AHP framework to assist lean deployment in Abu Dhabi public healthcare delivery system

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Abstract

Purpose – The purpose of this paper is to introduce lean concept to the field of healthcare management, expands the conceptualization of lean management beyond the manufacturing companies to consider key waste reduction opportunities which are posited to be requisites to lean practices and implements the proposed framework in the three public hospitals in Abu Dhabi.
Design/methodology/approach – This research is designed by decomposing complex and unstructured issue into a set of components organized in a multi-level hierarchical form. To deal with this complexity of multi criteria decision-making process, analytical hierarchical process (AHP) method is used in this research.
Findings – AHP framework for this study resulted in a ranking of 21 healthcare wastes based on the evaluations of local situations by experienced healthcare professionals. It has been found that management in healthcare systems of Abu Dhabi is putting more emphasis on the inventory waste.
Research limitations/implications – The future directions of the research would be to apply a lean set of tools for the value stream optimization of the prioritized key improvement areas.
Practical implications – This is a contribution to the continuing research into lean management, giving practitioners and designers a practical way for measuring and implementing lean practices across health organizations.
Originality/value – The contribution of this research, through successive stages of data collection, measurement analysis and refinement, is a set of reliable and valid framework that can be subsequently used in conceptualization, prioritization of the waste reduction strategies in healthcare management.

Keywords Healthcare, Operations management, Analytical hierarchy process, Abu Dhabi

Paper type Research paper

1. Introduction

In this age of cut throat competition, businesses are increasingly looking to ways that can help continuously improve their processes by ensuring a highly quality output at a minimum cost. Lean methodology with its origin in the Toyota production system (TPS) is one such approach that can help businesses overcome inefficiencies. The lean concept of "waste minimization" for process improvement is no longer limited to the automotive or manufacturing companies but services such as healthcare have adopted the lean management as a process improvement program. The healthcare sector has been under pressure for the last few years as the budgets shrank and the demand jumped which necessitated the embracing of "lean thinking" by the healthcare so that "more could be achieved with less" (Poksinska, 2010).

Despite a global agreement that lean is critical for healthcare process improvement, the full deployment of lean principles was reported to be as low as 4 percent for the US hospitals with 53 percent of the hospitals reporting only some level of lean implementation (ASQ, 2009). This is not surprising given the complexity and the range of healthcare operations and the fact that lean healthcare is still a relative new phenomenon with limited literature support for a consolidated lean deployment

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strategy (De Souza and Pidd, 2011; Al-Balushi *et al.*, 2014; Mazzocato *et al.*, 2014). Weintraub (2011) suggested a careful adaptation of lean to the complex healthcare chain by initiating small scale projects restricted to one process/department as a lean "inception" stage for targeted improvements that can deliver quick and visible successes for waste reduction and quality improvement. The idea is that the small scale financial and operational gains realized in the inception stage are likely to increase an organization wide awareness and commitment to lean facilitating the broadening of lean implementation. Therefore, it can be argued that the identification, prioritization and selection of improvement opportunities that can deliver rapid and observable productivity gains are crucial to the successful implementation of lean healthcare. This warrants the use of a structured decision-making framework involving all stake holders that quantitatively ranks different alternatives for lean improvement opportunities. It appears that the selection of lean projects by a structured decision-making methodology, such as the analytical hierarchy process (AHP), has not received enough academic attention despite its strong links to a better lean deployment and improved healthcare productivity.

This paper proposes and implements an AHP framework to assist the decision-making process for the identification, prioritization and selection of waste reduction opportunities from the experience of the healthcare staff and management which is likely to maximize the lean benefits. This research was conducted in three public hospitals of Abu Dhabi, the capital city and the largest emirate in the United Arab Emirates (UAE). This study's originality stems from its emphasis on the inclusion of all seven types of wastes which were identified in the context of lean healthcare. Each healthcare waste was further divided into three types or sub-criteria in the AHP's lexicon. The decision problem is decomposed into qualitative criteria and sub-criteria that are further transformed into quantitative indicators providing a framework for identification of key improvement areas in a healthcare system. The complexity of multi criteria decision-making process is handled by the AHP which is known for handling both qualitative and quantitative data (Saaty, 2008). The results of this study have implications for the UAE public health delivery system because the aim is to assist the lean implementation by prioritizing the improvement opportunities based on the judgments of experienced healthcare staff.

The remainder of this paper is organized as follows: the next section provides a survey of the relevant literature and the Section 3 presents overview of AHP, Section 4 presents analyses and discussion and Section 5 offers conclusion.

2. Literature review

2.1 Introduction to lean methodology

As mentioned in Section 1, the lean methodology has its origin in the production system (TPS) employed at Toyota Japan that enabled it to become world's leader in quality and process efficiency. Such was the success of the TPS that it was hailed as "the machine that changed the world" (Womack *et al.*, 2007). Table I mentions some key manufacturing statistics for GM and Toyota assembly plants in 1986. The superior performance of Toyota as compared to GM establishes the lean production as a methodology that can help businesses overcome inefficiencies.

At the core of lean production is the concept of systematic elimination of "waste" or non-value-adding activities that are not desired or are not necessary to fulfill a customer request. The typical manifestations of waste are overproduction, waiting, conveyance, over processing, excess inventory, unnecessary movement and defects. An accurate description of the customer value is key to bifurcating the product flow into value and non-value-adding activities; value-adding activities transform materials and information into something the customer wants whereas the non-value-adding activities consume resources and do not directly contribute to the end result desired by the customer. Lean optimizes value and non-value-adding activities which can have a dramatic effect on productivity, cost and quality.

The success of lean at Toyota resulted in its production philosophy being emulated not only by its competitors in the automotive industry but other manufacturing sectors also saw the applicability of the waste reduction concept to their settings and aggressively adopted it with great success. Though the service sector differs on various counts but the optimization of value-adding and non-value-adding activities, ensuring built in quality, standardizing and simplifying processes is equally valid for services process improvement specially because lean methodology is focussed on the process itself and not on the process's output (Damrath, 2012). Abdi *et al.* (2006) examined five lean principles of identification of customer value, the value stream mapping, smoothing the process flow, pull demand and the perfection pursuit for potential applications in services and concluded that lean is applicable to service operations. Similarly, Ahlstrom (2004) opined that lean would be applicable to services if the contingencies stemming from the characteristics of services were taken into consideration. Bonaccorsi *et al.* (2011) highlighted the tailoring of lean tools/concepts of value stream mapping, take time and pitch to the specific requirements of services as one of the challenges to the successful implementation of lean resulting in significant operational improvements. This has led to the adoption of lean concepts by the services sector and there has been increasing evidence within the literature demonstrating clear business improvements for "lean services." Piercy and Rich (2009) reported significant improvements in quality and cost positions with minimal investment through adoption of lean tools in call centers. Similarly, Staats *et al.* (2011) investigated the applicability of lean production to software services firm and concluded that the lean software projects performed better than non-lean software projects. Productivity gains and quality improvements have also been reported with the introduction of lean in the financial services (Leyer and Moormann, 2014; De Koning *et al.*, 2008; Leseure *et al.*, 2010a). Wang and Chen (2010) found that the adoption of lean tools in the US banking sector led to the reduction of waiting times and costs while improving the process capacity. Lean tools have also been applied to other services such as the telecommunications industry (Psychogios *et al.*, 2012), airline industry (Psychogios and Tsironis, 2012), disaster relief services (Christian and Chu-Hua, 2014), public services (Radnor and Walley, 2008; Mi Dahlgaard-Park *et al.*, 2009; Leseure *et al.*, 2010b; Barton and Barton, 2011; Radnor and Johnston, 2013), logistics and distribution (Jones *et al.*, 1997; Hines *et al.*, 1999; Baudin, 2004; Reichhart and Holweg, 2007) and warehousing

Table I.
General Motors Framingham plant vs Toyota Takaoka plant, 1986

	GM Framingham	Toyota Takaoka
Gross assembly hours/car	40.7	18
Assembly defects/100 cars	130	45
Assembly space/car	8.1	4.8
Inventories of parts (average)	2 weeks	2 hours

Source: Womack *et al.* (2007)

(Dharmapriya and Kulatunga, 2011). Similarly, lean in healthcare has generated a great deal of interest given the improvement potential. The next section mentions in detail the benefits reaped by introducing lean to the healthcare in different parts of the world.

