2014-07-06

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***Abstract* — Recently, the application of lean thinking in healthcare has grown significantly in response to rising demand, caused by population growth, ageing and high expectations of service quality. However, insufficient justifications and lack of quantifiable evidence are the main obstacles to convince healthcare executives to adopt lean philosophies. This paper presents a real application of the successful implementation of a methodology that integrates Value Stream Mapping (VSM) and simulation modelling to improve an emergency department (ED) of a University hospital in Dublin. Appling lean approach in operations will minimize the patient waiting time and improve service time. VSM points out to the value-added and non-value-added activities in a clear schematic way. Simulation Model is also developed for the department in order to account for the variability and complexity resulted in healthcare processes due to dynamism and sharing resources. A comparative analysis of current and future state of the ED is provided and presented to managers to illustrate the potential benefits of adopting lean practices.**

Keywords: Lean; Modeling and Simulation; Healthcare; Capacity Planning.

I. Introduction

Health systems are complex [1]. Although a significant fraction of many governments' budgets is allocated to health, results have hardly matched expectations as many health system performance indicators have shown limited improvement. Long waiting lists, overcrowding, and patient's dissatisfaction are the main symptoms of the healthcare system in Ireland with over 46,400 adults and children waiting for hospital treatment, according to the latest figures from the Health Service Executive (HSE) in Ireland [2]. Healthcare managers are challenged by intrinsic uncertainty of the demands and outcomes of healthcare systems [3]; high public demand for increased quality [4]; high level of human involvement at both patients level and resource level (doctor, nurses, etc.); limited budget and resources; and large number of variables (e.g., staff scheduling, number of beds, etc.). As a result, service providers and healthcare managers are continuously studying the efficiency of existing healthcare systems and exploring improvement opportunities.

Traditionally, critical decisions are made based on the vast arrays of data contained in clinical and administrative records. This approach cannot succeed in representing the dynamic interaction between the interconnected components of the healthcare system. Consequently, this approach has limited use when it comes to predicting the outcomes of changes or proposed actions to the system. Analytical tools are needed to support managers' decisions at different levels within the healthcare system. If analytical models are impractical in the healthcare settings, it is usually due to the imposed simplifications on the model. Accordingly, important details and features of the underlined systems cannot be captured. Lean thinking and simulation modeling offer two distinct frameworks which healthcare organizations can adapt to address their challenges.

In the rest of the paper, Section 2 reviews related work. Section 3 introduces the case study and the application of lean and simulation, followed by experimentation and analysis in Section 4, while Section 5 concludes the paper.

II. Literature Review

With the healthcare organizations aim to improve the patient experience and system's effectiveness and efficiency, they were confronted with increasing costs, demand on services and expectations in service quality. Corresponding to these challenges, decision makers were forced to think of new flexible ways to reduce waste, improve process control and improve utilization of resources. Lean is one of the most valuable techniques that can be used to achieve these ambitions [5]. Lean is a concept related to philosophies derived from Toyota production system to create more value with less. The lean process evaluates operations step by step to identify waste and inefficiency and then creates solutions to improve operations and reduce cost [6]. The lean process represent an unending cycle toward perfection, in which the services in continually refined and improved [7]. The existing number of publications proves the importance of lean in healthcare [8]. Lean has been utilized effectively in healthcare to reduce waiting times and improve system performance by eliminating the wasteful activities from the existing processes [9], [10] in many departments across the hospital setting including the emergency [11], [12] and surgery departments [13]. Despite the efficiency of implementing lean philosophy, reports reflected on few drawbacks especially related to the interpretations of changes.

