

2014-07-06

## Optimization of Resources to Improve Patient Experience in the New Emergency Department of Mater Hospital Dublin

Heba Habib

*Technological University Dublin, heba.habib@tudublin.ie*

Waleed Abo-Hamad

*Technological University Dublin*

Amr Arisha

*Technological University Dublin, amr.arisha@tudublin.ie*

Follow this and additional works at: <https://arrow.tudublin.ie/buschmarcon>



Part of the [Business Administration, Management, and Operations Commons](#), and the [Operations and Supply Chain Management Commons](#)

---

### Recommended Citation

Abo-Hamad, W., Habib, H. & Arisha, A. (2014) Optimization of Resources to Improve Patient Experience in the New Emergency Department of Mater Hospital Dublin, *Sixth International Conference on Advances in System Simulation, SIMUL 2014*, Nice – France, 12 - 16 October.

This Conference Paper is brought to you for free and open access by the School of Marketing at ARROW@TU Dublin. It has been accepted for inclusion in Conference papers by an authorized administrator of ARROW@TU Dublin. For more information, please contact [arrow.admin@tudublin.ie](mailto:arrow.admin@tudublin.ie), [aisling.coyne@tudublin.ie](mailto:aisling.coyne@tudublin.ie).



This work is licensed under a [Creative Commons Attribution-NonCommercial-Share Alike 4.0 License](#)  
Funder: College of Business

# Optimization of Resources to Improve Patient Experience in the New Emergency Department of Mater Hospital Dublin

Heba Habib, Waleed Abo-Hamad, Amr Arisha

3S Group, College of Business  
Dublin Institute of Technology DIT  
Dublin, Ireland

heba.habib@mydit.ie, waleed.abohamad@dit.ie, amr.arisha@dit.ie

**Abstract**— Healthcare systems globally are facing capacity issues due to the increased demand of health services, the high cost of resources and the level of quality anticipated of service providers. Emergency Departments (ED) are the most pressurized unit in healthcare systems due to uncertainty in demand and limited resources allocated. Mater Hospital (one of leading hospitals) in Dublin has built a new (state-of-the-art) unit for ED yet faced an issue in resourcing the unit to optimize performance. This paper presents an integrated solution to optimize the capacity of the new ED before opening to public and examine improvement interventions in the ED area. This solution provides ED management with a tool that can contribute significantly in enhancing patient experience by reducing the waiting time from 21 hours to 6 hours while achieving utilization below the 80% burn-out threshold. The model is recommended by Health Service Executives to be used national wide.

**Keywords**—Health-care management; patient experience; discrete-event simulation; emergency department.

## I. INTRODUCTION

Healthcare management, globally, is under constant pressures of increasing service costs, public demands, and quality expectations from patients. This drives the strategy into one direction, namely, continual improvement of strategies related to patients experience.

While hospitals represent an important part of healthcare service providers, Emergency Departments (EDs) are considered the front line defense in managing the flow of patients into hospitals. The problem faced by ED managers is related to the fact that number of patients who arrive at ED usually exceed the physical capacity of the waiting rooms [1]. Overcrowding can lead to dramatic consequences that may include higher mortality rates for patients [2]. Crowding involves the patients waiting for ED admission, being monitored in non-treatment areas (corridors) and those waiting to be admitted in the hospital (inpatient). Those patients utilize resources in non-treatment areas and their waiting times exceed reasonable periods [3] and the problem can get worse with higher arrival rate [4].

In an Irish context, the Health Service Executive (HSE) is the government entity responsible for the provision of health and social services. The HSE has always addressed in its strategies the urgency to bring real and sustained reforms to Irish healthcare services. In 2007, a scheme has been presented by HSE to reward hospitals that maintain high

performance levels [5]. To support continual improvement that leads to reduce the pressure on EDs, HSE has set a target of less than 6 hours to overall Patient Experience Time (PET), i.e., length of stay, within the ED that has been adopted ever since [6].

The ED managers in Irish hospitals have developed a need, since then, for innovative solutions and applications to help them to achieve the target set by HSE and reduce the patient experience time in the emergency department to less than 6 hours. These solutions have to be capable of understanding their system dynamics and increase efficiency, while taking resources utilization and process rationalization into consideration. The challenge for these solutions would be in meeting the aforementioned pressures and managing the huge gap between the needs and costs of healthcare.