2.2 Lean healthcare

The lean tenets of waste elimination to create extra healthcare capacity has been identified as an effective approach to meet an ever increasing demand for medical treatments (Young *et al.*, 2004). However, as pointed out in the previous section, the application of lean concepts in services including healthcare need to adapt to its specific requirements. The manufacturing seven wastes of Ohno (1988) have been extended to the service sector by Bicheno and Holweg (2008) and to the healthcare by NHSIII (2007). This explanation of the healthcare wastes (Table II) seems to have the agreement of other studies such as Radnor *et al.* (2012) and Robinson *et al.* (2012).

For a pure manufacturing environment, the "inventory" waste is defined as the excessive stocks of raw materials, finished products, component parts, supplies and work-in-process (Hussain *et al.*, 2012) but for a "core service" like healthcare, the number of flow units in a healthcare process was deemed as a more representative definition of the healthcare inventory waste where the flow units could be the medical supplies, stock items and patients waiting list for a medical treatment. This perspective also allows the "waiting" waste to reflect the "health services timeliness" which has been identified as a key healthcare quality improvement challenge by the Institute of Medicine (Mayberry *et al.*, 2006). Similarly, the hospital layouts generally cause the "transportation" waste which also has been modified along with the "over processing," "overproduction," "defects" and "motion" wastes to reflect a healthcare setting.

There has been extensive evidence in the literature that the lean management has been instrumental in increasing the healthcare system's capacity without any extra cost by systematically addressing the seven wastes mentioned in the Table II. Luciano Brandao de (2009) gave a chronological account of the introduction of lean thinking in the healthcare industry suggesting that the use of Lean in the UK public healthcare

Manufacturing wastes	Examples in healthcare
Transportation	Staff walking to the other end of a ward to pick up notes Central equipment stores for commonly used items instead of locating items where they are used
Inventory	Excess stock in storerooms that is not being used Patients waiting to be discharged Waiting lists
Motion	Unnecessary staff movement looking for paperwork Not having basic equipment in every examination room
Waiting (delay)	Patients, theater, staff results, prescriptions and medicines Doctors to discharge patients
Overproduction	Requesting unnecessary tests from pathology Keeping investigation slots "just in case"
Over-processing	Duplication of information Asking for patients' details several times
Defects	Readmission because of failed discharge Repeating tests because correct information was not provided

Source: NHSIII (2007)

Table II.
The original seven wastes of Toyota production system and healthcare examples

first appeared in 2001 and, in the USA in 2002. Similarly, Kenney (2010) described the lean transformation of Virginia Mason Medical Center in Seattle Washington, from a struggling hospital in 2002 to become one of the world's top health facilities. By working to eliminate waste, Virginia Mason created more capacity in existing programs and practices so that planned expansions were scrapped, saving significant capital expenses: $1 million for an additional hyperbaric chamber that was no longer needed; $1 to $3 million for endoscopy suites that no longer needed to be relocated; $6 million for new surgery suites that were no longer necessary.

The successful implementation of lean healthcare has also been reported in many other healthcare settings. Spear (2005) described three American hospitals that used lean concepts to minimize the infections (a "defect waste") that may potentially lead to patients' death. Jimmerson *et al.* (2005) credited lean healthcare for process improvement at Intermountain Hospital with little or no investment as the "waiting waste" for frontline workers was reduced enabling a faster turnaround of pathology reports from five to two days. Thompson *et al.* (2003) mentioned dramatic reductions in the number of missing medications, time and money savings as a result of lean-driven changes at the University of Pittsburgh Medical Center health system. Similarly, Kim *et al.* (2006) reported the productivity improvements made possible by lean healthcare at Park Nicollet Health Services Minnesota which created a capacity of ten additional chemotherapy and antibiotic infusion patients per day reducing the waiting time of patients from 122 to 53 minutes in the urgent care clinic.

For the National Health Services Bolton, England, Fillingham (2007) described the benefits that were achieved with lean redesigning of trauma care including a 42 percent reduction in paperwork, 38 percent reduced patients turnaround time, total length of patient stay was reduced by 33 percent and most importantly, the mortality rate was reduced by 36 percent. Similarly, Furman and Caplan (2007) cited an implementation of patients safety alert system as part of lean initiative which drastically reduced the time required to resolve them. Kruger (2014) described the lean implementation in the South African public health system whereas Mazzocato *et al.* (2012) reported improvements in Swedish emergency care by lean-inspired interventions. Aherne and Whelton (2010) compiled a number of successful lean healthcare implementations such as access to vascular surgery outpatient clinic, patient registration, reducing waiting times at a medical oncology unit, process improvement to reduce operating room cancellation and improving laboratory operations.

These selected citations are just a small part of a long list of the process improvements that have been achieved by identifying and eliminating wastes yielding significant cost savings and improving process efficiency. The next section reviews the attributes of well-planned deployment strategies that yielded these beneficial lean transformations.

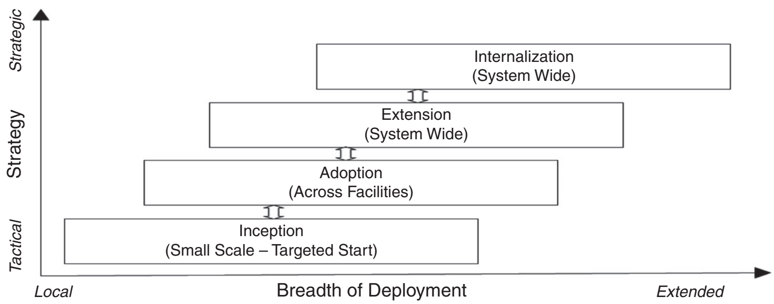
2.3 Lean deployment strategies

The starting point of a lean journey is to determine the degree of conformance of any business to the lean thinking by determining the inherent inefficiencies in the system. During the initial stages of a lean deployment program, the range and scope of these inefficiencies may overwhelm and discourage lean improvement efforts. One way to avoid this is the strategy of identification of "focus areas." The focus areas, as part of a lean transformation process, reveal gaps that need to be prioritized for attention so that an enterprise could reach its desired level of operational performance (Nightingale and Mize, 2002). The focus areas emerge as a result of information synthesis from research and/or from the experience of the healthcare staff and management.

The lean methodology advocates worker empowerment and many studies have credited the successful lean deployment to the active engagement of the healthcare staff for the information on the identification of focus areas. Roberts and Singh (2009) also reported the contribution of the frontline staff for identifying improvement opportunities which the authors felt were vital for their lean improvement project in the primary care. Similarly, Dickson *et al.* (2009) credited the ideas generation from the frontline providers for the successful implementation of lean in the emergency department of University of Iowa Hospital.

