ORIGINAL ARTICLE

Lean Public Emergency Department Efficiency Evaluation by Slack-based Measure Data Envelopment Analysis

Tiong Ngee-Wen[1], Suhaiza Zailani[1], Azmin Azliza Aziz[1], Rashidi Ahmad[2]

[1] Department of Operations and Management Information Systems, Faculty of Business and Accountancy, University of Malaya, 50603 Kuala Lumpur, Malaysia
[2] Department of Emergency Medicine, Faculty of Medicine, University of Malaya, 50603 Kuala Lumpur, Malaysia

ABSTRACT

Introduction: Lean healthcare outcome is usually measured with multiple key performance metrics but there is a lack of tools that enabled efficiency assessment. This research aimed to assess the efficiency among lean public emergency departments (ED) through Slack-Based Measure Data Envelopment Analysis (SBM-DEA) and evaluate the impact of lean on the efficiency in public emergency departments. **Methods:** A retrospective observational study design using data on the number of support staff, number of doctors, number of discharge, arrival to consultant and length of stay. Efficiency scores of 20 Malaysian public EDs were computed using SBM-DEA modelling and compared between before and after lean implementation. **Results:** A total of 13 out of 20 public EDs exhibited improvement in arrival to consultant and length of stay upon lean implementation. However, only 9 out of the 13 public EDs have had an improvement in efficiency score. **Conclusion:** Lean healthcare demonstrated a positive impact on the efficiency level of some public EDs. The SBM-DEA model offers the benchmarking capability and slack elimination information that may complement the lean continuous improvement philosophy.

Keywords: Administrative efficiency, Benchmarking, Lean healthcare, Performance evaluation, Public emergency department

Corresponding Author:
Suhaiza Zailani, PhD
Email: shmz@um.edu.my
Tel: +6012-4270063

INTRODUCTION

In 2014, the Malaysian public emergency department (ED) was faced with a critical problem of long waiting time and congestion (1). The Malaysian Ministry of Health has adopted lean management technique to decipher and resolve the issue (2). Lean healthcare, a quality management approach was implemented to improve the waiting time and operational processes in the selected pioneer hospitals. The implementation was facilitated through the assistance of the Performance Management and Delivery Unit, which is a third-party organization linked to the governmental department. To date, multiple lean projects have been implemented in 36 public hospitals that might potentially benefit from the lean healthcare initiative (3).

Studies have shown that although lean healthcare project main aim is to improve efficiency, but the use of resources during the implementation process is inevitable (4,5). An inadequate understanding of the efficiency in lean implementation may potentially led to more wastages instead of improving the existing operational processes (6). Existing lean healthcare literature focused more on the process of improvement activities but lacks an assessment of efficiency (7). The gap in the literature highlighted the needs to uncover more information on lean healthcare performance from the perspective of efficiency. In specific, this research is interested to uncover what is the impact of lean healthcare on the efficiency level of public EDs? Therefore, this research aimed to assess the efficiency level among the selected public EDs in Malaysia that had implemented lean healthcare initiative.

MATERIALS AND METHODS

Study sample

This study used retrospective observational data from Malaysian public EDs that had implemented lean healthcare initiative between the year 2014 to 2016. The applied parameters for this study were extracted from the data envelopment analysis (DEA) literature in the healthcare settings (Table I). Two inputs (x1 and x2) and one output (y1) were selected based on the most commonly used variables for DEA healthcare research (8). Additional two outputs (y2 and y3) were included based on the lean key performance indicator used to monitor the outcome of lean healthcare implementation

(2).

Relevant ethical clearance was sought from the Medical Research Ethical Committee under the Malaysian National Institute of Health, followed by subsequent approval from the Clinical Research Committee at the selected hospitals before the commencement of data collection process. The actual hospital name was substituted to protect the privacy for each of the individual hospitals. Similar to Vermeulen et al. (9), the inclusion criteria were public hospitals and EDs that had adopted lean healthcare initiative. The number of sample size followed Gollany et al. (10) recommendation, using at least a twice the number of parameters used in the DEA modelling.

