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MULTI-CRITERIA FRAMEWORK FOR EMERGENCY DEPARTMENT IN IRISH HOSPITAL

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ABSTRACT

Health research is one of these priorities in every economy and through this research an emphasis will be put on translational research in the context of more sustainable and efficient healthcare system (translation of operations management practices to clinical applications). Healthcare systems in general and Emergency Departments in particular around the world are facing enormous challenges in meeting the increasingly conflicting objectives of providing wide accessibility and efficiency while delivering high quality and prompt services. The proposed framework integrates simulation modeling, balanced scorecard, and multi-criteria decision analysis aiming to provide a decision support system to emergency department managers. Simulation outputs are aggregated using analytic hierarchy process (AHP) to provide marginal performance regarding the achievement of the defined strategic as well as tactical and operational objectives. Communicating the significance of investigated strategies has encouraged managers to implement the framework recommendations in the emergency department within the hospital partner.

1 INTRODUCTION

Healthcare managers are constantly under pressure to control rapidly escalating expenses whilst simultaneously fulfilling the growing demand for healthcare services. As a result, they are continuously studying the efficiency of existing healthcare systems and exploring improvement opportunities. The evaluation of these proposed interventions is crucial prior to their actual implementation, though challenged by intrinsic uncertainty of demands and outcomes of healthcare systems; high level of human involvement at both patient's level and resource level; limited budget and resources; and large number of variables. Patients, on the other hand, are understandably no longer prepared to wait in queues for essential health services. Accordingly, the healthcare service concept has shifted from optimizing resources to finding a balance between service for patients and efficiency for providers (Brailsford and Vissers 2011). Dealing with these inevitable complexities within healthcare processes and services and addressing the challenges in the decision making process is the focus of this paper.

Efforts to develop simulation models have been advancing since the late 1980s when the impact of key resources on waiting times and throughput of patients was investigated by simulation modeling (Saunders et al. 1989). Since that time, simulation models have been used to study the effect of a wide range of health interventions on healthcare processes' performance (Dittus et al. 1996, Ingolfsson et al. 2003, Kim et al. 1999, Litvak et al. 2008). Recently, applications for operational decision support are widespread and have become increasingly significant (Eldabi et al. 2006). For example, simulation has been used to analyze the effect of the physical expansion of emergency departments (ED) on patient stay times (Samaha et al. 2003) and to study the impact of different patient triage methods on service times (Connelly and Bair 2004). Moreover, the effect of staffing levels was investigated by Sinreich and Jabali (2007) to reduce patient's length of stay (LOS) and by Ahmed and Alkhamis (2009) to determine the optimal number of required staff. Additionally, the impact of staff scheduling on overall utilization and burnout issues related to over-utilized staff was examined by Thorwarth et al. (2009). However, aforementioned studies only consider a small number of key performance indicators (KPIs) such as

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waiting time and LOS, while other performance measures such as resource utilization, productivity, and layout efficiency are rarely considered. Moreover, linking these KPIs to the international standard and national metrics is mostly neglected. On the other hand, the balanced scorecard (BSC), pioneered by Kaplan and Norton (1992), is a systematic methodology that uses strategy-linked leading and lagging performance measures and actions for planning and implementing an organization's strategy (Kaplan and Norton 2001). With many successful implementations at different organizations, BSC is considered as a popular model and effective means for performance management and strategy execution. Furthermore, the BSC concept has been modified and successfully developed at different types of healthcare organizations (Zelman et al. 2003). Yet, the BSC performance measures are interacting among themselves simultaneously, influencing each other in a complex relationship network, often under conditions that involve randomness, and requires the observation and evaluation of numerous decision criteria. Therefore, a structured technique is needed for dealing with problems with multiple and complex criteria influencing decision making (Saaty 1990, Dyer et al. 1992, Liberatore and Nydick 2008).

The objective of this paper is to develop a simulation-based decision support framework to improve planning and efficiency of healthcare processes. A real-world case study of an emergency department in one of the largest university hospitals in Dublin is investigated in order to enhance patients' experience using the proposed framework.

2 PROPOSED METHODOLOGY

The key components of the integrated decision support framework for healthcare managers and planners to use in a practical and reflective way is presented in Figure 1.