Simulation is a powerful tool used to capture the complexity and dynamic features of ED processes. Simulation models have been proven to be an excellent and flexible tool for modeling such kinds of complex environment. A simulation model is an effective tool for testing the effect of different resource allocation schemes, which is crucial for efficient utilization of resources within the ED [7]. A simulation model is also a flexible tool that can be used to simulate the effect of different possible ED settings on patient waiting time [8]. Moreover, multi-performance indicators can easily be measured using a simulation model, as stated by [9]. Simulation modeling used to examine staff scheduling impact on overall utilization and burnout issues related to over-utilized staff [10]. A number of studies in the literature used simulation to model the operation of ED using patient's waiting time and throughput time as the main target service quality [11]. The impact of staff scheduling can also be investigated using simulation and modeling [12]. It can also be used to analyze the impact of the enhancements, made to the system after the relocation of the emergency department, on the patients flow [13].

Aforementioned studies show that modeling and simulation is currently seen as a competent tool for EDs performance analysis, which allows the effects of actions and changes to be understood and predicted more easily. Compared to change initiatives, tools such as discrete event simulation provide a low risk, lower cost method to develop improvement strategies, test assumptions, and observe potential outcomes of decisions prior to implementation. Numerous discrete event simulation applications are found in healthcare, but very few demonstrate a pre-/post-intervention comparison [14]. Frequently, healthcare decision makers use

subjective information from frontline staff, providers, and other stakeholders to make strategic improvement decisions. Change attempts whether to structures (e.g., change in floor plan or layout) or to processes, may prove costly in terms of time and capital [15].

This paper presents a simulation based solution to the key healthcare service providers (i.e., Public Hospitals) in order to help them to make the optimum decision in such stochastic environment. The simulation-based model will offer a tool for the decision makers to examine different scenarios for the given variables of the system. This will enable them to envisage the impact of the decisions on patient throughput time and resource utilization. The interpretations of the model output also allow the decision makers to gain new insights into the complexity of the interrelated variables and the effect of changes on the overall performance of the ED units. This research is a continuity of research work published in WSC 2012 [16]. Their work contributed to the simulation application in healthcare services with particular interest in ED in Irish hospitals [17]. This paper presents a simulation-based solution to develop effective strategies to reallocate an existing ED to a new ED in one of the largest hospitals in Dublin. The impact of the additional capacity on patient experience time will be assessed prior to opening the ED to the public. The main objective is to evaluate the effectiveness of the new capacities and accordingly optimize nursing staff to cope with the increased demand of care.

Section II gives an overview of the project's background, highlighting the nature of the partner hospital. Section III describes the suggested scenarios proposed by the ED management. Section IV presents and discusses results from the different scenarios used and applied. Section V concludes the paper, presenting the best proposed scenario to decrease the PET.

## II. PROJECT BACKGROUND

Mater University hospital in Dublin is an acute care public hospital in North Dublin. It provides a variety of healthcare services and has a total of 570 beds on premises, with a 24-hour ED that receives over 55,000 patients annually. The current ED of the hospital has 13 monitored trolley spaces, 3 of which are in a resuscitation area and are reserved for major trauma and critical care patients; an ambulatory care area (capacity 6 trolley spaces); two isolation rooms; a psychiatric assessment room; two rapid assessment triage bays; and two other triage rooms. The layout of the ED is shown in Figure 1, provided by the ED management.

Five distinct areas can be identified: a waiting room for walk-in patients waiting for triage, a diagnostics area (X-ray and CT scan), an ambulatory care unit (ACU) area, an ED resuscitation area (CPR), and an ED major assessment area. Patients arriving by ambulance – usually in critical condition – are routed directly to the resuscitation area, whereas patients whose conditions require monitoring stay in the major assessment area. The ambulatory care area is for walk-in patients, who may be suffering from abdominal pain, headache, limb problems, wounds, head injuries, and facial

problems. As a 24-hours department, the ED has three consultants, two nursing managers, and eleven nurses during the day and nine nurses at night, divided into six types of nurse: Advanced Nurse Practitioners (ANPs), triage nurses, resuscitation nurses, respiratory nurses, majors/minors nurses, and health-care assistants. Physicians (excluding the three consultants who provide cover between 9 am and 5 pm (or 8 am and 8 pm) with 24/7 on-call provision) are divided into three types, registrar/specialist registrars; Senior House Officers (SHOs), and interns, and are distributed as follows when the roster allows: three registrars per day working 10-h shifts starting at 8am, 12pm and 10pm; two interns working daily 8 am – 5 pm shifts Monday to Friday; and 12 SHOs working fixed shifts during the day and night to keep the ED running.

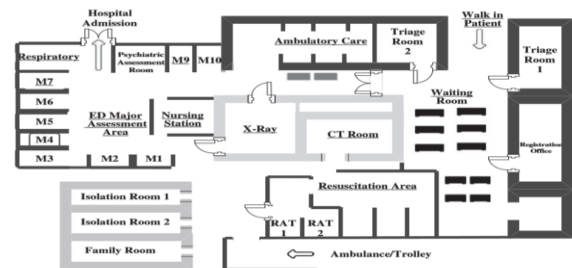


Figure 2 ED physical layout and main care areas.

