, teamwork, A3 reports, color-coding, and numbered equipment supermarket shelving.

Table 2: Healthcare institution lean assessment framework (HLAF)

Lean Tenet	Lean Element	Authors
Identify & Specify Value (HLAF1)	• Value stream identification (HLAF11) • Top management and leadership support (HLAF12) • Intention to train hospital employees (HLAF13) • Physician involvement (HLAF14) • 5S (HLAF15) • Documentation of treatment guidelines (HLAF16) • Employee and supplier feedback (HLAF17) • A3 problem solving (HLAF18) • Daily ward tour (HLAF19) • No-layoff policy (HLAF110) • Checklist maintenance (HLAF111) • Internal communication and teamwork (HLAF112) • Information transparency across the supply chain (HLAF113)	King et al. (2006); Jimmerson et al. (2005); Chalice (2007); Alukal & Chalice (2007); Ben-Tovim et al. (2007); Pham et al.(2007); Balle & Regnier (2007); Kim et al. (2007); Caton-Hughes et al. (2007); Fine et al. (2009); Smith et al. (2011); Toussaint and Berry (2013);
Evaluate Value Stream (HLAF2)	• Value stream mapping (for patient family and disorders including process mapping with staff) (HLAF21) • Hospital layout alignment with value stream (HLAF22) • Waste identification (HLAF23) • Efficient scheduling (HLAF24) • Treatment delivery synchronization through standardization (HLAF25)	King et al. (2006); Jimmerson et al. (2005); Kollberg et al. (2007); Ben-Tovim et al. (2007); Pham et al.(2007); Balle & Regnier (2007); Kim et al. (2007);
Creating continuous Flow (HLAF3)	• Minimizing complex queuing (HLAF31) • Patient waiting time reduction (HLAF32) • Patient flow streamlining & transfer minimization (HLAF33) • Mistake proofing and Defect minimization (HLAF34) • Reports & procedural delay reduction (HLAF35) • Multi-skilled teams (HLAF36) • Load leveling (through patient family grouping and demand based scheduling) (HLAF37) • Standardized work sequencing for physicians (HLAF38) • Medical device preparation and downtime reduction (HLAF39)	King et al. (2006); Jimmerson et al. (2005); Weber (2006); Kollberg et al. (2007); Ben-Tovim et al. (2007); Kim et al. (2007);
Establishing pull system (HLAF4)	• Work prioritization (in case of multiple customer pulls) (HLAF41) • Interaction and participation of stakeholders (HLAF42) • Patient satisfaction (comfort, treatment, respect, and participation) (HLAF43) • Visual graphs monitoring daily performance (HLAF44) • Just-in-time (HLAF45) • Resource overcapacity and under capacity minimization (HLAF46) • Supermarket arrangement (color coded and numbered equipment) (HLAF47) • Supplier collaboration (includes pharmacy, chemical, diagnostic equipment, etc. suppliers) (HLAF48)	Kollberg et al. (2007); Ben-Tovim et al. (2007); Pham et al.(2007); Balle & Regnier (2007); Toussaint and Berry (2013);
Seeking Perfection (HLAF5)	• Continuous improvement (HLAF51) • Real-time continuous process evaluation (HLAF52) • Process control & systematic audit (HLAF53) • Lean improvement teams (HLAF54) • U-shaped OT and laboratory design (HLAF55) • Quality monitoring teams (HLAF56) • Zero out-of-date practice (HLAF57) • Patient and visitors feedback (including cost performance) (HLAF58)	Kollberg et al. (2007); Weber (2006); Alukal & Chalice (2007); Pham et al.(2007); Smith et al. (2011);

Table 3: Distribution of employees in the case hospital

Role	Number
Doctors	31
Administration	8
Nursing	90
Housekeeping	25
Pharmacy	10
Front office and billing	8
Laboratory	17
Medical record keeping	13
Maintenance	8
Others	46
Total	256