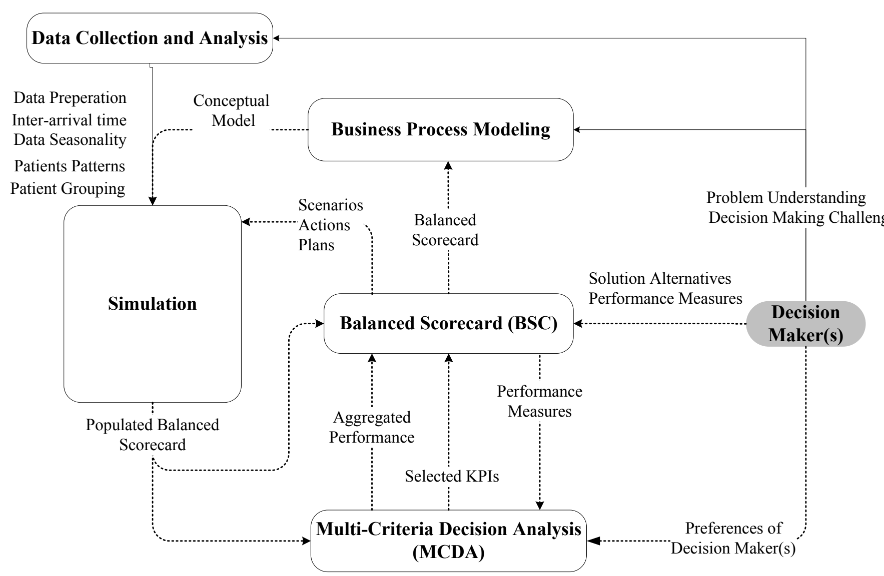


Figure 1: An overview of the integrated framework proposed

Though limitations of BSC, in terms of its measurement capabilities, can be resolved by its integration with simulation (Ismail et al. 2010), there are still challenges in the selection of the *key* performance measures. The selection of these measures is challenged by the split between different views about the KPIs. Furthermore, the number of performance indicators (i.e., criteria) delays the evaluation and analysis of the results. This is due to the fact that some of these criteria are of a conflicting nature and oppose each other. Multi-criteria decision analysis (MCDA) tools play a great role addressing these challenges. In the design phase of the BSC, MCDA methods can be applied for the selection of appropriate performance measures, where decision-makers can evaluate and prioritize competitive performance measures (i.e., multiple-criteria). The selected performance measures are represented in a *value tree* that represents the selected key performance indicators. Following the KPIs selection, the resulting value tree is passed to the simulation model in the form of balanced scorecard. Due to the large number of performance indicators in the populated BSC, MCDA can effectively aggregate the marginal performance of the indicators considering the preferences of the decision makers regarding the achievement of the defined strategic objective. This dual usage of MCDA within the integrated framework can contribute greatly in the decision making process and in making informed decisions for improving and managing healthcare business process.

3 FRAMEWORK IMPLEMENTATION

3.1 An Emergency Department – A Case study

The university hospital partner in this paper is one of the leading university hospitals in the Republic of Ireland. This 570-bed hospital provides secondary, specialized, and tertiary healthcare services, with a 24hr "on-call" ED which services over 55,000 patients annually. The department has officially, 13 monitored trolley spaces; 3 of these trolley spaces (resuscitation area) are reserved for major trauma and critical care patients. The ED also has an ambulatory care area with a capacity of six trolley spaces. Two triage rooms are also provided by the ED. Five distinct areas can be identified: a waiting room for walk-in patients waiting for triage, a diagnostics area (e.g. X-Ray), an ambulatory care unit area (ACU), a ED resuscitation area (CPR) and an ED major assessment area. Patients arrive by ambulance – usually in a critical condition – are routed directly to the resuscitation area, while patients who require their conditions to be monitored stay in the major assessment area. The ambulatory care area is for patients suffering from abdominal pain, headache, limb problems, wounds, head injuries, and facial problems (amongst all other ambulant patients).