Figure 1. ED physical layout and main care areas

According to the task force report in 2007 [18], the overall physical space of the ED and infrastructure were inadequate. The hospital – which was operating at approximately 99% occupancy – had difficulty in accommodating the increasing flows in ED admission numbers. Therefore, patients who required critical care (ICU/HDC) beds suffered from significant delays and the ED could not meet the national target of 6 hours average Length Of Stay (LOS) for patients. The ED figures showed a clear evidence of overcrowding with an average of 17% of its patients choosing to leave before being seen by the ED clinician. The report also indicated that the average time from ED registration to discharge was 9.16 hours, that is 3.16 hours over the 6 hours metric set by the HSE, and the average LOS from registration to acute admission was 21.3 hours with a standard deviation of 17.2 hours (i.e., 3.5 times higher than the same national metric). Obviously, patients who are admitted will usually experience longer LOS times than those who are discharged due to delays between admission referral by an ED doctor, the allocation of a bed, and time taken to transfer the patient to the bed.

To cope with these challenges, a simulation-based framework was developed by Abo-Hamad and Arisha [16], using ExtendSim v.8 [19], aiming to identify performance bottlenecks and explore improvement strategies to meet the HSE targets. To reduce the time of the model development cycle and to increase the confidence of the ED simulation model results, verification and validation were carried out throughout the development phases of the model. Furthermore, each model development phase was verified and validated against the previously completed phases. The final results of the simulation model were validated using

face validation and comparison testing. Face validation was performed by interviewing ED senior managers and nursing staff to validate the final results of the simulation model. Comparison testing involved comparing the output of the simulation model with the real output of the system under identical input conditions. According to the ED managers, the goal was to assess the performance of the ED if the average LOS of patients complies with the HSE 6 hours target. Therefore the framework was developed and used to assess the implications of a number of strategies. These strategies were the impact of variation in medical staffing, increasing clinical assessment space and finally assessing the impact of incorporating a 'zero-tolerance' policy regarding exceeding the national 6 hours LOS. The importance of this assumption was emphasized by the senior hospital decision makers to identify the real factors that contribute the unacceptable overcrowding status of the current ED; inappropriate physical space, insufficient staffing levels, or operational difficulties beyond the direct control of the ED. By using the model, the ED managers were able to reveal that enforcement of the national benchmark of 6-hour limit for EDs would have a significantly greater impact on reducing average LOS for all ED patients than increasing medical staff or assessment cubicles. Access block therefore, has been shown by the model to have the highest impact on prolonged average LOS for patients. Based on these recommendations, the ED management proposed the introduction of a new unit called Acute Medical Unit (AMU) that is co-located with the ED.

Meanwhile, a new campus for the hospital was completed. The hospital development was a €284 million redevelopment including 55,000m<sup>2</sup> of new acute hospital services including a new Emergency Department, Outpatients Department, GI unit, 12 new operating theatres, ICU and HDU, Radiology Department and 134 single ensuite bedrooms. However, the new campus planners and senior hospital management wanted to model the relocation of the present ED to the new ED. The purpose is to assess the capacity of the new ED before opening to the public and to check whether the new capacities will cope with the demand of care or other strategies will be required. The assessment of the impact of these changes will be discussed in the next sections.

### III. STRATEGY ASSESSMENT

Three strategies were proposed by the ED management to be assessed by the proposed model. The first is the new changes of the ED layout. The objective of these changes was to provide better patient flow and more space to avoid overcrowding and allowing the management team to increase the number of beds in each medical assessment area (Table I).

The second scenario suggests that the hospital opens an AMU. The unit will be divided into two units; an acute medical assessment unit (AMAU) that opens from 8am to 8pm and a Short Stay Unit (SSU). The purpose of the AMAU is to facilitate the immediate medical assessment, diagnosis and treatment of medical patients who suffer from

a wide range of medical conditions who present to, or from within, a hospital requiring urgent or emergency care. The required patients can be admitted to the SSU for a short period for acute treatment and/or observation where the estimated length of stay is less than 48 hours. The logic behind limiting the working hours in the AMAU to only 12-hours is to allow enough time for patients to be admitted to the hospital and make sure that this new pool of beds will always be available at the beginning of the next day. The unit will act then as a gateway between the ED and the wards of the hospital, and it will help increasing the throughput of the ED to achieve the national target of 6 hours.