Table I: SBM-DEA Parameters Definition and References

Parameter	Type	Definition
Full-time equivalent staff ()*	Input	The total number of support staff, including nurses and medical assistants.
Full-time equivalent medical ()*	Input	The total number of doctors, including medical officers, specialists, and consultants.
Number of discharge ()*	Output	The total number of discharge in the ED for a given year.
Arrival to consultant ()^	Output	The total number of patients with arrival to consultant less than 90 minutes.
Length of stay ()^	Output	The total number of patients with length of stays less than 120 minutes.

Note:
* Kohl et al., 2018
^ Performance Management & Delivery Unit, 2014

SBM-DEA modelling

Data envelopment analysis (DEA) is a non-parametric linear optimisation method used to assess the efficiency among a group of a homogeneous unit (11). The ability to incorporate multiple inputs and outputs has made DEA one of the preferred choices of method in the assessment of relative efficiency, including the healthcare sector (8). The DEA computation produces an index number representing the efficiency level achieved by the unit under evaluation compared to its peers (11).

This research adopted SBM-DEA modelling, which was developed by Tone (12). The model selection was justified based on two reasons: (1) the flexibility of the model to incorporate multiple inputs and outputs in assessing lean efficiency level, and (2) the ability of the model to directly deal with the slack level within the DEA model. In other words, every reference set identified by SBM-DEA model is 100% efficient and all inefficiency on the horizontal and vertical axis will be accounted for (13).

The SBM-DEA model adopted a non-oriented approach. The selection of non-oriented approach is justified with the following reasoning. First, it is almost impossible to track and estimate actual demand from patients since healthcare needs are contributed by multiple external factors that are beyond the control of healthcare provider and management (14). The demand may fluctuate and varies according to the season, accident, natural disaster, epidemic outbreak, and so on (15). Second, the non-orientation reflects the dynamic environment of public hospitals, whereby hospital resources allocation may vary according to the availability of inputs (resources) from the policymakers. Public hospitals have an obligation to fulfill the healthcare needs and social well being of society, which makes them different from privately owned hospitals that are profit oriented (16). On top of that, the selection of non-orientation is also in line with previous literature conducted for evaluation of public healthcare organization, which focus on minimization both inputs and outputs variables (16,17). The use of SBM-DEA modelling in lean management assessment has been validated in the existing literature (16,13).

Data Analysis

Data used were baseline data before the lean implementation of each hospital and 1-year post lean implementation. Since lean was implemented in two batches, data used was from the year 2014 until 2016 (lean cohort 1 was conducted in 2014, while lean cohort 2 was initiated a year later). The SBM-DEA efficiency score was computed using the R programme, an open software platform for statistical computing and graphics developed by the R Foundation for Statistical Computing. The efficiency score obtained was used for comparison between before and after lean implementation.

RESULTS

A total of 20 out of 36 EDs that had implemented lean responded favourably to participate in this research (representing 55.6% response rate) and met the minimum sample size requirement (10). The profile of the samples used was provided in Table 2. From here onwards, each individual ED was referred to as the Decision Making Unit (DMU), similar to existing research (15). There were 9 state hospitals and 11 specialist hospitals included in the analysis. The population served by all the hospitals involved ranging from 100,000 to more than 1.5 million people (based on the data from the Malaysian Department of Statistics, 2010). The lean healthcare implementation was carried out in two phases and therefore, there were two cohorts of lean healthcare identified. The first cohort of lean healthcare project was initiated in the year 2014, while the second cohort started in the year 2015.

The descriptive data gathered for the 20 public EDs were shown in Table 3. Overall, the average percentage of change in data after lean implementation showed input parameters x1 and x2 had an increment by 4.62% and 10.13% respectively. On the other hand, output parameter y1 showed an increase of 0.87%, demonstrating a slight increase in healthcare demand.

Meanwhile, parameter y2 and y3 demonstrated an average percentage increment to 26.80% and 14.75%, respectively.