Reviewing the portfolio of techniques and tools that assist in implementing lean, three groups can be distinguished. While some of these tools such as process mapping are used to review the performance of the organization in terms of waste and process, improvement tools are focusing on redesigning and developing the existing processes. Finally, monitoring tools, such as visual management, are used to examine the existing and the developing processes [14]. Furthermore, while some of these tools are focusing on the entire organization as the unit of analysis, others such as Value Stream Mapping (VSM) are more focused on a product value stream. A value stream is a mapping tool that is used to identify Value-Added activities (VA) from Non-Value added (NVA) activities, the NVA activities increase throughput time and develop an undue service time [15]. In recent years, VSM has emerged as the preferred assist to implement lean [16] and in particularly with complex dynamic systems such as emergency department [17]. VSM is considered a valuable tool in helping health care managers to recognize waste and its sources. The content of VSM does not only include information about the materials flow but also about the flow time based performance [18]. VSM can be formulated in three steps; the first step is to formulate the current state value map to give a snapshot of the current processes. To achieve this, managers illustrate every step in service and document facts such as cycle time, buffer sizes, and personal requirements [19]. The second step consists in the identification and analysis of the waste encountered along the value stream. Finally, a parallel map is developed to describe the ideal future state without the removed waste [20] Critique to VSM approach is due to the fact that it is a static tool and sometimes unable to illustrate the dynamic behavior between system components. For managers, this might affect their judgments to recognize whether the best future state as regards to the desired level of system performance is achieved or not [21]. At the moment, there is a need to wait for few months to monitor the impact of the changes on the system key performance indicators. Consequently, a complementary tool with VSM is required to handle uncertainty and model the dynamics between system components for different future state maps [22]. Using simulation modeling in the assessment process of lean implementation would explore the various opportunities of process improvement and the impact of the proposed changes before implementation [23]. The future state has to be validated before implementation in order to minimize risks and reduce trial and error adjustments. Simulation can also be used to systemically identify the best alternatives of the future state. By using simulation, operation process data can be analyzed fully to examine the parameter's variability and uncertainty in operation [24] and [25]. Simulation has been widely proven to be a flexible tool to model the uncertainty and complexity [26]. By testing design alternatives, simulation analysis will provide an effective way of examining solutions prior to their actual implementation and reducing the risk associated with lean process.

III. SIMULATION-BASED VALUE STREAM MAPPING

A. *Hospital and ED Background*

In Ireland, with more than 1.2 millions attending the ED every year, the ED overcrowding has been declared a national emergency. The shortage of beds coupled with the high patient demand and shortage of staff has affected the ED capability to provide efficient and safe care to patients. Prolonged waiting times has been reported with more than 40% of the patients waiting between 10-24 hours (HSE Performance Monitoring Report, 2010). Consequently, the hospitals are not compliant with the Health Service Executive (HSE) waiting time targets (6 hour patient experience time target). It was also reported by the task force in 2007 that the overall ED physical space and infrastructure is insufficient. Accordingly, analysing the patient flow in emergency departments to optimise the ED capacity in order to minimize the length of stay has become a crucial requirement. The hospital studied is a public, adult teaching hospital that holds 463 beds and handles almost 220,000 patients annually. Its ED logs over 45000 patients a year. The ED has 4 resuscitation beds, 4 minor injury beds, 9 major beds, 1 triage room, and 2 X-ray rooms. It has also a Clinical Decision Unit (CDU), which is designated for patients who are still under ED physicians and need further investigations. The uncertainty and complexity of the ED processes require a technique that can handle system variation and validate improvements steps before it can be implemented [27]. The proposed framework is used to identify VA and NVA activities and model the complexity of the ED to explore potential solutions to meet the national metrics.

B. *Data Collection and Analysis*

In order to acquire knowledge about the ED processes and build a VSM, extensive information was gathered. Direct observation to the service delivery operation was conducted to represent the interaction between the different service delivery processes and to deliver average processes times. Extensive interviews with ED doctors, nurses, administrators, nursing staff, and unit porters were conducted to gain precious insights into the ED operation processes in theory and practice. The vast amount of data collected was very valuable in determining the current ED service delivery processes and developing the VSM. ED service delivery process have the following sets of activities, some occur in sequential; some are omitted for different patient conditions. These activities are: patient arrival; triage process; initial ED doctor assessment; diagnostic tests; doctor follow up or treatment planning; admission or discharge.

There are two main ways for patient's arrival to EDs, ambulance or walk-in. Patients arriving via ambulance are always giving priority as they are considered as urgent and need to be triaged immediately. By using the Manchester triage system, patients are categorized into 5 groups and each group is given a color: Blue, Green, Yellow, Orange, and Red. The red category signals a very sick patient that needs to be seen immediately and blue signals the non-urgent patient. For the purpose of this paper, the patient flow was given number from 1-15. The Patient arrives and is registered by a receptionist. In the next step, the patient will be triaged by a senior nurse to determine the severity of their condition and the patient will be labeled by a triage category. If the patient is given the red or orange category, the patient will be moved to resuscitation or to major immediately. The triaged patients (yellow, green, and blue category) will wait in the designated area (waiting room) for an available bed. The patients will be seen according to their triage category. If the ED cubicles are full or the doctors are busy with life threatening case, the patients have to wait longer to be seen, resulting in overcrowding. Hence, the arrival of critically ill patients will be given priority to be seen ahead of other patients. The patients will be called by a nurse and allocated a cubicle waiting to be assessed by ED doctor. Depending on the initial ED doctor assessment, one or more diagnostic tests are recommended. Following the diagnostic tests, the patient will be reviewed by ED doctor to recommend admitting them to the hospital or discharged from ED or further investigation required. If the patient requires a medical or surgical assessment, the bleep system will be used to contact the designated team and a verbal handover will be given by ED doctor.