Apart from the active engagement of healthcare staff, Atkinson (2004) suggested a lean deployment strategy of initiating small scale projects that can yield quick results particularly because the tangible improvements provide the best medium to communicate the lean philosophy across the organization for an ownership that would facilitate full lean deployment. Likewise, Weintraub (2011) recommended a small scale start as a lean "Inception" stage for targeted improvements that can deliver quick and visible success for waste reduction and quality improvement within a single department (Figure 1). The key element is the selection, identification and prioritization of improvement opportunities in consultation with the management. With department-level financial and operational benefits realized in the Inception stage, the efforts can be expanded to broaden the implementation of Lean to other departments as part of the second "adoption" stage. The third lean implementation stage "extension" extends the benefits of waste reduction to extend outside the four walls of the healthcare organization reaching supplier/partners. The highest level of lean deployment, Internalization, requires a healthcare organization to fully embrace the ideology of waste reduction by continuously identifying, selecting, prioritizing and ultimately implementing improvements.

While observing the healthcare process improvement programs implemented in the UK, Powell *et al.* (2009) identified a careful consideration of local circumstances followed by application in the local context in a structured and sustained way as a pre-requisite for a successful deployment. This strengthens the argument of this paper that engaging healthcare staff and management for information collection and collation aligns the lean adaptation to the needs of local environments, therefore, facilitating successful deployment of process improvement projects. The information synthesis could be in all stages of a lean implementation starting from the identification of waste minimization opportunities as has been conducted in this study which uses AHP, a structured decision-making framework to recognize, rank and select the improvement projects.



Source: An adaptation of Weintraub (2011)

Figure 1.
Four key stages of a lean deployment program

The common theme of all the cited work in this section is the prioritization from a plethora of improvement opportunities in consultation with the employees. This study aims to use the judgment of senior healthcare personnel in a structured way to help rank the waste minimization opportunities for the Abu Dhabi public hospitals.

3. Overview of AHP

AHP methods structure the decision process into a hierarchy and the decision making involves choosing an option from different alternatives. Through a set of pair-wise comparisons at each level of the hierarchy, a matrix can be developed, where the entities indicate the strength with which one element dominates another with respect to a given criterion. AHP is a principle of measurement through pair-wise comparisons and relies on the judgment of experts to derive the priority scales. These scales measure the intangibles in relative terms. The comparisons are made using a scale of absolute judgment that represents how much more one element dominates another with respect to a given attribute. The main concern of AHP is dealing with inconsistencies arising with the judgment and improving this judgment (Vinodh and Joy, 2012). AHP judges and selects the elements/concepts which have a greater influence on predetermined objective. AHP has been used to accurately evaluate the influence of the criteria in terms of goals. Figure 2 presents the outline of AHP method employed in this research.

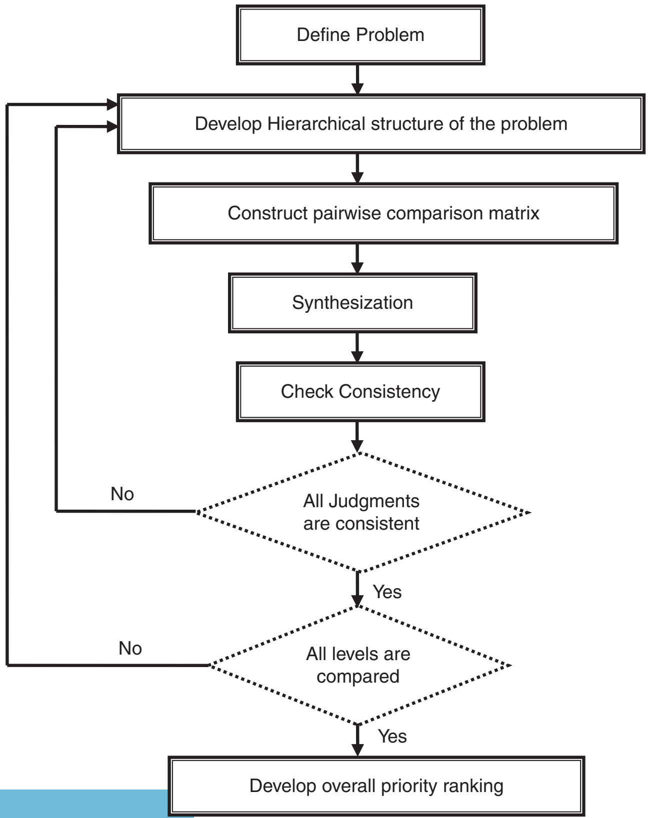


Figure 2.
Outline of AHP method applied

AHP is a methodology developed by Saaty (1980) to analyze rational and irrational values comprehensively according to the level of importance to the decision-making process. AHP facilitates formulating and simulating the human decision-making mechanism in multi criteria evaluation procedures. In addition, it is an effective procedure to analyze the strategic concepts of a company by the representation of a complex problem into a disintegrated hierarchical problem. This disintegrated representation of multiple-level hierarchy helps the decision makers to identify and deal with a problem in a structured manner. The complexity of the problem determines the number of levels of hierarchy. Ishizaka *et al.* (2012) also highlighted the usefulness of AHP's multi-level hierarchical structure of objectives, criteria and alternatives for improving consistency and comparing relative performance of an organization.

The suitability of AHP for this study is determined by a number of factors such as AHP's ease of use and flexibility for a wide range of unstructured problems. Furthermore, AHP integrates a deductive approach for solving complex problems dealing with the interdependencies of system elements. It also reflects the natural tendency of human mind to sort elements of a system into different levels and group like elements (Hussain *et al.*, 2015). Above all, AHP provides a scale to measure and prioritize intangibles allowing this research to draw upon the experience of practitioners for the identification and ranking of process improvement opportunities in the health sector.

Recently, there has been a renewed interest in the AHP as an emerging solution approach to complex real world and multi criteria decision-making problems (Lee and Drake, 2010; Ishizaka *et al.*, 2012). AHP has been successfully implemented in various fields. For example, Ghodsypour and O'brien (1998), Korpela *et al.* (2001) and Hsu Lee and Hsu (2004) implemented AHP in logistics management; for the manufacturing sector (Braglia *et al.*, 2001; Korpela *et al.*, 2001; Çebi and Bayraktar, 2003); in healthcare management (Lee and Kwak, 1999; Kwak and Lee, 2002); in environmental management (Kurttila *et al.*, 2000; Handfield *et al.*, 2002; Masozera *et al.*, 2006); in marketing discipline (Kwak *et al.*, 2005); in knowledge management (Ngai and Chan, 2005; Xiao-qing and Fang-fang, 2010; Grimaldi and Rippa, 2011). AHP has also been used in various contexts, for example, to select between alternatives (decision making) or ranking prioritizing (Badurdeen *et al.*, 2011). Over the years, AHP has become one of the most widely used tools for decision support for researchers and decision makers (Subramanian and Ramanathan, 2012).

Healthcare and medical decision making has also been an application area for the AHP. Liberatore and Nydick (2008) reported over 50 papers that utilized AHP for the healthcare ranging from diagnosis, patient participation for medical decision making, for the evaluation and selection of medical treatments, organ transplant eligibility and allocation decisions and project evaluation and selection. This study is a first for implementing an AHP framework to utilize the experience the healthcare staff for identification, prioritization and selection of lean opportunities as an initial phase of a lean transformation process.