TABLE I. CAPACITIES OF ED BEFORE AND AFTER CHANGING THE LAYOUT

Area	Current ED	New ED
CPR Area	03	05
ACU Area	10	15
ED Majors Area	06	11
<b>Total</b>	<b>19</b>	<b>31</b>

The third strategy scenario is related to the optimization of the staff levels with particular interest in nursing team due to the burn-out factor in two areas in the ED: Resuscitation Area and Majors Area. The ED managers were concerned that the nurses will be well over utilized due to the increase in the ED physical capacity. Therefore an optimization experiments were conducted to find the best combination of nurses for each shift which will enable the hospital to achieve the national 6-hour target without exceeding the threshold of staff burn-out. Flexibility in resource allocation and optimization of workload is a matter of urgency to the ED management team [10].

In summary, the strategy scenarios will model the impact of variation of layout, increasing the capacity in each assessment area, namely, CPR, majors area, and ACU area, open AMAU & SSU to avoid access blockage of patients to the 'upstream' hospital beds, and finally assessing the impact of optimizing the nursing staff level in each shift (Table II).

TABLE II. SIMULATION VARIABLES FOR BASE SCENARIO AND SCENARIOS 1, 2, AND 3

	Change Layout	CPR	Majors	ACU
<b>Base line</b>	No	3	10	6
<b>Sc. 1</b>	Yes	5	15	11
<b>Sc. 2</b>	Yes	5	15	11
<b>Sc. 3</b>	Yes	5	15	11
	Open AMU	Nurse - Day	Nurse - Night	
<b>Baseline</b>	No	6	4	
<b>Sc. 1</b>	No	6	4	
<b>Sc. 2</b>	Yes	6	4	
<b>Sc. 3</b>	Yes	6 - 11	4 - 9	

#### IV. RESULTS ANALYSIS

The first investigated scenario is to change the layout of the ED and increase the capacities of the three main assessment areas, and investigate the effect of that change on PET. Increasing the physical space by 65% (i.e., scenario 1) will decrease the number of patients in the waiting room, though the number of admitted patients will increase. The effect will be cascaded back through the ED progressively with more patients waiting on trolleys to be admitted to the hospital. Consequently the PET will increase for patients who are waiting to be admitted to the hospital (Table III). As a result, there will be no space left to meet the timely needs of the next patients who need emergency care.

TABLE III. COMPARISON BETWEEN SIMULATION RESULTS OF CURRENT ED AND NEW ED

Performance Indicators	Current ED	New ED
PET-Admitted (hours)	20.9	23.4
PET-Discharged (hours)	10.0	10.3
No. patients in waiting room	16.5	04.8

To prevent access blockage of patients who are required to be admitted to the hospital, the introduction of the acute medical assessment unit was the second suggested scenario. The question was how many beds are needed to unlock the access blockage, given the current demand of care. The unit was modeled as an additional assessment unit that deals with a wide variety of medical patients that present to the ED. A number of experiments were designed determine the optimal number of beds needed for the unit, as shown in Table IV.

TABLE IV. SIMULATION OUTPUT FOR DIFFERENT BED SETTINGS OF THE AMU

Performance Indicators	Number of beds in AMU				
	22	23	24	25	26
PET-Admitted (hours)	17.15	14.34	12.49	11.81	11.22
PET-Discharged (hours)	11.85	11.73	11.91	12.21	12.08
% Patients Treated	90%	91%	92%	93%	94%
No. patients in waiting room	17.30	16.40	15.80	14.30	16.30
No. patients waiting to be admitted	06.23	03.65	01.82	01.05	00.52

The capacity of the 25 beds was agreed to be divided between the two new units, namely AMAU and SSU, with 12 beds being assigned to the AMAU and 13 beds to the SSU. After that, the management decided to increase the capacity of the SSU with 6 more beds, leading to 19 beds overall in the SSU. Arguably, it was justified that the increase in the number of beds in the short stay unit was due to the utilization of the SSU in comparison to the AMAU. Integrating the new factors into the simulation model developed has showed that the national 6 hours admission target is still not met. However, the introduction of this intervention has provided a new decline in the PET (Table V).

ED Management demonstrated interests in the optimization of resources – with a particular emphasis on nurses. The question is “How many nurses should be availed

in every shift to achieve the national target of 6-hours)?”. The management team also emphasized on the importance of avoiding the burn-out of nurses due to long working hours. A full factorial design of experiment was constructed based on an orthogonal array (L36) [20]. Thirty six experiments were carried out with different levels of nursing staff, varying between 6-11 nurses during the day and 4-9 nurses during the night shift. The L36 design allows for testing the two factors at each of their levels to analyze their impact on the responses (i.e., outputs), namely the PET-All, PET-Admitted, PET-discharged and the utilization of the nurses, as recommended by the managers for each experiment. Table VII shows the impact of different levels of nursing staff for each shift on the performance indicators and on the nurses utilization.