If the surgical team is carrying out an operation in Theatre, the patient has to wait for few hours before an assessment will be carried out. If the patient needs further investigation under ED doctor care, the patient will be admitted to CDU. During the patient stay in CDU, the medical care is provided by ED health care staff. If the diagnostic test comeback as abnormal, the patient will be referred to the appropriate medical/surgical team and will be admitted to the hospital, otherwise the patient will be discharged. If a decision is taken to admit the patient, the hospital bed manager has to be notified to allocate a bed. During the wait time for ward bed, the ED nurses are responsible for the patient's care.

C. Development of the VSM

Data for the current stat map was collected as recommended by Rother and Shock [28]. The data collection for the ED process started at patient leaving ED (admission or discharge), and worked backward all the way to the patient arrivals, gathering snapshots of data such as process cycle time, waiting time before each process, number of employees for each process and their qualification. The VSM for ED is presented in Figure 1.

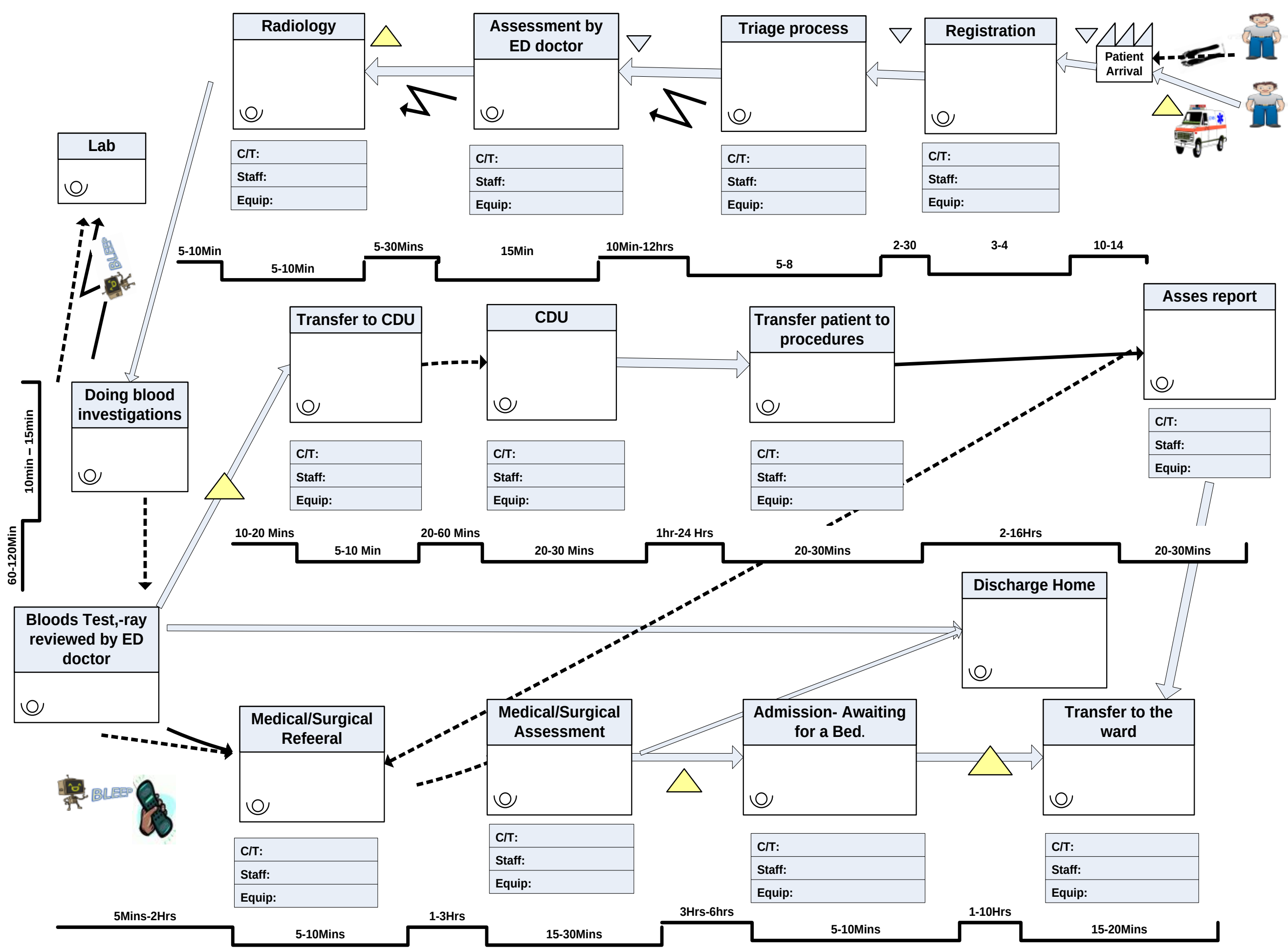

Figure 1. Current State Value Stream Map of the ED

 ISBN: 978-1-61208-371-1

The large boxes in the map represent the process and steps needed to achieve it. Also, each process has a data box below, which contains the health care staff in each process, and the facility required. The timeline at the bottom has two elements. The first element of the timeline is the processing time (VA time). VA time is obtained by summing all the processing times in the value stream. The second component of timeline is the process waiting time (NVA). This time is calculated by adding the waiting time before each process.

As represented in the VSM, the average waiting time to see a doctor is between 10 to 420 minutes depending on the patient's condition and the availability of a bed in ED. Despite the process of doing blood investigation average time is between 10-15 minutes, waiting for the results to be ready for review is between 60-120 minutes. There are three possible paths for patients in ED after the ED doctor review the diagnostic test results and commence follow up or begin treatment of the patient. These paths are:

1. The patient need further diagnostic tests but still under ED physician care. The average process time from patient arrival to ED to be ready to be discharged or admitted to the ward is between 103-157 minutes compared to 182-2154 minutes average waiting time.

2. Patient treatment is finished and is to be discharged. The average process time from arrival to ED to be discharged is 48-77 minutes while the waiting average time is between 102-654 minutes.