Table 4: Details of employees interviewed in the case hospital

Designation/ Role	Number of people	Details
Managing director	1	As LT implementation needs to be initiated and supported by top management, managing director (MD) was involved in the team. In addition, MD commanded great respect from all the employees as MD was instrumental in the growth of the hospital from its beginning.
Physicians from different departments	3	Physician's involvement plays a key role as they are the one interfacing with patients and add a significant amount of value by addressing their needs.
Quality manager	1	Presence of a team member who is knowledgeable about the basic quality and operations concepts and healthcare standards is a necessity. Will take the responsibility of implementing lean initiatives in accordance with compliance regulations. Primary responsibility for technical training programs also lies with the quality manager.
HR manager	1	Core of LT implementation is at the culture and employees of the hospital. HR policies play a key role in motivating employees towards successfully implementing LT initiative. Most of the LT initiatives fail due to the resistance of employees to change or fear of losing their job.
IT manager	1	Involvement of IT manager was felt necessary to receive inputs on how IT can be used to reduce the wastes identified and make patients much comfortable in the hospital. Responsibility for training the employees to overcome their resistance towards new IT systems lies with IT manager.
Public relations officer	1	Public relations officer (PRO) was involved as a team member to ensure that the process improvements addressed by the hospital were actually those valued by the patients and visitors to the hospital. PRO received the grievances of the customers and circulated it to the concerned in charge.
Marketing manager	1	Involvement of marketing manager is necessary to bring in the initiatives taken by other hospitals in the country to improve their processes and also to communicate the improvement initiatives taken by the hospital to customers.
Medical records manager	1	Medical records manager was involved in this team to receive inputs on the implementation of electronic medical records system in the hospital.
Assistant nursing superintendent	1	Monitored the completion of improvement initiatives taken by this team. Was also responsible for updating the team on the achievement of the initiatives taken and also the problems faced. Need to work closely with his/her direct reports to ensure accountability and open communication. Assistant nursing superintendent also needs to make other employees buy the hospital initiatives as their own responsibility.
Nursing assistant	2	Supported assistant nursing superintendent to achieve the objectives set for the processes.

Table 5: Linguistic variables and their corresponding fuzzy numbers

Degree of Implementation (Weight)				Degree of Importance (Rating)			
Linguistic variable	**Fuzzy numbers**			**Linguistic variable**	**Fuzzy numbers**		
Worst [W]	0	0.05	0.15	Very Low [VL]	0	0.05	0.15
Very Poor [VP]	0.1	0.2	0.3	Low [L]	0.1	0.2	0.3
Poor [P]	0.2	0.35	0.5	Fairly Low [FL]	0.2	0.35	0.5
Fair [F]	0.3	0.5	0.7	Medium [M]	0.3	0.5	0.7
Good [G]	0.5	0.65	0.8	Fairly High [FH]	0.5	0.65	0.8
Very Good [VG]	0.7	0.8	0.9	High [H]	0.7	0.8	0.9
Excellent [E]	0.85	0.95	1	Very High [VH]	0.85	0.95	1

Table 6: Snapshot of linguistic implementation rating and importance weight of lean elements under the tenet "HLAF1"

Lean Tenet ($HLAF_i$)	**Lean Element ($HLAF_{ij}$)**	**Assessors linguistic implementation rating**					**Assessors linguistic importance weight**				
		A1	**A2**	**A3**	**A4**	**A5**	**A1**	**A2**	**A3**	**A4**	**A5**
HLAF1							H	VH	VH	H	H
	HLAF11	G	VG	VG	G	VG	VH	H	VH	VH	H
	HLAF12	G	G	F	VG	G	FH	H	FH	FH	M
	HLAF13	VG	G	G	G	VG	H	VH	H	H	VH
	HLAF14	VG	G	G	VG	G	H	H	FH	VH	H
	HLAF15	G	F	G	G	F	FH	H	FH	M	M
	HLAF16	F	G	F	F	G	H	FH	FH	VH	H
	HLAF17	VG	E	VG	E	VG	H	FH	H	H	FH
	HLAF18	E	VG	E	VG	E	VH	VH	H	VH	VH
	HLAF19	VG	G	G	G	VG	H	VH	H	H	VH
	HLAF110	VG	G	G	VG	G	H	H	FH	VH	H
	HLAF111	G	F	G	G	F	FH	H	FH	M	M
	HLAF112	F	G	F	F	G	H	FH	FH	VH	H
	HLAF113	VG	E	VG	E	VG	H	FH	H	H	FH

Table 7: Conversion of linguistic implementation rating and importance weight on lean element "HLAF15" into fuzzy numbers

Assessors	**Linguistic implementation rating**	**Equivalent Fuzzy Number**			**Linguistic importance weighing**	**Equivalent Fuzzy Number**		
A1	Good [G]	0.5	0.65	0.8	Fairly High [FH]	0.5	0.65	0.8
A2	Fair [F]	0.3	0.5	0.7	High [H]	0.7	0.8	0.9
A3	Good [G]	0.5	0.65	0.8	Fairly High [FH]	0.5	0.65	0.8
A4	Good [G]	0.5	0.65	0.8	Medium [M]	0.3	0.5	0.7
A5	Fair [F]	0.3	0.5	0.7	Medium [M]	0.3	0.5	0.7
Fuzzy average implementation rating of HLAF15		0.42	0.59	0.76	**Fuzzy average importance weighing of HLAF15**	0.46	0.62	0.78