4. AHP model and analysis

As shown in Figure 2, the first step is to identify the problem. The purpose of the research is to identify, prioritize and select waste minimization opportunity based on the experience and judgment of the staff and management of three Abu Dhabi hospitals. Therefore, this research is designed by composing multi criteria attributes of lean management principles. Figure 3 depicts the hierarchy of the AHP model for

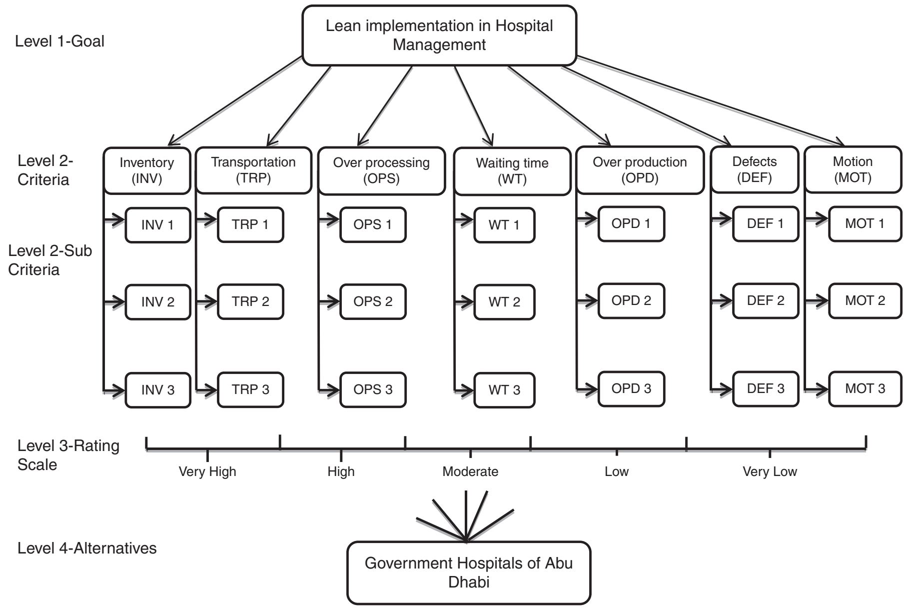


Figure 3.
AHP model for prioritization of lean opportunities

evaluating the lean practices in a healthcare setting. The multi criteria attributes are organized in a hierarchical with the highest level of the hierarchy being the overall goal, i.e. to identify and prioritize the lean improvement opportunities in the public hospitals. The seven wastes of lean healthcare are represented as the criteria in level 2. Each healthcare waste is further divided in level 2 into three types (sub-criteria) to illustrate common manifestations of the respective waste (criteria).

As discussed in Section 1, one of the contributions of this study is its emphasis on the inclusion of all seven types of wastes; inventory, transportation, over processing, waiting time, over production, defects and motion. The fundamental principle of lean management is the systematic elimination of "waste" and therefore, it is felt that the sequencing order for future process improvements must be based in terms of the inherent waste in a system. The seven criteria and associated sub-criteria have been adapted from NHSIII (2007) to suit the UAE public healthcare system in light of the discussions held with the industry experts (Table III). The three waiting wastes included in this study are the patients wait for admission and paperwork, for elective surgeries and delay to discharge patients. Similarly, the inventory waste in the UAE public hospitals is more likely to be reflected by the excessive stocks and patients waiting for tests/appointments. Furthermore, the "transportation," "over processing," "overproduction," "defects" and "motion" wastes appearing in Table III are more likely to represent the UAE hospitals public healthcare delivery system.

The formulation of the AHP hierarchy was followed by the data collection from the three main public hospitals of Abu Dhabi. As suggested by Saaty (1980), the questionnaire was designed on nine-point scale (see Table IV) based on seven wastes (criteria) of lean management and three common indicators of each waste in a healthcare setting (sub-criteria). The questionnaire was pilot tested using industry experts and academics, and some of the items had to be rephrased to make them more representative of the intended constructs. An evaluation team comprising two quality

Main criteria	Sub-criteria	Examples of healthcare wastes (NHSIII, 2007)
Inventory (INV)	1. Stocked items (INV 1)	Excess stock in storerooms that is not being used
	2. Patients waiting list (INV 2)	There is a long patients waiting list for a medical examination/procedure/diagnostic test
	3. Process of patient receiving urgent items (INV 3)	Patients have to wait for an instrument/item so that medical examination/diagnostic test could be carried out
Transportation (TRP)	4. Physical environment (TRP 1)	Staff walking to the other end of a ward to pick up notes
	5. Centralized store (TRP 2)	Centralized store for supplies such as medicines and instruments
	6. Imaging facilities (TRP 3)	Medical imaging facilities are located at central spot
Over processing (OPS)	7. Duplication of information (OPS 1)	Patients are required to give history at different stages of treatment
	8. Patient's details (OPS 2)	Asking for patients' details several times
	9. Duplication of test (OPS 3)	Laboratory/X-ray tests may be repeated for accurate diagnosis
Waiting time (WT)	10. Access and admission (WT 1)	The patients have to wait for admission and paperwork
	11. Surgical process (WT 2)	Patients have to wait for a long time to undergo a surgery
	12. Discharge process (WT 3)	Delay to discharge patients
Overproduction (OPD)	13. Test process (OPD 1)	Requesting unnecessary tests from pathology
	14. Investigation process (OPD 2)	Keeping investigation slots "just in case"
	15. Staff scheduling (OPD 3)	Number of staff to be appointed is determined by the patient load
Defects (DEF)	16. Clarity of information (DEF 1)	Repeating tests because correct information was not provided
	17.Readmission due to errors (DEF 2)	Readmission because of failed discharge
	18. Equipment errors (DEF 3)	Diagnostic test sample is identified electronically by barcode
Motion (MOT)	19. Unnecessary staff movement (MOT 1)	Unnecessary staff movement looking for paperwork
	20. Visual signs (MOT 2)	Visual signs are used to guide patients
	21. Shortage of basic equipment in examination room (MOT 3)	Not having basic equipment in every examination room

Table III. Criteria and sub-criteria of lean management framework in healthcare system

Intensity of importance	Definition	Explanation
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance	Judgment slightly favor one over another
5	Strong importance	Judgment strongly favor one over another
7	Very strong importance	A criterion is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	Importance of one over another affirmed on the highest possible order
2, 4, 6, 8	Intermediate values	Used to represent compromise between the priorities listed above

Table IV. 1-9 scale for AHP preferences managers and three frontline operations staff was selected in each hospital. It was made sure that the selected evaluators had sufficient experience and knowledge of lean management practices. This combined with the key designations of the evaluators in their respective hospitals has given us confidence about the validity of the proposed research framework.

The target respondents comprised the quality and the operations manager of three public hospitals of Abu Dhabi. According to Cheng and Li (2001), small sample size is acceptable from the AHP methodology perspective. The AHP solves the survey fatigue problem by only asking participants to compare the importance of two needs at a time. These comparisons are called judgments. A judgment of only two items is much easier for the participants to complete than comparing a list of 20 items. The judgments we apply in making paired comparisons combine logical thinking with the feeling developed from the experience. Pair-wise comparisons generate more information and therefore, improve judgment consistency (Saaty, 2012). Thereafter, the sample size of 20 experts/respondents is considered to be satisfactory for this research (Saaty, 2012; Drake *et al.*, 2013). In line with Saaty's (2012) suggestion, the geometric mean approach was preferred over the arithmetic mean to combine the individual pair-wise comparison judgments to obtain the consensus pair-wise comparison judgment matrices for the entire team.