3. Finally, if the patient required a medical/surgical consultation, the average process time is between 58-97 minutes while the average waiting time is between157-934 minutes.

To find the causes behind the long NVA time in the ED process, conducting a root cause analysis is essential.

D. Root Cause Analysis

Root cause analysis is an applied tool developed by Professor Ishikaua in 1943 [29] to analyze possible causes or problems while organizing the causal relationships. A root cause analysis was conducted to explore the causes behind the long waiting time (NVA) in ED process. Figure 2 represents a root cause analysis diagram. According to the diagram, six categories were found to be the main contributors in extending waiting time for patients in the ED journey. These categories were:

1. Resources:
   a. The shortage of beds in ED and hospital resulting from the high patients demand has impacted negatively on ED performance. Admitted patients have to wait a long time in ED before transferring them to their wards is not only blocking ED beds, but is also over utilized ED resources.
   b. Because of the lack of ED doctor's access to outpatient clinic, chronic patients were found to occupy acute beds in ED.

2. Information Technology (IT):

   There was no IT system found in order to inform ED staff members that blood results or X-ray are ready for collection. The waiting time for diagnostic results when they are ready to be reviewed is NVA time.

3. Manpower:
   a. There was no dedicated nurse in minor injury. The nurse in minor injury was distracted to help in resuscitation if needed. This causes longer waiting time to patients attending minor injury area.
   b. When the nurses on duty were not skilled to take bloods, the ED doctors have to do it themselves.
   c. If the senior doctor was busy in resuscitation, there will be no decision maker available to discharge or admit patients. Junior doctors have to wait to discuss patient case with senior doctor to direct the patient treatment plan.

4. Investigations:

   The limited access to diagnostic tests, such as CT scan at night and weekends, increases the patient's length of stay in ED dramatically.

5. Communication
   a. If a patient triaged and labeled with red or orange, triage nurse have to search for the nurse manager to allocate a bed immediately. No communication system in place available between triage nurse and nurse manager.
   b. Medical/surgical teams were not available all the time to respond to consultation referral from ED.
   c. Laboratory technicians were not informed about sending blood samples to the lab.