TABLE V. COMPARISON BETWEEN SIMULATION RESULTS OF CURRENT ED WITH AMU AND NEW ED WITH AMU

Performance Indicators	Current ED + AMU	New ED + AMU
PET-All (hours)	09.85	6.52
PET-Admitted (hours)	13.91	6.88
PET-Discharged (hours)	07.66	6.31

Sensitivity analysis of number of nurses in each shift and different performance indicators (Figure 3) demonstrated that assigning 9 nurses on the day shift and 7 nurses on the night shift will improve performance. This resource schedule along with other recommendation can easily help the hospital to achieve the national target while maintaining the utilization level of the nurses at 80% (less than burn-out level) [10].

The results of the simulation model showed that the adoption of scenario 3 has the greatest impact on the patient experience time in the ED as shown in Figure 4. The recommendations of scenario 3 are changing the layout of the ED along with increasing the capacity of the assessment areas by 65%, open an AMAU and SSU units with 12 and 19 assessment areas respectively, and change the number of nurses on floor to 9 nurses during the day and 7 nurses at night. Scenarios 1 and 2 both showed a significant improvement from the baseline scenario, with patient experience times decreasing substantially, yet both failed to achieve the national target of less than 6 hour for the experience time of patients.

For verification of the simulation results, an overall confidence of interval of the simulation output was obtained with at least 95% confidence level that all KPIs lie in the dimensional box defined by the confidence intervals. Ten replicas of each scenario was generated to obtain the results of the confidence intervals for each KPI (Table VI).

To avoid the inflated error rate that resulted from using separate confidence intervals, a joint confidence region was constructed, based on Hotelling's  $T^2$  distribution, which is a generalization of the univariate t-distribution [21]. The three KPIs were chosen for calculating the  $T^2$  value, namely, the PET-All, PET-Admitted, and the PET-Discharged. The confidence regions were calculated for each of the three

scenarios. For simplicity, Figure 2 shows confidence regions between each pair of the three main KPIs of the ED along with their individual confidence intervals.

TABLE VI. SIMULTANEOUS CONFIDENCE INTERVALS

	Simultaneous CIs (t = 4.0947)					
	New ED		New ED + AMU		New ED + AMU + Staff Opt.	
	LB	UB	LB	UB	LB	UB
PET-All	6.6	8.9	5.7	7.6	4.1	6.1
PET-Admitted	6.8	9.4	6.3	8.3	4.5	6.7
PET-Discharged	6.4	8.5	5.4	7.2	3.9	5.7

The following figures compare the confidence region of each pair of the performance indicators, namely the PET of all patients; PET of admitted patients and PET of discharged patients across the three scenarios. The confidence region on the upper left corner of each graph represents the region formed by the two indicators under the first scenario, i.e., changing the layout of the ED and increase the capacity of the three assessment areas by 65%. While the region formed in the center of each graph shows the confidence region of each pair of indicators for the second scenario. Finally the lower right corner of each graph is the confidence region for the third scenario; that combines the first and second scenarios with optimum number of nurses. Figure 2 shows that increasing the capacity of the ED will not solve the overcrowding problem unless other interventions are introduced. Thus, finding the appropriate staffing levels is a key to cope with such increase in capacity along with the incorporation of a block-free unit (i.e., AMU)

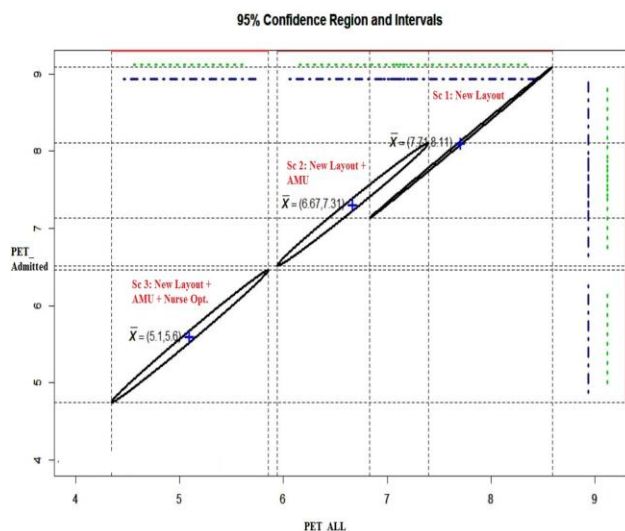


Figure 2. a. Confidence regions between PET of all patients, and PET of admitted patients for three scenarios