As a 24hr department, the ED has eleven nurses during the day and nine nurses at night which collectively are divided into six types of nurses; Advanced Nurse Practitioner (ANP), triage nurse, resuscitation nurse, respiratory nurse, majors/minors nurse, and healthcare assistant. Physicians (excluding the 3 Consultants who provide shop floor cover between 9-5 or 8-8 with 24/7 on-call provision), referred to as non-consultant hospital doctors (NCHD), are divided into three types: registrar/specialist registrar (i.e., receiving advanced training in a specialist field of medicine in order eventually to become a consultant), Senior House Officer (SHO) (i.e., a junior doctor undergoing training within a certain speciality), and intern that are distributed as follows when the roster allows: three registrars per day with a 10hr shift starting at 8am, 12pm, and 10pm; two interns with a one shift per day from 8am to 5pm Monday to Friday; and overlapping shifts of SHOs during the day to make it possible to have more than one SHO at specific time (i.e. from 2 to 6 SHOs during the day).

According to the task force report in 2007 (HSE 2007), the overall ED physical space and infrastructure is inadequate. Additionally, the partner hospital is operating at approximately 99% occupancy, with resultant difficulty in accommodating surges in numbers of ED admissions. This is often aggravated by delays in patient transfer to critical care such as intensive care unit (ICU) beds. The ED figures show a clear evidence of overcrowding with an average of 17% of patients leaving the ED before being seen. Moreover, the average time from registration to discharge is 9.16 hrs with 2.58 hrs standard deviation, i.e. 3.16 hrs over the 6hrs nation target set by health service executive (HSE) in Ireland. Also, the average time from registration to acute admission is 21.3 hrs with a standard deviation of 17.2 hrs, which is 15.3 hrs above the national metric. Obviously, patients to be admitted usually experience a longer LOS than discharged patients due to the delays which can occur between admission referral by an ED doctor, bed allocation, and patient transfer from ED to the allocated bed. Therefore, the introduction of the proposed framework has the potential to model and manage the aforementioned complexities in a cost neutral, safe and controlled environment, without the need to implement risky and potentially costly change prematurely in real systems.

3.2 Process Mapping

Upon arrival at the ED and registration, walk-in patients (self-referral or general practitioner (GP) referral) remain in the waiting area to be triaged. When a patients name is called, depending on triage staff availability, the patient is assessed by a triage nurse. Based on the patient's condition and triage assessment, each patient is assigned a clinical priority (triage category) according to the Manchester Triage System (MTS) that is widely used in UK, Europe, and Australia (Cronin 2003). The MTS uses a five level scale for classifying patients according to their care requirements; immediate, very urgent, urgent, standard, and non-urgent. Once a triage category is assigned, the patient may be sent back to the waiting room until a bed or trolley is available in an appropriate treatment area, based on the type and intensity of their care requirements. The patients waiting time depends on the triage category of patient and the availability of both medical staff (i.e. ED physician or advanced nurse practitioner (ANP)) and empty trolleys, which are a prerequisite for a complete and accurate assessment. Following the patients assessment by ED clinician, a decision is made: either the patient is to be discharged or admitted to the hospital. Figure 2 shows a detailed flowchart for patient journey through the ED.