On the individual level, there was a mixed impact of lean healthcare to each of the DMUs. Some DMUs experienced an improvement, while others had a regressed lean metric performance. For instance, DMU A demonstrated an increment of outputs y1, y2 and y3. Meanwhile, DMU L showed a decreased of output y1, y2 and y3. Another DMU C showed an increment of y1 and y2 while y3 had a reduction.

Table II: Profile of Hospitals Included in SBM-DEA Analysis

Hospital	Status	Population Served*	Lean Cohort
DMU A	State hospital	> 1.5 million	First cohort
DMU B	State hospital	> 1 million	First cohort
DMU C	State hospital	> 1 million	First cohort
DMU D	State hospital	> 800 thousands	First cohort
DMU E	State hospital	> 600 thousands	First cohort
DMU F	State hospital	> 500 thousands	First cohort
DMU G	Specialist hospital	> 500 thousands	Second cohort
DMU H	Specialist hospital	> 400 thousands	First cohort
DMU I	Specialist hospital	> 400 thousands	First cohort
DMU J	State hospital	> 400 thousands	First cohort
DMU K	Specialist hospital	> 400 thousands	Second cohort
DMU L	State hospital	> 300 thousands	First cohort
DMU M	Specialist hospital	> 300 thousands	Second cohort
DMU N	Specialist hospital	> 300 thousands	Second cohort
DMU O	Specialist hospital	> 200 thousands	First cohort
DMU P	Specialist hospital	> 200 thousands	Second cohort
DMU Q	Specialist hospital	> 200 thousands	Second cohort
DMU R	Specialist hospital	> 200 thousands	Second cohort
DMU S	Specialist hospital	> 200 thousands	Second cohort
DMU T	State hospital	> 100 thousands	Second cohort

Note:
* Malaysian Department of Statistics, 2010.

Next, the results from the SBM-DEA modelling were presented in Table 4. The SBM-DEA efficiency score obtained showed an average efficiency of 0.6826 for lean public ED in Malaysia. Twelve EDs exhibited improvement in efficiency, with four DMUs elevated to become efficient frontiers after lean implementation. In specific, DMU A, P, N and K shifted from inefficient units prior to lean initiative to become efficient frontiers post-lean implementation. Two DMUs (DMU E and F) recorded an unchanged efficiency while 6 DMUs (DMU H, I, O, D, L and C) had a regressed efficiency after lean implementation.

Interestingly, a closer examination of the descriptive data for the two DMUs (H and D) revealed a slight improvement in the output parameter y2 and y3, but their efficiency scores dropped due to increased efficiency among other units in the analysis. This phenomenon may suggest that lean initiative had elevated the efficiency frontiers towards a greater height due to improvements recorded in new frontiers (DMU A, P, N and K). As a result, the existing efficient unit was relegated into becoming less efficient units.

Table III: Descriptive statistics on inputs and outputs variables for before and after lean implementation