6. Process:
   a. Over processing in triage process. Because of the long waiting times to see a doctor, the tri-age nurse has to carry out a comprehensive over processing triage.
   b. Delay in transporting blood samples to the lab.

 ISBN: 978-1-61208-371-1

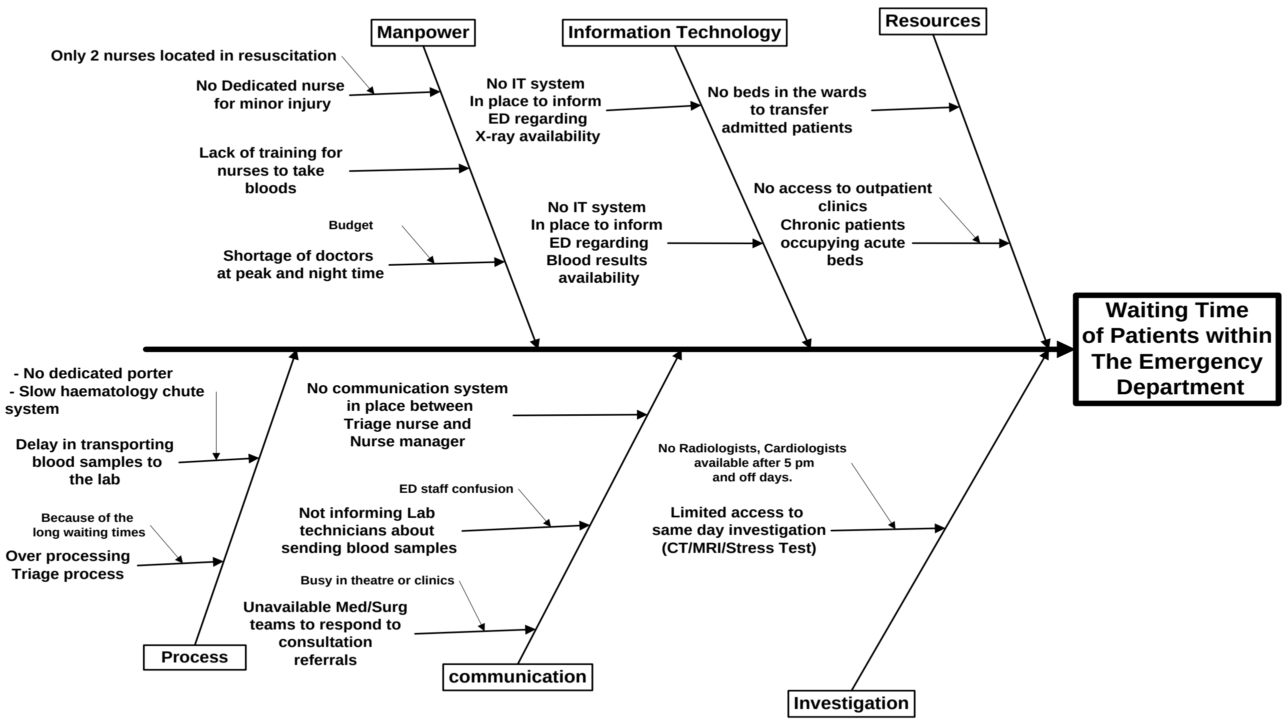

Figure 2. Root cause analysis

E. *Simulation Model Development*

Based on the discussed patient flow, VSM, and root case analysis, a comprehensive simulation model was developed. As the work involves processes at the patient level, Discrete-Event Simulation (DES) is suitable. The simulation model has been designed to reflect the interaction between entities in the ED real world. Starting from the early stage of the development process, it took into consideration the whole model into the hierarchy scheme to enable the modularity and extendibility. Mainly, the simulation model is divided into three basic stages; patient generation and arrival, patient treatment and patient discharge. Generation of the patient arrival pattern in the first stage depended on the distributions extracted from the real data of the ED. Patients arrival has two sources; patients come with the ambulance and patients come as walk in. There are two entry points to the ED zones one for the ambulance patients who has higher priority and the other one for the walk in patients. The treatment stage of the model contains the main zones and labs of the ED. This stage starts with the triage block, which decides the priority level of treating patient on scale from 1 to 5 with 1 determining the highest priority. Patients move from triage to the zones or the waiting room according to the severity level. There are three zones for patient treatment, the first one zone1 is dedicated to the most severe cases such as unconscious or non-breathing patients, the second one is zone2 which receives patients with major injuries and the third one is zone3, which is dedicated to the minor injuries patients. Each zone provides a sequence of treatment and examining processes according to the severity level of the patient.