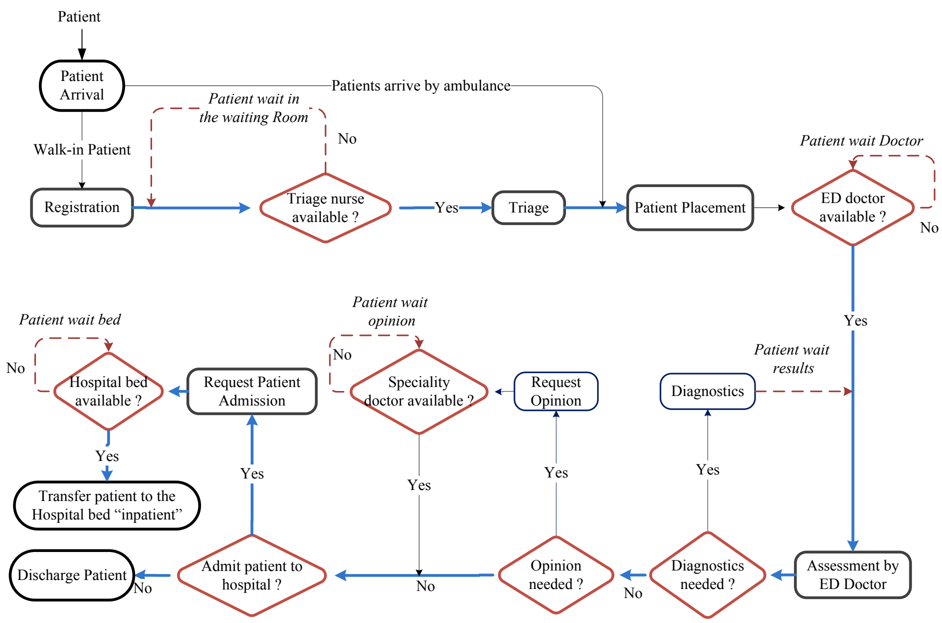


Figure 2: Detailed patient flow through the ED

3.3 Balanced Scorecard

The outcomes of the interviews, focus groups, and quality circles include the agreement on four performance perspectives that formed the ED balanced scorecard: internal ED business processes, learning and growth, patient, and community engagement perspectives (Figure 3). The main objective in the internal *ED business processes perspective* is to improve the ED performance which is driven by layout efficiency, patient throughput, ED productivity, and resources utilization. The HSE performance targets and the national emergency medicine program (EMP) are considered in the *community engagement perspective*. The performance target of the HSE is that all patients are processed through the ED in 6 hours or less from time of arrival to time of separation (including admission for designated cases). The overarching aim of the EMP is to improve the safety and quality of patient care in EDs and to reduce waiting times for patients.

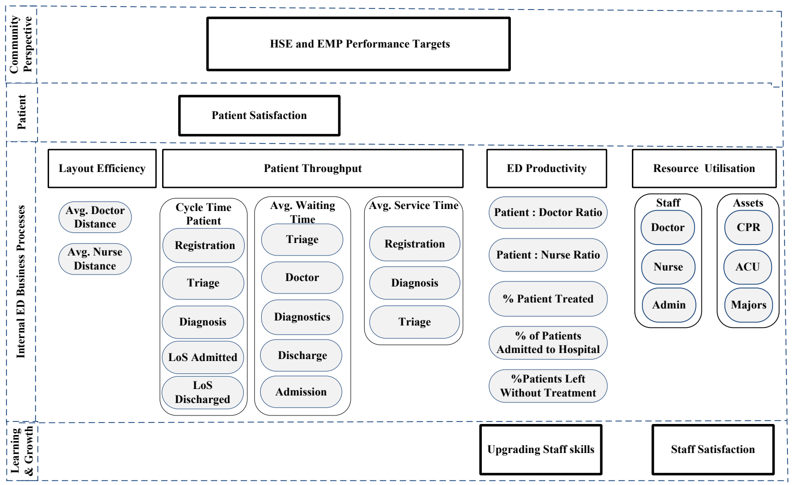


Figure 3: The emergency department balanced scorecard

Due to the critical role of healthcare professionals, two main performance measures are selected in the *learning and growth perspective*: staff development and staff satisfaction levels. In designing the ED BSC, "*patient*" was selected as a sole perspective and "patient satisfaction" as the main measure for this perspective. The efficiency of internal ED processes impacts the patient satisfaction level, therefore patient average waiting time and patient average length of stay are connected to the patient satisfaction performance measure.

3.4 Emergency Department Simulation Model

Historical patients' records for the ED information system were provided by hospital managers during a 16-month period with a total of 59,986 anonymous patient records. Each patient record describes the following patient-level variables: (1) triage category assigned to patient, (2) patient presenting medical complaint, (3) mode of patient arrival, (4) patient attend date/time, (5) patient triage date/time, (6) date/time patient seen by doctor, and (7) whether the patient left without seen, discharged, or admitted to the hospital. Table 1 shows the grouping of patients subject to their triage category.

Table 1: Input settings for different control parameters

Triage Category	% of Patients	Mode of Arrival	
		Walk-in	Ambulance
1	1.1 %	5 %	95 %
2	16.5 %	40 %	60 %
3	58 %	61 %	39 %
4	23.9 %	81 %	19 %
5	0.5 %	72 %	28 %

For each patient group, an estimation of patient arrival distribution is used to replicate the arrival pattern in the simulation model. From the simulation perspective, the inter-arrival data is required, not the arrival time, which describe the time delay between two consecutive patient arrivals. To do so, the difference between the arrival times of patients was obtained for each group. These inter-arrival times were then grouped into time slots where the relative frequency (i.e., percentage) of each time slot was accumulated and represented in a histogram. This was followed by the determination of a fitted distribution for each inter-arrival histogram. Based on the ED business process model, the designed BSC, and the empirical data analysis, a comprehensive simulation model for the ED was developed. Modules of the simulation model were assigned to represent different activities in the ED. A database was built to save the measured KPIs after each simulation run (i.e., replicate), followed by exporting the populated BSC in a tabular form for future analysis and validation.