As shown in Figure 3, the next step in the AHP is to determine pair-wise comparison among the criteria applied. For defining pair-wise comparison, Saaty (2012) has suggested a nine point scale as shown in Table IV. For example, if an evaluator identifies that motion (MOT) is moderately more important than defects (DEF), then the former is rated "3" and the latter as "1/3" in this comparison and so on. To check the consistency, the consistency index (CI) is applied. Saaty (1980) defined consistency as follows:

$$\mathrm{CI} = (\lambda_{\max} - n)/(n-1) \tag{1}$$

where $\lambda_{\max}$ is the maximum eigenvalue of the matrix of the importance ratios and n is the number of factors. Then, the consistency ratio (CR) is used to assess whether a matrix is sufficiently consistent or not. This is the ratio of the CI to the random index (RI), which is the CI of a matrix of comparisons generated randomly:

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \tag{2}$$

Random pair-wise comparisons have been simulated to produce average random indices for different sized matrices. The values of RI are given in Table V (Saaty, 1980). According to Saaty (1980), if the value of CR is smaller or equal to 0.10, the inconsistency is acceptable.

Table VI presents the geometric means of pair-wise comparison for seven main criteria. The next step is to define the relative priorities of criteria (the final column of Table VI) by computing "priority vectors." Saaty (1990) introduced a "consistency principle" for calculating priority vectors. Consistency principle says that $a_{ik} = a_{ij} \cdot a_{jk}$

Table V.
Random index

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.48

Note: *n*, number of factors

Table VI. Geometric means of pair-wise comparison of main criteria

	Inventory	Transportations	Over processing	Waiting time	Over production	Defects	Motion	Priority vector
Inventory	1	3	2	2	3	3	2	0.26
Transportation	1/3	1	3	2	2	5	3	0.22
Over processing	1/2	1/3	1	3	2	3	4	0.17
Waiting time	1/2	1/2	1/3	1	3	2	4	0.14
Over production	1/3	1/2	1/2	1/3	1	3	2	0.09
Defects	1/3	1/5	1/3	1/2	1/3	1	2	0.06
Motion	1/2	1/3	1/4	1/4	1/2	1/2	1	0.05

Note: CR = 0.01 < 0.10 (acceptable)

and subsequent argument for using the special case of the consistency matrix formed by elements $a_{ik} = w_i/w_j$, where w_i and w_j are the elements of the priority weight vector corresponding to criteria i and j.

Table VI reveals that the inventory (INV) wastes is considered as most important by the respondents with a priority weight of 26 percent followed by the transportation (TRP) waste which had a competitive priority of 22 percent. over processing (OPS), waiting (WT) and overproduction (OPD) wastes were ranked third, fourth and fifth, respectively with defects (DEF) and (MOT) being considered as the two least important wastes by the consensus feedback of the three teams of the evaluators. It is pertinent to note here that the consensus responses in Table V fulfill the acceptable CR requirement.

To gain a better understanding of the priorities reported in Table VI, a pair-wise comparison of the sub-criteria within each criteria is also carried out based on the consensus responses of the evaluators (Tables VII-XIII). As shown in Table III, each criterion (waste) was further divided in level 2 into three common indicators (sub-criteria) of the respective waste. For inventory (INV) waste, excessive stock items (INV 1), patient's waiting list (INV 2) and the process of patient receiving urgent items (INV 3) were the three sub-criteria. Table VII gives the priority listing of the consensus pair-wise comparison for the three Inventory sub-criteria. The biggest concern is the excessive

Table VII. Pair-wise comparison matrix for the inventory sub-criteria

	INV 1	INV 2	INV 3	Priority weight
INV 1	1	2	4	0.53
INV 2	1/2	1	5	0.37
INV 3	1/4	1/5	1	0.10

Note: CR = 0.09 < 0.10 (acceptable)

Table VIII. Pair-wise comparison matrix for the transportation sub-criteria

	TRP 1	TRP 2	TRP 3	Priority weight
TRP 1	1	4	8	0.69
TRP 2	1/4	1	5	0.24
TRP 3	1/8	1/5	1	0.07

Note: CR = 0.09 < 0.10 (acceptable)

stock of items (53 percent) followed by unwarranted extension of patients stay as the discharge is delayed (37 percent).

Similarly, within the transportation (TRP) waste (Table VIII), the physical environment (TRP 1) that may cause the staff to travel extra distance for carrying out their duties is considered very important with a priority score of 69 percent followed by the issue of centralized keeping of medicines and instruments (TRP 2). Both of these transportation wastes arise because of a poor facility layout design which may have

Table IX. Pair-wise comparison matrix for the over processing sub-criteria

	OPS 1	OPS 2	OPS 3	Priority weight
OPS 1	1	4	7	0.69
OPS 2	1/4	1	4	0.23
OPS 3	1/7	1/4	1	0.08

Note: CR = 0.07 < 0.10 (acceptable)

Table X. Pair-wise comparison matrix for the waiting sub-criteria

	WT 1	WT 2	WT 3	Priority weight
WT 1	1	3	6	0.63
WT 2	1/3	1	5	0.29
WT 3	1/6	1/5	1	0.08

Note: CR = 0.09 < 0.10 (acceptable)

Table XI. Pair-wise comparison matrix for the over production sub-criteria

	OPD 1	OPD 2	OPD 3	Priority weight
OPD 1	1	5	8	0.72
OPD 2	1/5	1	4	0.21
OPD 3	1/8	1/4	1	0.07

Note: CR = 0.08 < 0.10 (acceptable)

Table XII. Pair-wise comparison matrix for the defects sub-criteria

	DEF 1	DEF 2	DEF 3	Priority weight
DEF 1	1	6	7	0.74
DEF 2	1/6	1	3	0.18
DEF 3	1/7	1/3	1	0.08

Note: CR = 0.09 < 0.10 (acceptable)

Table XIII. Pair-wise comparison matrix for the motion sub-criteria

	MOT 1	MOT 2	MOT 3	Priority weight
MOT 1	1	5	6	0.73
MOT 2	1/5	1	3	0.24
MOT 3	1/6	1/3	1	0.03

Note: CR = 0.07 < 0.10 (acceptable)

serious repercussions for the productivity and the throughput of any healthcare system. Possible lean interventions may include a cellular layout design which encourages the physical layout of hospital to match the sequence of its operations. Within the over processing (OPS) waste (Table IX) the evaluators rated the information duplication (OPS 1) and (OPS 2) as the two important improvement opportunities. It appears that the respondents were confident that diagnostics tests were not unnecessarily being repeated (OPS 3) in their hospitals affirming lean conformance on this count.

Table X gives the pair-wise comparison of the three sub-criteria within the waiting (WT) waste. Unlike most publically funded healthcare where there is substantial waiting for elective surgeries (WT 2), the evaluators thought that the excessive paperwork causing patients admission is the biggest improvement opportunity within the waiting (WT) waste. For the over production (OPD) waste (Table XI), the testing procedure (OPD 1) was ranked as the top priority followed by the appointment scheduling (OPD 2). For the two lowest ranked wastes (Tables XII and XIII), the information flow (DEF 1) and unnecessary staff movement (MOT 1) were identified as the principle lean candidates for defect (DEF) and motion (MOT) wastes.

The final step in the AHP is to develop the overall priority of the 21 waste indicators by multiplying the sub-criteria ranking with the criteria priority matrix (Figure 4). The physical environment (TRP 1) is the highest ranked waste minimization opportunity (14.89 percent) despite being part of the transportation (TRP) waste which was listed as the second most important criteria. The excessive stock (INV 1) is a close second with an overall priority of 13.86 percent followed by the duplication of information (OPS 2) sub-criteria at 12.10 percent. Patients' waiting list (INV 2) at an overall priority of 9.53 percent, access and admission (WT 1) at 8.76 percent, unnecessary tests (OPD 1) at 6.70 percent and the centralized store (TRP 2) at 5.26 percent are the next four lean priorities according to the surveyed healthcare professionals. The cumulative percent curve in Figure 4 reinforces the value of the Pareto principle because nearly 70 percent of the priority is attributed to the top seven ranked waste indicators (sub-criteria) and a focus on these seven lean opportunities is likely to contribute the most to the lean transition.