DMU	Before lean implementation					After lean implementation					% Changes in parameter				
	x_1	x_2	y_1	y_2	y_3	x_1	x_2	y_1	y_2	y_3	x_1	x_2	y_1	y_2	y_3
A	268	61	340,827	268,231	237,897	271	61	361,413	325,272	281,179	1.12%	0.00%	6.04%	21.27%	18.19%
B	167	43	204,020	167,296	36,724	158	37	186,150	168,968	169,750	-5.39%	-13.95%	-8.76%	1.00%	362.24%
C	86	28	145,980	112,259	79,559	115	33	150,975	113,835	51,332	33.72%	17.86%	3.42%	1.40%	-35.48%
D	133	19	132,320	114,324	82,435	142	30	127,972	119,654	87,917	6.77%	57.89%	-3.29%	4.66%	6.65%
E	66	32	162,481	152,082	142,983	65	32	155,896	85,275	48,640	-1.52%	0.00%	-4.05%	-43.93%	-65.98%
F	96	25	149,913	113,934	117,382	99	26	185,209	127,794	120,386	3.13%	4.00%	23.54%	12.17%	2.56%
G	137	41	119,595	51,426	45,446	133	45	129,146	78,133	51,400	-2.92%	9.76%	7.99%	51.93%	13.10%
H	71	34	176,164	103,584	102,704	73	42	159,866	125,815	79,933	2.82%	23.53%	-9.25%	21.46%	-22.17%
I	143	34	192,957	147,419	118,090	169	39	200,757	166,628	152,575	18.18%	14.71%	4.04%	13.03%	29.20%
J	115	21	69,689	49,897	28,921	116	23	65,410	61,263	27,243	0.87%	9.52%	-6.14%	22.06%	-5.80%
K	56	21	100,154	88,136	65,100	53	18	100,263	92,743	78,105	-5.36%	-14.29%	0.11%	5.23%	19.98%
L	76	19	118,497	71,454	66,358	93	22	112,226	59,199	49,570	22.37%	15.79%	-5.29%	-17.15%	-25.30%
M	84	38	122,318	35,472	42,811	86	41	120,462	76,614	73,000	2.38%	7.89%	-1.52%	115.98%	70.52%
N	46	24	109,135	74,212	65,481	50	36	115,727	94,896	83,671	8.70%	50.00%	6.04%	27.87%	27.78%
O	63	26	66,818	20,045	8,686	65	25	65,636	36,973	24,686	3.17%	-3.85%	-1.77%	84.45%	184.19%
P	60	20	87,067	83,584	71,395	61	19	101,849	98,794	83,516	1.67%	-5.00%	16.98%	18.20%	16.98%
Q	68	23	99,369	71,546	54,653	75	23	110,349	82,541	60,030	10.29%	0.00%	11.05%	15.37%	9.84%
R	69	42	93,178	59,634	65,225	74	42	99,684	61,106	61,106	7.25%	0.00%	6.98%	2.47%	-6.31%
S	171	69	111,708	79,760	78,196	171	77	112,435	66,854	76,006	0.00%	11.59%	0.65%	-16.18%	-2.80%
T	74	28	103,732	73,235	74,065	71	28	103,340	99,206	90,939	-4.05%	0.00%	-0.38%	35.46%	22.78%

Note:
DMU – Decision making unit

Table IV: Efficiency score and slacks results of SBM-DEA (ρ) model before and after lean implementation

DMU	SBM-DEA	Rank	Efficiency change	Slack					Referent	
	ρ			s_1^-	s_2^-	s_1^+	s_2^+	s_3^+	λ	
A	0.7856 [1.0000*]	3 [1]	Improved	82 -	- -	- -	42348 -	15070 -	E (0.8488) -	F (1.3536) -
B	0.3053 [0.8085]	12 [3]	Improved	78 -	0 -	14314 -	155410 -	37064 -	E (1.3438) -	- -
C	0.7005 [0.5031]	7 [10]	Regressed	21 [18]	- -	- [32841]	46492 [91860]	20004 [56194]	E (0.7455) K [1.8333]	F (0.1658) -
D	1.0000^ [0.5966]	1 [7]	Regressed	- [54]	- -	- [39133]	- [42258]	- [34918]	- K [1.6667]	- -
E	1.0000^ [1.0000*]	1 [1]	Unchanged	- -	- -	- -	- -	- -	- -	- -
F	1.0000^ [1.0000*]	1 [1]	Unchanged	- -	- -	- -	- -	- -	- -	- -
G	0.2537 [0.3439]	15 [12]	Improved	52 [1]	- -	88584 [121512]	137751 [143862]	143429 [153725]	E (1.2813) K [2.5000]	- -
H	1.0000^ [0.8779]	1 [2]	Regressed	- -	- -	- -	- [30365]	- [4724]	- E [0.1206]	- N [0.8418]
I	0.8066 [0.7416]	2 [5]	Regressed	34 [54]	- -	- [16480]	38851 [16652]	9852 [34315]	E (0.7259) K [2.1667]	F (0.8845) -
J	0.3048 [0.3144]	13 [14]	Improved	72 [48]	- -	36939 [62704]	64912 [72557]	49907 [57242]	E (0.6563) K [1.2778]	- -
K	0.7311 [1.0000*]	4 [1]	Improved	13 -	0 -	6474 -	28733 -	11668 -	E (0.6563) -	- -
L	1.0000^ [0.5159]	1 [8]	Regressed	- [28]	- -	- [10318]	- [45891]	- [54154]	- K [1.2222]	- -
M	0.2726 [0.5085]	14 [9]	Improved	6 -	- [12]	70628 [42229]	126981 [53736]	145125 [73875]	E (1.1875) K [1.6226]	- -
N	0.7257 [1.0000*]	5 [1]	Improved	- -	2 -	4109 -	34174 -	31785 -	E (0.6970) -	- -
O	0.3435 [0.3199]	11 [13]	Regressed	9 -	- [3]	65198 [57328]	107488 [71103]	103521 [76769]	E (0.8125) K [1.2264]	- -
P	0.7120 [1.0000*]	6 [1]	Improved	19 -	- -	14484 -	17970 -	11467 -	E (0.6250) -	- -
Q	0.5556 [0.6702]	8 [6]	Improved	21 [7]	- -	17414 [17765]	48116 [39771]	37763 [35964]	E (0.7188) K [1.2778]	- -
R	0.3974 [0.4517]	10 [11]	Improved	- -	9 [17]	76689 [40306]	84258 [47946]	99361 [68384]	E (1.0455) K [1.3962]	- -
S	0.2456 [0.2466]	16 [15]	Improved	29 -	- [19]	238642 [211055]	230112 [175993]	248167 [232,374]	E (2.1563) K [3.2264]	- -
T	0.5476 [0.7540]	9 [4]	Improved	16 -	- [4]	38439 [30975]	51045 [13692]	59837 [25,035]	E (0.8750) K [1.3396]	- -