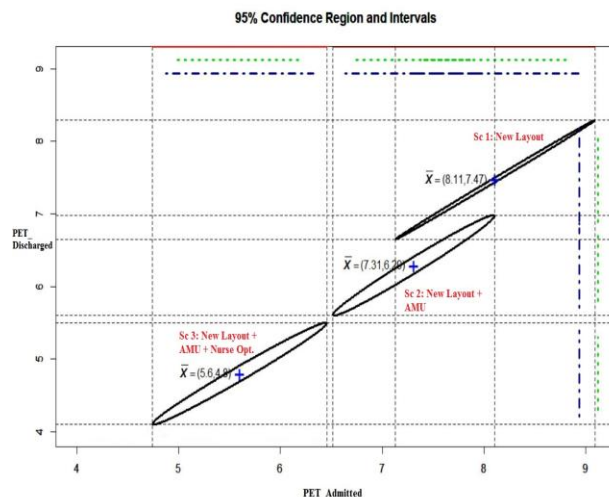
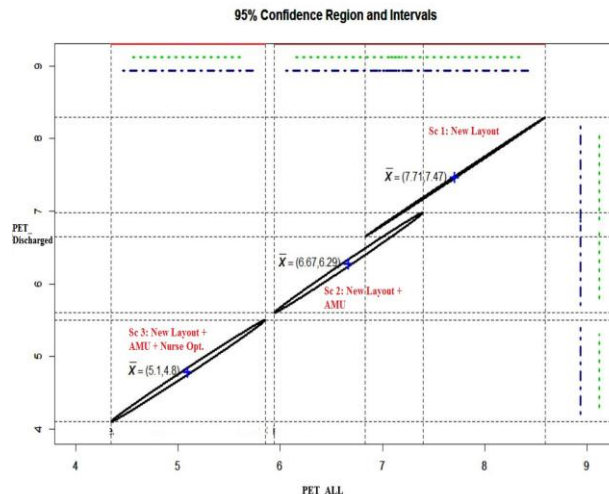


Figure 2. b. Confidence regions between PET of all patients, PET of admitted patients and PET of discharged patients for three scenarios

### V. CONCLUSION

The increased demand for ED services in Irish Hospitals puts an immense pressure on healthcare systems to meet patients' expectations. It is evident that increasing one or two particular resources (e.g., layout) will not be adequate to significantly improve the patient experience time in the ED. The delays that the patients experience is strongly related to bed access 'upstream' in the hospital, thus whether a bed is available for the patient to be admitted or not is one of the main factors influencing the patient throughput. This paper presented a simulation-based solution that is used to develop effective strategies to reallocate the present ED to the new ED for Mater hospital in Dublin.

The business model of the present ED was projected into the layout of the new ED to assess the impact of the additional capacity on patient experience time. These changes were investigated before opening the ED to the public to check whether the new capacities will cope with the demand of care or other strategies will be required. The first

intervention was the changes in the layout of the ED from 19 to 31 assessment areas that were proposed to enhance the patient flow. The simulation model showed that the new capacity will not reduce patient experience time. However, it will help to decrease the number of patients in the waiting room, though the number of admitted patients will increase. The second intervention that was assessed is the introduction of an acute medical unit (AMU) with access to a minimum of 25 assessment areas. This intervention was recommended based on previous research on the present ED. The unit is to be collocated with the ED and should have limited working hours allowing the pool of assessment areas to be vacant for the next following day. This unit contributed significantly in addressing the problem of upstream bed blockage in the hospital, leading to more than 50% reduction of the total patient experience time in the ED. Also, combining these interventions together led to more than 70% reduction in the total patient experience time. Finally the third scenario is to optimize the allocation of nurses in two areas of the ED: Resuscitation Area and Majors Area. The optimization process resulted into allocating 9 nurses in the day shift and 7 nurses in the night shift. Optimizing the resources in the ED will enhance the overall performance of the unit and also maintain the burn-out factor below 85%. The combination of these three interventions resulted in a significant reduction of PET from 21 hours to 6 hours and also to achieve 95% of patients to be seen by a doctor in less than 6 hours. ED management has engaged in the process of the solution and the confidence of the simulated results has increased significantly after the validation of the model.

Due to the flexibility and extensibility features of the framework, it provided the hospital management with a lower cost method to develop improvement strategies, test assumptions, and observe potential outcomes of decisions prior to implementation. The confidence level of the project output encouraged the HSE to adopt the framework to design and plan the introduction of the AMU in every hospital across the country. A pilot study has been initiated for the largest six hospitals in Dublin, which will be implemented at a later stage national wide.