5. Conclusion and directions for future research

The UAE healthcare sector has seen exceptional growth with healthcare expenditure per capita being ranked among the top 20 in the world (Deloitte, 2011). With an aim of

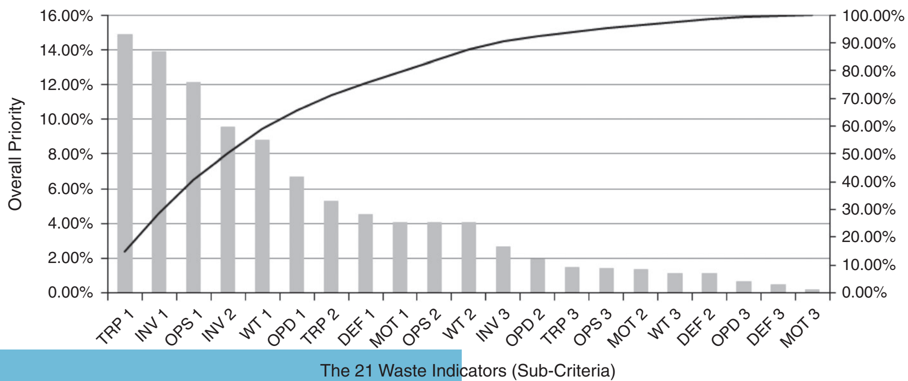


Figure 4. The overall priority of the 21 waste indicators (sub-criteria)

establishing itself as a preferred destination for domestic patients and a hub for global medical tourists seeking high-quality and cost-effective procedures and treatments, the UAE healthcare sector has attracted major international healthcare players but the healthcare providers still face significant challenges for operational excellence restricting their competitiveness. Lean methodology is likely to improve both quality and productivity of the UAE healthcare delivery system but there is a pressing need to investigate the lean deployment strategies both from the academic and the managerial perspectives. This study attempts to fulfill this research gap by proposing a lean deployment framework for the identification, prioritization and selection of improvement opportunities for quality and productivity gains. The continued success of the lean thinking over the last two decades makes it as one of the main building blocks of any operational excellence initiative.

The aim of this research is to identify and prioritize the lean improvement opportunities in the public hospitals. The seven wastes of lean healthcare have been identified (criteria) and each healthcare waste is further divided into three types (sub-criteria) to illustrate common manifestations of the respective wastes (criteria). This was achieved by using AHP which strength lies in a structured transformation of the qualitative judgment of senior healthcare personnel into quantitative data that ranks the waste minimization opportunities for the Abu Dhabi public hospitals. The formulation of the AHP hierarchy was followed by the data collection from the three main public hospitals of Abu Dhabi.

AHP framework for this study resulted in a ranking of 21 healthcare wastes based on the evaluations of local situations by experienced healthcare professionals. It has been found that management in healthcare systems of Abu Dhabi is putting more emphasis on the inventory waste. Within the healthcare inventory waste, a major component is the excessive supplies or inventory carrying contributing significantly to healthcare costs. Mostly the inventories are held as a buffer between organizational elements to balance operations. The healthcare materials management generally ensures a greater availability of needed supplies because of the high stakes involved. Possible lean interventions could be the just in time deliveries with smaller and more frequent shipments. The patients waiting for medical services were understandably deemed as the second most important inventory waste because there could be several weeks before a patient is given the a medical appointment in the UAE. Various operations research tools could be employed as part of the lean process improvement.

Pair-wise comparison of seven waste criteria showed that transportation waste has got the second highest priority weight. The centralized stores for supplies of medicines/instruments and the central location of the medical imaging facilities cause unnecessary staff movements. This implies that top managers must make greater efforts to ensure that facility layouts have been designed to minimize unnecessary staff and patients' movement and basic equipment are provided at the departmental level. The cellular facility design is generally regarded as a layout which minimize the transportation wastes.

Interestingly, it has been found that the least importance in terms of future lean projects is given to prevention and reduction of defects and the motion wastes. This shows that the hospitals under study are reasonably confident of their quality practices and they do not see it as a concern. This is in contrast to some other parts of the world such as the findings of Australian Commission on Safety and Quality in Health Care which found that medication errors (defects) remain the second most common type of medical incidents reported in hospitals with tests repetition (overproduction waste), omission (defect waste) or overdose of medicines (defect waste) also occurring frequently (ACSQHC, 2012). Similarly, Ammenwerth *et al.* (2008) also observed that the medication errors (defect) was the most common waste in the American healthcare and suggested that the electronic prescribing may reduce the medication errors. Since, UAE public healthcare has embraced complete automation for prescriptions which may explain the lack of concern for the medication errors in our results.

This study is part of a larger project to facilitate the lean practices in the UAE public hospitals and the future directions of our research would be to apply a lean set of tools for the value stream optimization of the identified key improvement areas. An interesting future research area would be to compare the observed improvements with the consensus ranking obtained by the AHP framework in this paper.

References

Abdi, F., Shavarini, S.K., Hoseini, S. and Mohammad, S. (2006), "Glean lean: how to use lean approach in service industries?", *Journal of Services Research*, Vol. 6, pp. 191-202.

ACSQHC (2012), *Electronic Medication Management Systems – A Guide to Safe Implementation*, Australian Commission on Safety and Quality in Health Care, 2nd ed., ACSQHC, Sydney.

Aherne, J. and Whelton, J. (2010), *Applying Lean in Healthcare: A Collection of International Case Studies*, CRC Press, New York, NY.

Ahlstrom, P. (2004), "Lean service operations: translating lean production principles to service operations", *International Journal of Services Technology and Management*, Vol. 5 Nos 5-6, pp. 545-564.

Al-Balushi, S., Sohal, A., Singh, P.J., Alhajiri, A., Al-farsi, Y.M. and AlAbri, R. (2014), "Readiness factors for lean implementation in healthcare settings – a literature review", *Journal of Health Organization and Management*, Vol. 28 No. 2, pp. 135-153.

Ammenwerth, E., Schnell-Inderst, P., Machan, C. and Siebert, U. (2008), "The effect of electronic prescribing on medication errors and adverse drug events: a systematic review", *Journal of the American Medical Informatics Association*, Vol. 15 No. 5, pp. 585-600.

ASQ (2009), "Lean six sigma hospital study advisory committee", *Quality Progress*, Vol. 42 No. 8, pp. 44-50.

Atkinson, P. (2004), "Creating and implementing lean strategies", *Management Services*, Vol. 48 No. 2, pp. 18-29.

Badurdeen, F., Wijekoon, K. and Marksberry, P. (2011), "An analytical hierarchy process-based tool to evaluate value systems for lean transformations", *Journal of Manufacturing Technology Management*, Vol. 22 No. 1, pp. 46-65.

Barton, H. and Barton, L.C. (2011), "Challenges, issues and change: what's the future for UK policing in the twenty-first century?", *International Journal of Public Sector Management*, Vol. 24 No. 2, pp. 146-156.

Baudin, M. (2004), *Lean Logistics: The Nuts and Bolts of Delivering Materials and Goods*, Productivity Press, New York, NY.

Bicheno, J. and Holweg, M. (2008), *The Lean Toolbox: The Essential Guide to Lean Transformation*, Picsie Books, Buckingham.