Table 8: FPII's and ranking scores of 43 lean practices

Lean Element	Ri			[(1.0, 1.0, 1.0) - Wi]			FPII			Ranking score	Rank
HLAF11	0.62	0.74	0.86	0.04	0.11	0.21	0.02	0.08	0.18	0.096	18
HLAF12	0.50	0.65	0.80	0.20	0.35	0.50	0.10	0.23	0.40	0.243	1
HLAF13	0.58	0.71	0.84	0.06	0.14	0.24	0.03	0.10	0.20	0.112	15
HLAF14	0.58	0.71	0.84	0.10	0.20	0.31	0.06	0.14	0.26	0.153	9
HLAF15	0.42	0.59	0.76	0.22	0.38	0.54	0.09	0.22	0.41	0.242	3
HLAF16	0.38	0.56	0.74	0.12	0.23	0.35	0.05	0.13	0.26	0.144	11
HLAF17	0.76	0.86	0.94	0.14	0.26	0.38	0.11	0.22	0.36	0.229	5
HLAF18	0.79	0.89	0.96	0.02	0.08	0.18	0.02	0.07	0.17	0.087	21
HLAF19	0.58	0.71	0.84	0.06	0.14	0.24	0.03	0.10	0.20	0.112	14
HLAF110	0.58	0.71	0.84	0.10	0.20	0.31	0.06	0.14	0.26	0.153	8
HLAF111	0.42	0.59	0.76	0.22	0.38	0.54	0.09	0.22	0.41	0.242	2
HLAF112	0.38	0.56	0.74	0.12	0.23	0.35	0.05	0.13	0.26	0.144	10
HLAF113	0.76	0.86	0.94	0.14	0.26	0.38	0.11	0.22	0.36	0.229	4
HLAF21	0.32	0.50	0.68	0.04	0.11	0.21	0.01	0.06	0.14	0.070	27
HLAF22	0.62	0.74	0.86	0.08	0.17	0.28	0.05	0.13	0.24	0.139	12
HLAF23	0.38	0.56	0.74	0.20	0.35	0.50	0.08	0.20	0.37	0.214	6
HLAF24	0.26	0.44	0.62	0.08	0.17	0.27	0.02	0.07	0.17	0.088	20
HLAF25	0.69	0.80	0.90	0.10	0.20	0.31	0.07	0.16	0.28	0.169	7
HLAF31	0.30	0.50	0.70	0.04	0.11	0.21	0.01	0.06	0.15	0.071	26
HLAF32	0.14	0.26	0.38	0.22	0.38	0.54	0.03	0.10	0.21	0.112	16
HLAF33	0.16	0.29	0.42	0.02	0.08	0.18	0.00	0.02	0.08	0.034	41
HLAF34	0.18	0.32	0.46	0.08	0.17	0.27	0.01	0.05	0.12	0.064	32
HLAF35	0.10	0.20	0.31	0.04	0.11	0.21	0.00	0.02	0.07	0.030	43
HLAF36	0.26	0.44	0.62	0.08	0.17	0.28	0.02	0.07	0.17	0.090	19
HLAF37	0.14	0.26	0.38	0.20	0.35	0.50	0.03	0.09	0.19	0.103	17
HLAF38	0.06	0.14	0.24	0.08	0.17	0.27	0.00	0.02	0.06	0.031	42
HLAF39	0.32	0.50	0.68	0.10	0.20	0.31	0.03	0.10	0.21	0.114	13
HLAF41	0.36	0.53	0.70	0.04	0.11	0.21	0.01	0.06	0.15	0.073	25
HLAF42	0.22	0.38	0.54	0.06	0.14	0.24	0.01	0.05	0.13	0.065	31
HLAF43	0.12	0.23	0.34	0.10	0.20	0.31	0.01	0.05	0.11	0.054	36
HLAF44	0.18	0.32	0.46	0.06	0.14	0.24	0.01	0.04	0.11	0.055	35
HLAF45	0.20	0.35	0.50	0.02	0.08	0.18	0.00	0.03	0.09	0.041	40
HLAF46	0.32	0.50	0.68	0.00	0.05	0.15	0.00	0.03	0.10	0.042	38
HLAF47	0.30	0.47	0.64	0.06	0.14	0.24	0.02	0.07	0.15	0.079	23
HLAF48	0.22	0.38	0.54	0.06	0.14	0.24	0.01	0.05	0.13	0.065	30
HLAF51	0.36	0.53	0.70	0.04	0.11	0.21	0.01	0.06	0.15	0.073	24
HLAF52	0.22	0.38	0.54	0.06	0.14	0.24	0.01	0.05	0.13	0.065	29
HLAF53	0.14	0.26	0.38	0.10	0.20	0.31	0.01	0.05	0.12	0.061	33
HLAF54	0.18	0.32	0.46	0.06	0.14	0.24	0.01	0.04	0.11	0.055	34
HLAF55	0.20	0.35	0.50	0.02	0.08	0.18	0.00	0.03	0.09	0.041	39
HLAF56	0.32	0.50	0.68	0.00	0.05	0.15	0.00	0.03	0.10	0.042	37
HLAF57	0.30	0.47	0.64	0.06	0.14	0.24	0.02	0.07	0.15	0.079	22
HLAF58	0.22	0.38	0.54	0.06	0.14	0.24	0.01	0.05	0.13	0.065	28