The routers blocks in the simulation model control the pathway of the patient treatment process according to the statistics extracted from the ED real data. Different resources batches to the patient by joining the process. When the patient enters the zone, a trolley and cubicle resource is assigned to the patient. In the treatment process, a doctor or nurse assigned to the patient. It depends on the capacity and availability these resources.

The journey in each zones ends with the discharging stage, which distribute the patient to one of the discharge outcomes; Home, GP, Die, Transfer and Others. During the whole journey of the patient and at certain points, the average waiting time and patient experience time (PET) - length of stay - are accumulated for each patient to calculate the final average PET and waiting time for all patients. These measurements or KPIs are used later to examine the impact of the change of the simulation variables on the performance of the ED.

For the simulation model to be considered as representative of the processes within ED and to be able to use it for testing scenarios, validation and verification are needed. Using visual tracking, the simulation model was verified by examining every group of blocks to ensure that patients follow the correct care path. Also, the conceptual model was validated by the ED senior managers and senior staff. A face validation approach was performed with the ED senior managers to validate the generic simulation model.

Finally, the output of the simulation model was compared with actual ED processes time and the deviation average was not more than 5% from the actual values.

IV. Experimentation And Analysis

Simulation model scenarios are in relation to the ED capacity in terms of number of major and minor cubicles required to better manage current and future demand for care. Besides ED capacity concerns, three other bottlenecks have been identified; time to admit patients from ED to hospital wards, ED staffing level, and time for specialty team to see a patient. A summary of the simulation variables and their agreed range of values is given in Table I.

Table I Simulation Variables

Simulation Variable		**Possible rang of values**
ED Size	Major Cubicles	9, 15, 20, 25
	Minor Cubicles	6, 8, 10, 12
	Resus Cubicles	4, 6
ED to Wards time (hrs)		1, 2, 3, 4
ED Staffing level		Current, infinity
Specialty Team Time (hrs)		2, 3

The main Key Performance Indicator used in the simulation model is the percentage of patients with patient experience time (i.e., length of stay) less than 6 hours. Due to the large number of combinations of variables, a total of 45 scenarios have been selected

Regarding the staffing level, the value ‘c’ refers to the current staffing level where the value ‘i’ represents an infinite supply of staff. Although not realistic, the objective of the assumption of infinite supply of staff is to switch on and off the staffing bottleneck and to focus on the determining the ED size regardless of the actual staff needed as requested by the ED stakeholders. Each scenario was tested by the simulation model for 12 months for 15 runs.

As shown in Table II, percentage of patients staying the ED less than 6 hours does not improve with only increasing the ED size.

TABLE II SIMULATION RESULTS OF INCREASING CAPACITY

Speciality Time (HRS)	**Staffing Levels**	**ED to Wards**	**Major**	**Minor**	**Resus**	**PET<6hrs (%)**
3	c	4	25	12	4	36
3	c	4	20	10	6	40
3	c	4	15	8	6	45

Along with current staffing level, decreasing the waiting time for patients who need to be admitted to hospital wards is crucial for improving PET. Additionally, decreasing the time for specialty teams to check patients in the ED is important for decreasing overall PET (Table III).

With resolving these two bottlenecks, namely ED toward time and specialty team time, the effect of increasing the ED size on PET is constrained by the current staffing level. Assuming an infinite supply of staff, it was found that the ED needs to increase its major cubicles by at least 122% of its current capacity (from 9 to 20) and minor cubicles by 33% with no need to increase Resus cubicles.