Bonaccorsi, A., Carmignani, G. and Zammori, F. (2011), "Service value stream management (SVSM): developing lean thinking in the service industry", *Journal of Service Science and Management*, Vol. 4 No. 4, pp. 428-439.

Braglia, M., Gabbrielli, R. and Miconi, D. (2001), "Material handling device selection in cellular manufacturing", *Journal of Multi-Criteria Decision Analysis*, Vol. 10 No. 6, pp. 303-315.

Çebi, F. and Bayraktar, D. (2003), "An integrated approach for supplier selection", *Logistics Information Management*, Vol. 16 No. 6, pp. 395-400.

Cheng, E.W. and Li, H. (2001), "Analytic hierarchy process: an approach to determine measures for business performance", *Measuring Business Excellence*, Vol. 5 No. 3, pp. 30-37.

Christian, N.M. and Chu-Hua, K. (2014), "Disaster relief supply chain quality management (DRSCQM)", *International Journal of Quality & Reliability Management*, Vol. 31 No. 9, pp. 1052-1067.

Damrath, F. (2012), "Increasing competitiveness of service companies: developing conceptual models for implementing lean management in service companies", master thesis, KTH, School of Industrial Engineering and Management.

De Koning, H., Does, R.J. and Bisgaard, S. (2008), "Lean Six Sigma in financial services", *International Journal of Six Sigma and Competitive Advantage*, Vol. 4 No. 1, pp. 1-17.

De Souza, L.B. and Pidd, M. (2011), "Exploring the barriers to lean health care implementation", *Public Money & Management*, Vol. 31 No. 1, pp. 59-66.

Deloitte (2011), "Survey of the UAE healthcare sector opportunities and challenges for private providers", available at: www.deloitte.com/assets/Dcom-Lebanon/Local%20Assets/Documents/Consulting/Consulting%20Healthcare%20publication%20FV2.pdf (accessed July 21, 2014).

Dharmapriya, U. and Kulatunga, A. (2011), "New strategy for warehouse optimization – lean warehousing", *Proceedings of the 2011 International Conference on Industrial Engineering and Operations Management, Kuala Lumpur*.

Dickson, E.W., Singh, S., Cheung, D.S. *et al.* (2009), "Application of lean manufacturing techniques in the emergency department", *The Journal of Emergency Medicine*, Vol. 37 No. 2, pp. 177-182.

Drake, P.R., Myung Lee, D. and Hussain, M. (2013), "The lean and agile purchasing portfolio model", *Supply Chain Management: An International Journal*, Vol. 18 No. 1, pp. 3-20.

Fillingham, D. (2007), "Can lean save lives?", *Leadership in Health Services*, Vol. 20 No. 4, pp. 231-241.

Furman, C. and Caplan, R. (2007), "Applying the Toyota Production System: using a patient safety alert system to reduce error", *Joint Commission Journal on Quality and Patient Safety*, Vol. 33, pp. 376-386.

Ghodsypour, S.H. and O'brien, C. (1998), "A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming", *International Journal of Production Economics*, Vol. 56 No. 2, pp. 199-212.

Grimaldi, M. and Rippa, P. (2011), "An AHP-based framework for selecting knowledge management tools to sustain innovation process", *Knowledge and Process Management*, Vol. 18 No. 1, pp. 45-55.

Handfield, R., Walton, S.V. and Sroufe, R,e. (2002), "Applying environmental criteria to supplier assessment: a study in the application of the analytical hierarchy process", *European Journal of Operational Research*, Vol. 141 No. 1, pp. 70-87.

Hussain, M., Shoame, A. and Lee, D.M. (2012), "Impact of forecasting methods on variance ratio in order-up-to level policy", *International Journal of Advance Manufacturing Technology Management*, Vol. 59 Nos 1-4, pp. 413-220.

Hussain, M., Ajmal, M., Khan, M. and Saber, H. (2015), "Competitive priorities and knowledge management: an empirical investigation of manufacturing companies in UAE", *Journal of Manufacturing Technology Management*, Vol. 26 No. 6, pp. 791-806.

Hines, P., Rich, N. and Esain, A. (1999), "Value stream mapping: a distribution industry application", *Benchmarking: An International Journal*, Vol. 6 No. 1, pp. 60-77.

Ishizaka, A., Pearman, C. and Nemery, P. (2012), "AHPSort: an AHP-based method for sorting problems", *International Journal of Production Research*, Vol. 50, pp. 4767-4784.

Jimmerson, C., Weber, D. and Sobek, D.K. (2005), "Reducing waste and errors: piloting lean principles at Intermountain Healthcare", *Joint Commission Journal on Quality and Patient Safety*, Vol. 31 No. 5, pp. 249-257.

Jones, D.T., Hines, P. and Rich, N. (1997), "Lean logistics", *International Journal of Physical Distribution & Logistics Management*, Vol. 27 Nos 3-4, pp. 153-173.

Kenney, C. (2010), *Transforming Health Care: Virginia Mason Medical Center's Pursuit of the Perfect Patient Experience*, CRC Press, New York, NY.

Kim, C.S., Spahlinger, D.A., Kin, J.M. and Billi, J.E. (2006), "Lean health care: what can hospitals learn from a world-class automaker?", *Journal of Hospital Medicine*, Vol. 1 No. 3, pp. 191-199.

Korpela, J., Lehmusvaara, A. and Tuominen, M. (2001), "Customer service based design of the supply chain", *International Journal of Production Economics*, Vol. 69 No. 2, pp. 193-204.

Kruger, D.J. (2014), "Lean implementation in the Gauteng public health sector", *Portland International Conference on Management of Engineering & Technology (PICMET), 2014 IEEE, Kanazawa*, pp. 2699-2708.

Kurttila, M., Pesonen, M., Kangas, J. and Kajanus, M. (2000), "Utilizing the analytic hierarchy process (AHP) in SWOT analysis – a hybrid method and its application to a forest-certification case", *Forest Policy and Economics*, Vol. 1 No. 1, pp. 41-52.

Kwak, N. and Lee, C.W. (2002), "Business process reengineering for health-care system using multicriteria mathematical programming", *European Journal of Operational Research*, Vol. 140 No. 2, pp. 447-458.

Kwak, N., Lee, C.W. and Kim, J.H. (2005), "An MCDM model for media selection in the dual consumer/industrial market", *European Journal of Operational Research*, Vol. 166 No. 1, pp. 255-265.

Lee, C. and Kwak, N. (1999), "Information resource planning for a health-care system using an AHP-based goal programming method", *Journal of the Operational Research Society*, Vol. 50 No. 12, pp. 1191-1198.

Lee, C.E. and Hsu, S.C. (2004), "Outsourcing capacity planning for an an IC design house", *The International Journal of Advanced Manufacturing Technology*, Vol. 24 Nos 3-4, pp. 306-320.

Lee, D.M. and Drake, P.R. (2010), "A portfolio model for component purchasing strategy and the case study of two South Korean elevator manufacturers", *International Journal of Production Research*, Vol. 48 No. 22, pp. 6651-6682.

Leseure, M., Hudson-Smith, M. and Radnor, Z. (2010b), "Transferring lean into government", *Journal of Manufacturing Technology Management*, Vol. 21 No. 3, pp. 411-428.

Leseure, M., Hudson-Smith, M. and Delgado, C. (2010a), "The implementation of lean Six Sigma in financial services organizations", *Journal of Manufacturing Technology Management*, Vol. 21 No. 4, pp. 512-523.

Leyer, M. and Moormann, J. (2014), "How lean are financial service companies really? Empirical evidence from a large scale study in Germany", *International Journal of Operations & Production Management*, Vol. 34 No. 11, pp. 1366-1388.