To reduce the model development cycle time and to increase the confidence in the simulation model results, the verification and validation were carried out all the way through the development phases of the ED simulation mode. After each model development phase, the model was verified and validated with respect to other previously completed phases. For the verification process, the model logic is verified to ensure that patients follow the correct care path as expected. This was completed by visual tracking of patients using animation option and also by checking intermediate output values such as queue lengths and waiting times between processes. The conceptual model had been documented and validated by circulating the document among ED senior managers and senior nursing staff. All distributions determined from the data and used in the model were validated by using Kolmogorov Smirnov goodness of fit test with a 5% significance level (Massey 1951). The final results of the simulation model have been validated using two techniques; face validation and comparison testing. Face validation is performed by interviewing ED senior managers and nursing staff in order to validate the final results of the simulation model. The second approach was 'Comparison Testing' by comparing the output of the simulation model with the real output of the system under identical input conditions (Balci 1997).

4 REAL-TIME STRATEGIES FOR THE EMERGENCY DEPARTMENT

4.1 Key Performance Indicators Selection

The balanced scorecard developed in the previous section for the ED includes qualitative as well as quantitative measures. Examples of qualitative measures are the patient satisfaction, staff skills upgrading and staff satisfaction. These measures cannot be measured directly in the simulation model. However, these measures are directly related to the performance measures in the "Internal Business Processes" perspective, which are of a quantitative nature and can be directly measured using simulation. Nevertheless, there is redundancy among performance measures in that perspective (i.e., internal ED business process perspective). Moreover, some of the ED measures are of a conflicting nature such as staff utilization and staff satisfaction. Consequently, to narrow down the list of the measures and to achieve the trade-off between conflicting objectives, MCDA tools are used to systematically select the main KPIs. The selection process is based on the simple multi-attribute rating technique (SMART) (Edwards and Barron 1994) to identify the measures and criteria, which are relevant to the decision problem. SMART begins with identifying the alternatives performance measures, and specifying the criteria to be used for evaluating these measures. The SMART procedure is applied to the performance measures in the "Internal ED business processes" perspective; this is because these measures are interrelated with other performance perspectives and measures, such as patient and staff satisfaction indicators.

Consequently, the 26 performance measures within this perspective are considered the "decision alternatives" for the SMART procedure. Performance measures are then evaluated against the main drivers of the ED performance, namely, layout efficiency, patient throughput, ED productivity, and resource utilization. Within the SMART procedure, criteria are corresponding to these four performance dimensions. Once the criteria and decision alternatives were identified, a value tree was produced as shown in Figure 4a. The root of the tree represents the ED performance, the first level represents the evaluation criteria and finally the second level represents the candidate performance measures.

The ED managers (three consultants) have been asked to rank the measures against each criterion from most preferred to least preferred (i.e., from best to worst). The degree of agreement among the ED consultants was very high indicating a high level of consistency or inter-rater reliability (Gwet 2008). For each criterion, the ED managers assign a value of 100 for the most relevant measure, while a value of 0 is assigned to the least relevant one, which is an easy scale for decision makers to use (Valiris et al. 2005). For example, the average distance travelled by doctors within the ED is the most relevant to the layout efficiency criterion while the average registration service time is the least relevant for the same criterion.