TABLE III SIMULATION RESULTS FOR ALL VARIABLES

Speciality Time	Staffing Levels	ED to Wards	Majors	Minors	Resus	PET < 6 hrs (%)
3	c	4	25	12	4	36
3	c	3	25	10	6	39
3	c	4	20	10	6	40
3	c	3	20	12	4	43
3	c	2	25	8	4	44
3	c	2	20	6	6	45
3	c	4	15	8	6	45
3	c	3	15	6	4	49
3	c	1	25	6	4	49
3	i	4	15	8	6	50
3	i	4	20	10	6	52
3	c	1	20	8	4	52
3	c	2	15	12	6	52
3	i	4	25	12	4	54
3	c	1	15	10	4	56
3	i	3	15	6	4	56
3	c	3	9	8	6	57
2	i	4	15	8	6	57
3	i	3	20	12	4	57
2	i	4	20	10	6	58
3	c	2	9	10	4	59
2	i	4	25	12	4	59
3	i	3	25	10	6	60
3	c	1	9	12	6	61
3	i	3	9	8	6	62
3	i	2	15	12	6	62
3	i	2	20	6	6	63
2	i	3	9	8	6	63
3	i	1	15	10	4	64
3	i	2	9	10	4	65
3	i	2	25	8	4	65
2	i	3	15	6	4	66
3	i	1	20	8	4	67
3	i	1	9	12	6	68
2	i	2	9	10	4	68
2	i	3	20	12	4	68
3	i	1	25	6	4	70
2	i	3	25	10	6	71
2	i	2	15	12	6	71
2	i	1	9	12	6	72
2	i	2	20	6	6	75
2	i	1	15	10	4	76
2	i	2	25	8	4	77
2	i	1	20	8	4	82
2	i	1	25	6	4	84

V. Conclusion

Integrating lean thinking into decisions is a well-thought management practice in complex business systems. It can

 ISBN: 978-1-61208-371-1

help not only to improve the quality of service but it also eliminates non-value added activities. This approach can be applied to support healthcare managers to reduce costs and improve healthcare organization performance. To exploit the improvement opportunities, VSM was used to identify the non-value added activities in a structured diagram that presents system parameters (i.e. materials flow and the cycle time). This enables the management team to discover system bottlenecks and impact of changes on performance. Application of Simulation modelling was also utilised in the case study to demonstrate the dynamism of the key system resources. Results show that the integration between VSM and Simulation Modelling was effective in modelling capacity planning activities within the Emergency Department of one of the leading hospitals in Dublin. The framework has a potential to be used as a template of planning emergency departments in Ireland.

REFERENCES

[1] D. Balabanova, A. Mills, L. Conteh, B. Akkazieva, H. Banteyerga, U. Dash, L. Gilson, A. Harmer, A. Ibraimova, and Z. Islam, "Good health at low cost 25 years on: lessons for the future of health systems strengthening," The Lancet, vol. 381, pp. 2118-2133.

[2] HSE, "Health service executive emergency departments - patient profiles, experiences and perceptions," 2010. (Online). http://www.hse.ie,. (retrieved: July, 2014).

[3] K. Katsaliaki and N. Mustafee, "Applications of simulation within the healthcare context," Journal of the Operational Research Society, vol. 62, 2011, pp. 1431-1451.

[4] S. Al-Balushi, A. Sohal, P. J. Singh, A. Al Hajri, Y. Al Farsi, and R. Al Abri, "Readiness Factors for Lean Implementation in Healthcare Settings–A Literature Review," Journal of Health Organization and Management, vol. 28, 2014, pp. 135-153.

[5] C. Koelling, D. Eitel, S. Mahapatra, K. Messner, and L. Grove, "Value stream mapping the emergency department," 2005. (online). htp:/w.ientorg/upladefis/SHReourc_Libay/Detils180.pdf. (retrieved: July, 2014).

[6] E. W. Dickson, S. Singh, D. S. Cheung, C. C. Wyatt, and A. S. Nugent, "Application of lean manufacturing techniques in the emergency department," The Journal of emergency medicine, vol. 37, 2009, pp. 177-182.

[7] E. M. Wojtys, L. Schley, K. A. Overgaard, and J. Agbabian, "Applying lean techniques to improve the patient scheduling process," Journal for Healthcare Quality, vol. 31, 2009, pp. 10-16.

[8] R. L. Wijewardana and T. Rupasinghe, "Applicability of Lean Healthcare in Sri Lankan Healthcare Supply Chains," International Journal of Supply Chain Management, vol. 2, 2013, pp. 42-49.

[9] T. Papadopoulos, "Continuous improvement and dynamic actor associations: A study of lean thinking implementation in the UK National Health Service," Leadership in Health Services, vol. 24, 2011, pp. 207-227.

[10] A. Virtue, T. Chaussalet, and J. Kelly, "Healthcare planning and its potential role increasing operational efficiency in the health sector: A viewpoint," Journal of Enterprise Information Management, vol. 26, 2013, pp. 8-20.