Note:
DMU – Decision making unit
SBM-DEA – Slack-based measure data envelopment analysis
^ Indicates efficient frontier unit before lean implementation.
* Indicates efficient frontier unit after lean implementation.
[ ] Indicates results after lean implementation.

DISCUSSION

The descriptive data demonstrated that there was an increasing supply of healthcare staff, both clinical support staff and medical doctors. The changes observed are indeed parallel to the strategic plan devised by the Malaysian Ministry of Health to increase accessibility via service capacity expansion (18). Although human resources supply illustrated a growth, the ratio of a medical specialist to population is still low standing at 3 to 10,000 populations, when compared to other OECD nations ratio of 14 to 10,000 populations (19). Other than that, healthcare delivery services performed better operationally with a higher percentage of patients' throughput after lean was implemented. The growth of demand for public healthcare service is not surprising given the rising cost of living and healthcare cost. The trend showed an average improvement of operational performance among all the public EDs.

From the findings, the research provided a quantitative evidence to support the positive impact of lean healthcare onto the public emergency services sector. In general, most public EDs (13 out of 20) experienced an improvement in y2 and y3, thus reducing the waiting time for patients to obtain treatment and consultation. However, the lean healthcare key performance indicators utilised several performance metrics and thus making the comparison between peers difficult to interpret. For example, DMU C, which showed an improvement in y2 while, had a reduction in y3.

The use of SBM-DEA method enabled the identification of the efficient frontier unit even with multiple lean performance metrics (12). Most importantly, the efficiency score provided information on whether if there is an overutilisation or underutilisation of resources while implementing the changes in operational processes (16). In precise, nine public EDs (DMU A, B, G, K, M, N, P, Q & T) showed improvement in their human resources utilisation in conjunction with improvement in the waiting time. Based on the feedback obtained, among the factors leading to the improvement including reduction of non-value activities, simpler procedures, better communication and closer working relationship. Similarly, Bal et al. (21) highlighted the need to remove unnecessary staff and patient's movement, which may contribute to non-value activities. The use of lean tools and activities such as value stream mapping, kaizen workshop and continuous monitoring of key performance indicators have been demonstrated to be positively affecting on the performance of healthcare organisations (21,22). Besides, studies have shown that greater involvement and communications between staff may also enhance the operational efficiency (21,23).