#### REFERENCES

- [1] L. F. McCaig and C. W. Burt, "National Hospital Ambulatory Medical Care Survey: 2002 emergency department summary.," *Adv. Data*, no. 340, pp. 1–34, Mar. 2004.
- [2] E. J. Carter, S. M. Pouch, and E. L. Larson, "The relationship between emergency department crowding and patient outcomes: a systematic review.," *J. Nurs. Scholarsh.*, vol. 46, no. 2, pp. 106–115, Mar. 2014.
- [3] J. H. Han, D. J. France, S. R. Levin, I. D. Jones, A. B. Storrow, and D. Aronsky, "The effect of physician triage on emergency department length of stay.," *J. Emerg. Med.*, vol. 39, no. 2, pp. 227–33, Aug. 2010.
- [4] A. Joshi and M. Rys, "Study on the Effect of Different Arrival Patterns on an Emergency Department's Capacity Using Discrete Event Simulation.," *Int. J. Ind. Eng. 2011*, vol. 18, no. 1, pp. 266–275, 2011.
- [5] HSE, "Health Service Executive National Service Plan," 2007.
- [6] HSE, "Health Service National Service Plan 2014 Our Service Priorities," 2014.
- [7] M. A. Centeno, R. Giachetti, R. Linn, and A. M. Ismail, "A simulation-ILP based tool for scheduling ER staff," in *Proceedings of the 2003 International Conference on Machine Learning and Cybernetics*, 2003, vol. 2, pp. 1930–1938.
- [8] D. Sinreich and Y. N. Marmor, "A Simple and Intuitive Simulation Tool for Analyzing the Performance of Emergency Departments.," in *Proceedings of the 2004 Winter Simulation Conference, 2004.*, 2004, vol. 2, pp. 908–916.
- [9] M. E. Matta and S. S. Patterson, "Evaluating multiple performance measures across several dimensions at a multi-facility outpatient center," *Health Care Manag. Sci.*, vol. 10, no. 2, pp. 173–194, May 2007.
- [10] M. Thorwarth, P. Harper, and A. Arisha, "Simulation Model to Investigate Flexible Workload Management for Healthcare and Servicescape Environment," in *Proceedings of the 2009 Winter Simulation Conference, 2009*, 2009, pp. 1946 – 1956.
- [11] 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*, 2010, pp. 2340–2351.
- [12] W. Abo-hamad and A. Arisha, "Towards Operations Excellence: Optimising Staff Scheduling For New Emergency Department," in *Proceedings of the 20th International Annual EurOMA Conference*, 2013, pp. 9–12.
- [13] O. Rado, B. Lupia, J. M. Y. Leung, Y.-H. Kuo, and C. A. Graham, "Using Simulation to Analyze Patient Flows in a Hospital Emergency Department in Hong Kong," in *Proceedings of the International Conference on Health Care Systems Engineering*, 2014, vol. 61, pp. 289–301.
- [14] E. Hamrock, K. Paige, J. Parks, J. Scheulen, and S. Levin, "Discrete event simulation for healthcare organizations: a tool for decision making.," *J. Healthc. Manag.*, vol. 58, no. 2, pp. 110–124, 2013.
- [15] M. Jahangirian, S. J. E. Taylor, and T. Young, "Economics of Modeling and Simulation: Reflections and Implications for Healthcare," in *Proceedings of the 2010 Winter Simulation Conference*, 2010, pp. 2283–2292.
- [16] W. Abo-Hamad and A. Arisha, "Multi-Criteria Framework for an Emergency Department in an Irish Hospital," in *Proceedings of the 2012 Winter Simulation Conference*, 2012, pp. 1–12.
- [17] W. Abo-Hamad and A. Arisha, "Multi-criteria approach using simulation-based balanced scorecard for supporting decisions in health-care facilities: an emergency department case study," *Heal. Syst.*, vol. 3, no. 1, pp. 43–59, Nov. 2014.
- [18] HSE, "Chapter 4 - Task Force findings and recommendations by hospital," 2007.
- [19] I. T. Inc., "ExtendSim Simulation Software," 2014. [Online]. Available: <https://www.extendsim.com>.
- [20] G. Taguchi, S. Chowdhury, and Y. Wu, "Orthogonal Arrays and Linear Graphs: Tools for Quality Engineering," in *Taguchi's Quality Engineering Handbook*, 2005, pp. 35–38.

[21] C. Alexopoulos, "Statistical analysis of simulation output: state of the art," in *Proceedings of the 2007 Winter*

*Simulation Conference*, 2007, vol. 100, pp. 150–161.