Table 9: FPII's and ranking scores of five lean principles

Lean Tenet	Ri			[(1.0, 1.0, 1.0) - Wi]			FPII			Ranking score	Rank
HLAF1	0.578	0.710	0.838	0.060	0.140	0.240	0.035	0.099	0.201	0.112	2
HLAF2	0.453	0.607	0.759	0.080	0.170	0.270	0.036	0.103	0.205	0.115	1
HLAF3	0.187	0.326	0.468	0.060	0.140	0.240	0.011	0.046	0.112	0.056	3
HLAF4	0.246	0.400	0.554	0.020	0.080	0.180	0.005	0.032	0.100	0.046	4
HLAF5	0.245	0.401	0.557	0.020	0.080	0.180	0.005	0.032	0.100	0.046	4

Appendix 1: Review studies on the topic "LT implementation in healthcare"

S. No.	Author(s)	Year	Journal	Contribution
1	Kollberg et al.	2007	International Journal of Productivity and Performance Management	Review integrates literature from the health care sector and the lean production movement to understand the applicability of LT in the context of healthcare.
2	Cooper & Mohabeersingh	2008	Journal of Pre-Clinical and Clinical Research	Rationale for the review performed is to seek ways to minimize waste, improve efficiency, and create a harmonious working environment within a health care setting.
3	Young & McClean	2008	Quality and Safety in Health Care	Conducts a preliminary analysis of areas where the read-across from other sectors to healthcare is relatively well understood, based on a broad review of its impact on care delivery.
4	De Souza	2009	Leadership in Health Services	Describes the concept of LT application and assesses how the trends and methods of this approach in healthcare context have evolved.
5	Joosten et al.	2009	International Journal for Quality in Health Care	LT application to health care has been limited and focused on operational aspects leaving out the sociotechnical aspects.
6	Winch & Henderson	2009	The Medical Journal of Australia	Based on the review found that scant evidence exists to prove that re-engineering health care services in line with industrial models increases their efficiency.
7	Poksinska	2010	Quality Management in Healthcare	Discusses the current state of implementation of lean production in health care by focusing on the definition of lean in health care and implementation process, barriers, challenges, enablers, and outcomes of implementing lean production methods in health care.
8	DelliFraine et al.	2010	Quality Management in Healthcare	Review study attempts to answer whether the two quality improvement tools, six sigma and lean systems, actually improve health care quality.

S. No.	Author(s)	Year	Journal	Contribution
9	Mazzocato et al.	2010	Quality and Safety in Health Care	Conducted a review of empirical studies of LT applications in healthcare to understand how LT has been put into practice in healthcare and how it has worked.
10	Holden	2011	Annals of emergency medicine	Reviewed 18 articles describing the implementation of Lean in 15 emergency departments (ED) in the United States, Australia, and Canada.
11	McIntosh & Cookson	2012	British Journal of Healthcare Management	Review investigated whether lean management is merely a fad or it could alleviate the pressure the NHS faces. Inferred that healthcare organizations will need a paradigm shift in their management philosophy to adopt lean more widely.
12	Guimarães & de Carvalho	2012	American International Journal of Contemporary Research	Review presents the state-of-the-art of lean deployment in healthcare settings and tries to understand if national cultural resemblance to Japan means a deeper deployment of lean practices by healthcare organizations.
13	White et al.	2013	The International Journal of Leadership in Public Services	Paper reviews the lean healthcare and ProductiveWard: releasing time to care (RTC) literature and extracts the reported effects and impacts experienced by employees who implement it.
14	Al-Balushi et al.	2014	Journal of health organization and management	Purpose of this paper is to determine the readiness factors that are critical to the application and success of lean operating principles in healthcare organizations through a review of relevant literature.
15	Young	2014	International Journal of Business and Social Science	Reviews the use of 5S in healthcare services.
16	Lawal et al.	2014	Systematic reviews	Review tries to answer the following questions: (i) What can we learn from the existing evidence on lean to better understand the various methodologies used and the experience in evaluating the impact? (ii) What are the differences in lean implementation, and can we explain how those differences might lead to different

S. No.	Author(s)	Year	Journal	Contribution
				outcomes?
17	Andersen et al.	2014	BMJ open	Conflicting evidence exists on the outcomes of LT in the context of healthcare, with quantitative and qualitative studies often contradicting each other. Review has been conducted to deepen the understanding of lean in healthcare and attain a clarity on the outcomes.
18	McIntosh et al.	2014	International journal of health care quality assurance	Review tries to understand the contribution of lean management processes to higher organizational performance.

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