The findings also demonstrated an asymmetry efficiency score obtained by some of the public EDs although they received similar lean training from the external lean consultant (2). For example, the anomaly in the DMU S efficiency score (higher efficiency score but longer waiting time) could be contributed by the increased in the number of patients discharged although metrics on waiting time did not showed improvement (10). In addition, the failure of lean in some of the public EDs were similar to lean healthcare outcome in the study by Moraros et al. (20) and Vermeulen et al. (9) Among the factors that were found to be differentiating between the lean adopters including leadership, communication and teamwork (23). Lean implementations that lack in leadership, communication and management support were shown to be detrimental to the outcome (4). Previous studies also showed that there are other factors that may influence the outcome achieved by the lean adopters, such as complexity of medical procedures, environmental context and policy factors (24,25). However, further in-depth research is required to uncover the factors contributed to the variations found in this research.

This research offers three distinctive features in comparison to past literature. Firstly, the retrieved findings may enable policymakers to better understand the impact of lean healthcare from the efficiency perspective, namely human resources utilization (13). Besides, the ranking on the efficiency score provided a measure for public EDs to understand their performance among their peers (16). The identification of high performers may promote knowledge transfer between high-low performers, thus reducing the trial-and-error approach in future implementations. The inefficient department may look into the operational processes within their department and invest more time and resources to improve the performance in areas that were lacking compared to their benchmark peer. Secondly, to the best of the author's knowledge, studies concerning lean assessment using SBM-DEA approach are scarce in the healthcare setting, indicating that lean efficiency assessment in the healthcare sector is still in its nascent stage (26). Thirdly, a set of inclusion criteria had been determined in this study to allow only comparable peers to control the effects of exogenous factors. The determination of inclusion criteria ensured that methodological rigour is indeed preserved and to ascertain the reliability of the results.

The capability of SBM-DEA model has been limited by the selection of parameters used in the evaluation. The selection of parameters employed is crucial in determining the appropriate outcomes or interpretations (27). Hence, a thorough understanding of the context and participation of stakeholders are significant to determine inputs and outputs used in the assessment. In addition, due to the minimal assumption made from the model, researchers should make careful interpretation of the lean efficiency scores achieved, as the findings do not offer reasons or ways for the efficiency level to be achieved. Besides, the small sample size used in this research may also limit the generalizability of the findings onto other contexts. Nevertheless, the model only offered guidance on the possibility of results that could be achieved by the inefficient unit, but the further elaboration on how it may be achieved may require further examination.

There are three areas that this research intends to contribute. Firstly, SBM-DEA approach is useful for the public healthcare setting, where a public entity is usually comprised of multiple performance objectives, unlike profit maximization goal in private organizations (16). Secondly, the SBM-DEA model deals directly on slacks, which complements well with lean philosophy in eliminating waste found within systems (13). The excess of inputs and shortage of outputs information provided by the SBM-DEA model may assist in guiding lean practitioners on the possibilities to be achieved by an inefficient unit. Thirdly, information on the frontier lean efficient ED among a group of homogeneous units under evaluation may enable a shorter learning curve by adopting the best practices from the high-efficiency units (13).

For future studies, researchers may consider incorporating the qualitative approach to provide explanatory for variance in the performance achieved by the hospitals. In fact, the most efficient unit information provided by the SBM-DEA may assist in identifying a suitable yardstick for lean facilitators to solicit in-depth information on how lean healthcare can achieve better outcomes in efficiency. In addition, future researchers may consider cost-benefit analysis depending on the availability of information to offer justification if lean healthcare implementation is a justifiable correspondence to higher manpower and efficiency. The cost-benefit analysis could give policymakers greater confidence to push forward with lean healthcare program. Moreover, the proposed assessment method from this research provides lean assessment tools that could be utilized by lean policymakers in public healthcare to monitor performance in a continuous manner.

CONCLUSION

This research shows that lean healthcare positively improved the waiting time and efficiency in the some public EDs. The identification of efficient frontiers through SBM-DEA among the adopters of lean healthcare implementation may enable replication of success in the less efficient public EDs.

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