[11] M. J. Vermeulen, T. A. Stukel, A. Guttmann, B. H. Rowe, M. Zwarenstein, B. Golden, A. Nigam, G. Anderson, R. S. Bell, and M. J. Schull, "Evaluation of an Emergency Department Lean Process Improvement Program to reduce length of stay," Annals of emergency medicine, 2014, pp. 1-12.

[12] H. Chan, S. Lo, L. Lee, W. Lo, W. Yu, Y. Wu, S. Ho, R. Yeung, and J. Chan, "Lean techniques for the improvement of patients' flow in emergency department," World, vol. 5, 2014, pp. 24-28.

[13] R. M. Collar, A. G. Shuman, S. Feiner, A. K. McGonegal, N. Heidel, M. Duck, S. A. McLean, J. E. Billi, D. W. Healy, and C. R. Bradford, "Lean management in academic surgery," Journal of the American College of Surgeons, vol. 214, 2012, pp. 928-936.

[14] S. Robinson, Z. J. Radnor, N. Burgess, and C. Worthington, "SimLean: Utilising simulation in the implementation of lean in healthcare," European Journal of Operational Research, vol. 219, 2012, pp. 188-197.

[15] D. Hadfield, S. Holmes, S. Kozlowski, and T. Sperl, The New Lean Healthcare Pocket Guide: Tools for the Elimination of Waste in Hospitals, Clinics, and Other Healthcare Facilities: MCS Media, Incorporated, 2009.

[16] Y. H. Lian and H. Van Landeghem, "Analysing the effects of Lean manufacturing using a value stream mapping-based simulation generator," International Journal of Production Research, vol. 45, 2007, pp. 3037-3058.

[17] D. Cookson, C. Read, and M. Cooke, "Improving the quality of Emergency Department care by removing waste using Lean Value Stream mapping," The international journal of clinical leadership, vol. 17, 2011, pp. 25-30.

[18] A. Mahfouz, J. Crowe, and A. Arisha, "Integrating Current State and Future State Value Stream Mapping with Discrete Event Simulation: A Lean Distribution Case Study," in SIMUL 2011, The Third International Conference on Advances in System Simulation, 2011, pp. 161-168.

[19] P. Solding and P. Gullander, "Concepts for simulation based value stream mapping," in Procedding of the 2009 Winter Simulation Conference M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin and R. G. Ingalls, eds., 2009, pp. 2231-2237.

[20] A. J. Donatelli and G. A. Harris, "Combining value stream mapping and discrete event simulation," in Proceedings of the Huntsville Simulation Conference,[online, 21.02. 2012]: https://rsic. redstone. army. mil/hsc/papers/hsc003. pdf, 2001. (retrieved: July, 2014).

[22] S. Sigari and R. Clark, "Applying lean thinking to improve the production process of a traditional medium–size British manufacturing company," International Journal of Information and Operations Management Education, vol. 5, 2013, pp. 154-169.

[23] C. Chen, J. Snowdon, and J. Charnes, "The current and future status of simulation software," in Proceedings of the 2002 Winter Simulation Conference E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, eds., 2002, pp. 1633-1640.

[24] A. Arisha and P. Young, "Intelligent simulation-based lot scheduling of photolithography toolsets in a wafer fabrication facility," In Proceedings of the 2004 Winter Simulation Conference R .G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters, eds., 2004, pp. 1935-1942.

[25] A. Mahfouz, S. A. Hassan, and A. Arisha, "Practical simulation application: Evaluation of process control parameters in Twisted-Pair Cables manufacturing system," Simulation Modelling Practice and Theory, vol. 18, 2010, pp. 471-482.

[26] K. Ismail, W. Abo-Hamad, and A. Arisha, "Integrating balanced scorecard and simulation modeling to improve Emergency Department performance in Irish hospitals," In Proceedings of the 2010 Winter Simulation Conference B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan, eds., 2010, pp. 2340-2351.

[27] A. Tobail, P. Egan, W. Abo-Hamad, and A. Arisha, "Application of Lean Thinking Using Simulation Modeling in A Private Hospital," in SIMUL 2013, The Fifth International Conference on Advances in System Simulation, 2013, pp. 22-28.M.

[28] Rother, Shock, J, Learning to See: Value Stream Mapping to Add Value and Eliminate Muda: The Lean Enterprise Institute, Inc., Brookline, May, 1999.

[29] B. Anderson, and T. Fagerhaug, Root cause analysis:Simplified tools and techniques: Milwaukee: ASQ Quality Press, 2000.