Liberatore, M.J. and Nydick, R.L. (2008), "The analytic hierarchy process in medical and health care decision making: a literature review", *European Journal of Operational Research*, Vol. 189 No. 1, pp. 194-207.

Luciano Brandao de, S. (2009), "Trends and approaches in lean healthcare", *Leadership in Health Services*, Vol. 22 No. 2, pp. 121-139.

Masozera, M.K., Alavalapati, J.R., Jacobson, S.K. and Shreshta, R.K. (2006), "Assessing the suitability of community-based management for the Nyungwe Forest Reserve, Rwanda", *Forest Policy and Economics*, Vol. 8 No. 2, pp. 206-216.

Mayberry, R.M., Nicewander, D.A., Qin, H. and Ballard, D.G. (2006), "Improving quality and reducing inequities: a challenge in achieving best care", *Proceedings (Baylor University, Medical Center)*, Vol. 19 No. 2, p. 103.

Mazzocato, P., Holden, R.J., Brommels, M., Aronsson, H., Backman, U., Elg, M. and Thor, J. (2012), "How does lean work in emergency care? A case study of a lean-inspired intervention at the Astrid Lindgren 'Children's hospital, Stockholm, Sweden", *BMC Health Services Research*, Vol. 12 No. 1, pp. 28-39.

Mazzocato, P., Thor, J., Bäckman, U., Brommels, M., Carlsson, J., Jonsoon, F., Hagmar, M. and Savage, C. (2014), "Complexity complicates lean: lessons from seven emergency services", *Journal of Health Organization and Management*, Vol. 28 No. 2, pp. 266-288.

Mi Dahlgaard-Park, S., Suarez Barraza, M.F. and Smith, T. (2009), "Lean-kaizen public service: an empirical approach in Spanish local governments", *The TQM Journal*, Vol. 21 No. 2, pp. 143-167.

Ngai, E.W. and Chan, E. (2005), "Evaluation of knowledge management tools using AHP", *Expert Systems with Applications*, Vol. 29 No. 2, pp. 889-899.

NHSIII (2007), *Going Lean in the NHS*, NHS Instuitie for Innovation and Improvement, Warwick, available at: www.northamptongeneral.nhs.uk/Downloads/OurServices/ServiceImprovement/Toolsforimprovement/GoingleanintheNHS.pdf (accessed July 14, 2014).

Nightingale, D.J. and Mize, J.H. (2002), "Development of a lean enterprise transformation maturity model", *Information, Knowledge, Systems Management*, Vol. 3 No. 1, pp. 15-30.

Ohno, T. (1988), *The Toyota Production System: Beyond Large-Scale Production*, Productivity Press, Portland, OR.

Piercy, N. and Rich, N. (2009), "Lean transformation in the pure service environment: the case of the call service centre", *International Journal of Operations & Production Management*, Vol. 29 No. 1, pp. 54-76.

Poksinska, B. (2010), "The current state of lean implementation in health care: literature review", *Quality Management in Healthcare*, Vol. 19 No. 4, pp. 319-329.

Powell, A., Rushmer, R. and Davies, H. (2009), *A Systematic Narrative Review of Quality Improvement Models in Health Care*, NHS Quality Improvement, Edinburgh.

Psychogios, A.G. and Tsironis, L.K. (2012), "Towards an integrated framework for Lean Six Sigma application: lessons from the airline industry", *Total Quality Management & Business Excellence*, Vol. 23 Nos 3-4, pp. 397-415.

Psychogios, A.G., Atanasovski, J. and Tsironis, L.K. (2012), "Lean Six Sigma in a service context", *International Journal of Quality & Reliability Management*, Vol. 29 No. 1, pp. 122-139.

Radnor, Z. and Johnston, R. (2013), "Lean in UK government: internal efficiency or customer service?", *Production Planning & Control*, Vol. 24 Nos 10-11, pp. 903-915.

Radnor, Z. and Walley, P. (2008), "Learning to walk before we try to run: adapting lean for the public sector", *Public Money and Management*, Vol. 28 No. 1, pp. 13-20.

Radnor, Z.J., Holweg, M. and Waring, J. (2012), "Lean in healthcare: the unfilled promise?", *Social Science & Medicine*, Vol. 74 No. 3, pp. 364-371.

Reichhart, A. and Holweg, M. (2007), "Lean distribution: concepts, contributions, conflicts", *International Journal of Production Research*, Vol. 45 No. 16, pp. 3699-3722.

Roberts, S. and Singh, S. (2009), "Implementing lean in primary care", *British Journal of Healthcare Management*, Vol. 15 No. 8, pp. 380-386.

Robinson, S., Radnor, Z.J., Burgess, N. and Worthington, C. (2012), "SimLean: utilising simulation in the implementation of lean in healthcare", *European Journal of Operational Research*, Vol. 219 No. 1, pp. 188-197.

Saaty, T.L. (1980), *The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation*, McGraw-Hill, New York, NY.

Saaty, T.L. (1990), "How to make a decision: the analytic hierarchy process", *European Journal of Operational Research*, Vol. 48 No. 1, pp. 9-26.

Saaty, T.L. (2008), "Decision making with the analytic hierarchy process", *International Journal of Services Sciences*, Vol. 1 No. 1, pp. 83-98.

Saaty, T.L. (2012), *Decision Making For Leaders: The Analytical Hierarchy Process for Decision in Complex World*, RWS Publication, Pittsburgh, PA.

Spear, S.J. (2005), "Fixing health care from the inside, today", *Harvard Business Review*, Vol. 83 No. 9, pp. 78-89.

Staats, B.R., Brunner, D.J. and Upton, D.M. (2011), "Lean principles, learning, and knowledge work: evidence from a software services provider", *Journal of Operations Management*, Vol. 29 No. 5, pp. 376-390.

Subramanian, N. and Ramanathan, R. (2012), "A review of applications of analytic hierarchy process in operations management", *International Journal of Production Economics*, Vol. 138 No. 2, pp. 215-241.

Thompson, D.N., Wolf, G.A. and Spear, S.J. (2003), "Driving improvement in patient care: lessons from Toyota", *Journal of Nursing Administration*, Vol. 33 No. 11, pp. 585-595.

Vinodh, S. and Joy, D. (2012), "Structural equation modelling of lean manufacturing practices", *International Journal of Production Research*, Vol. 50 No. 6, pp. 1598-1607.

Wang, F.-K. and Chen, K.-S. (2010), "Applying Lean Six Sigma and TRIZ methodology in banking services", *Total Quality Management*, Vol. 21 No. 3, pp. 301-315.

Weintraub, P. (2011), "Successfully deploying lean in healthcare", available at: www.healthcare.philips.com/pwc_hc/main/shared/assets/documents/about/news/articles/deploying_lean.pdf (accessed June 28, 2014).

Womack, J.P., Jones, D.T. and Roos, D. (2007), *The Machine that Changed the World(the Story of Lean Production – Toyota's Secret Weapon in the Global Car Wars that is Revolutionizing World Industry)*, Free Press, New York, NY.

Xiao-qing, B. and Fang-fang, Z. (2010), "The performance evaluation of enterprise knowledge management based on AHP", *IEEE International Conference on Advanced Management Science (ICAMS), IEEE, Chengdu*, pp. 543-547.

Young, T., Brailsford, S., Connell, C., Davies, R., Harper, P. and Klein, J.H. (2004), "Using industrial processes to improve patient care", *British Medical Journal*, Vol. 328 No. 7432, pp. 162-164.

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