TABLE VII. RESULTS OF DOE FOR NURSE ALLOCATION IN DAY AND NIGHT SHIFTS

No.	Nurse-Day	Nurse-Night	PET-All	PET-Ad.	PET-Dis.	Utilization
1	6	4	7.8	8.4	7.4	100%
2	7	4	6.8	7.5	6.4	100%
3	8	4	6.5	7.2	6.1	98%
4	9	4	6.5	7.1	6.1	93%
5	10	4	6.2	6.8	5.9	88%
6	11	4	6.3	6.8	6.0	83%
7	6	5	6.5	7.2	6.1	100%
8	7	5	5.8	6.3	5.5	100%
9	8	5	5.7	6.3	5.3	94%
10	9	5	5.4	5.9	5.1	89%
11	10	5	5.6	6.3	5.2	84%
12	11	5	5.5	6.1	5.1	79%
13	6	6	6.0	6.5	5.6	100%
14	7	6	5.5	6.1	5.2	95%
15	8	6	5.2	5.6	4.9	90%
16	9	6	5.3	5.8	4.9	84%
17	10	6	5.0	5.4	4.8	80%
18	11	6	5.1	5.6	4.9	77%

No.	Nurse-Day	Nurse-Night	PET-All	PET-Ad.	PET-Dis.	Utilization
19	6	7	5.7	6.2	5.4	96%
20	7	7	5.3	5.7	5.0	90%
21	8	7	5.1	5.5	4.8	85%
22	9	7	5.1	5.6	4.8	81%
23	10	7	5.2	5.8	4.8	77%
24	11	7	5.1	5.5	4.8	74%
25	6	8	5.6	6.1	5.3	91%
26	7	8	5.2	5.8	4.9	86%
27	8	8	5.3	5.8	4.9	82%
28	9	8	4.9	5.3	4.7	78%
29	10	8	5.1	5.7	4.8	74%
30	11	8	4.9	5.3	4.7	71%
31	6	9	5.7	6.2	5.3	87%
32	7	9	5.3	5.8	4.9	82%
33	8	9	5.1	5.6	4.8	78%
34	9	9	5.0	5.4	4.7	75%
35	10	9	5.0	5.5	4.7	71%
36	11	9	5.1	5.6	4.7	69%

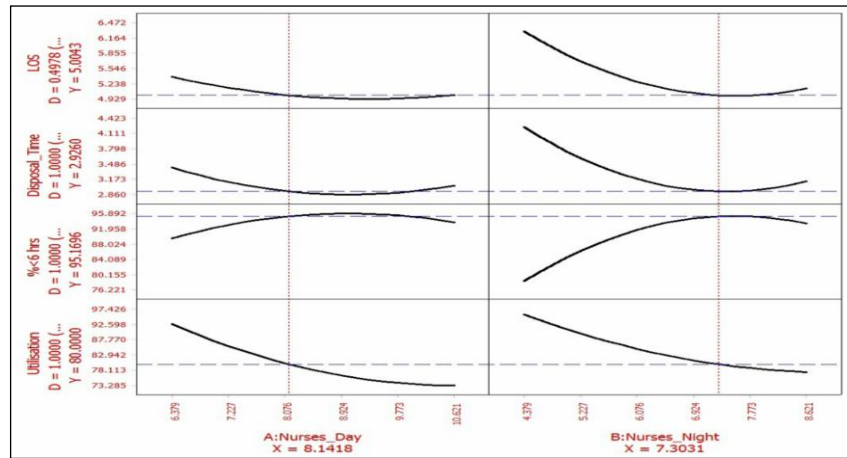


Figure 3. Sensitivity analysis of number of nurses in each shift against performance indicators

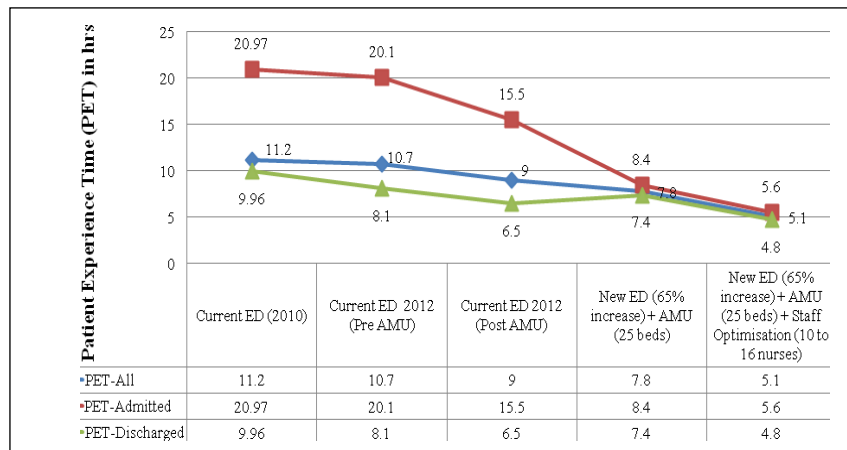


Figure 4. Comparison of simulation results of different scenarios