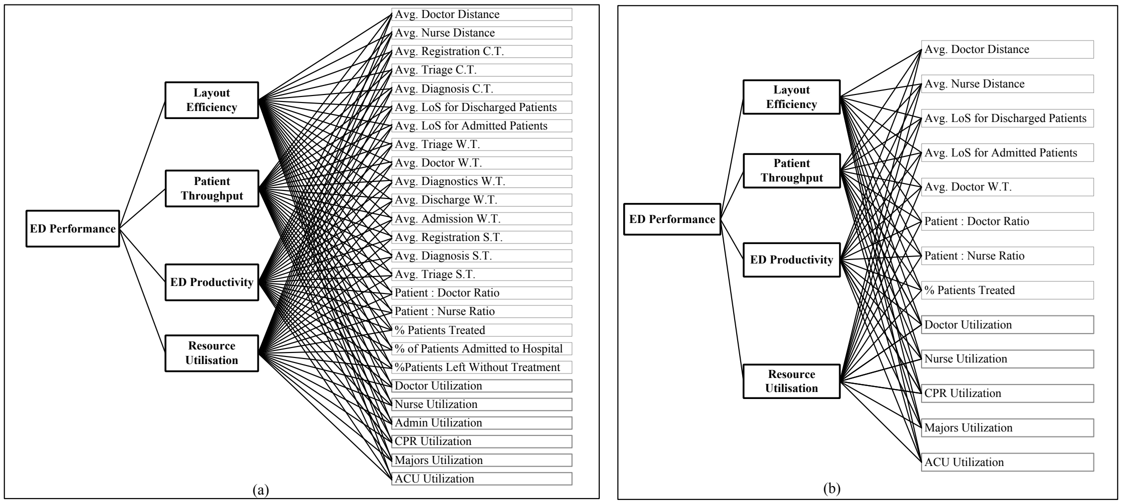


Figure 4: (a) Performance measures value tree, and (b) Selected Key Performance Indicators

The other set of remaining measures are then rated regarding the most relevant and the least relevant measures and assigned a value ranges from 0 to 100 by the ED manager. Because the evaluation criteria are not equally important, the relative importance of the criteria was ranked by the manager (Table 2a). The normalized weighting is calculated by dividing the value score by the total for all value scores i.e. for rank 1, 100/270 = 0.37. The total score for each alternative is then calculated as the weighted average of the value scores for all criteria for that alternative. For example, for "% of Patients Treated" measure see Table 2b.

Table 2: Performance Criteria Analysis

a- The relative importance of the evaluation criteria

Rank	Criterion	Value score	Normalized weighting
1	Patient Throughput	100	0.37
2	ED Productivity	80	0.29
3	Resource Utilization	60	0.22
4	Layout Efficiency	30	0.11

b- Aggregated weights and values for "% of Patients Treated" measure

Criterion	Value score	Criterion weight	Measure weight
Layout Efficiency	50	0.11	5.56
Patient Throughput	90	0.37	33.33
ED Productivity	100	0.29	29.63
Resource Utilization	80	0.22	17.78
Total			86.30

Table 3 summarizes the final weighted scores for all the measures (alternatives), where the rank of each measure is specified.

Table 3: The final score and rank of performance measure using SMART

Performance Measures	Total Score	Rank	Performance Measures	Total Score	Rank
Avg. Doctor Distance	70.37	8	Avg. Diagnosis S.T.	14.07	21
Avg. Nurse Distance	67.04	9	Avg. Triage S.T.	13.33	22
Avg. Registration C.T.	33.70	16	Patient to Doctor Ratio	80.74	3
Avg. Diagnosis C.T.	43.70	15	Patient to Nurse Ratio	77.78	5
Avg. Triage C.T.	30.37	17	% of Patients Treated	86.30	1
Avg. LoS for Discharged Patients	64.81	11	% of Patients Admitted	47.04	14
Avg. LoS for Admitted Patients	62.22	12	% of Patients Left Without Treatment	28.89	18
Avg. Triage W.T.	12.96	23	Doctor Utilization	82.59	2
Avg. Doctor W.T.	53.33	13	Nurse Utilization	80.37	4
Avg. Lab W.T.	6.30	26	Admin. Utilization	21.85	19
Avg. Admission W.T.	17.04	20	CPR Trolleys Utilization	75.19	7
Avg. Discharge W.T.	8.89	25	Majors Trolleys Utilization	76.30	6
Avg. Registration S.T.	11.11	24	ACU Trolleys Utilization	65.19	10

Finally, a threshold of 50 for the total score for the measures is set by the ED senior managers for the final set of KPIs (Figure 4b). KPIs are then passed to the simulation model where they are measured and presented as the simulation output.

4.2 Scenario Design

As recommended by the ED the management team, the simulation scenarios 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-hour LOS. Distinct study scenario variables (Table 4) were added to the simulation model and run for a 3 month continuous blocks. The three months was chosen for the stability of ED staffing levels offer this period, according to the ED managers.

Table 4: Simulation variables for base scenario and scenario 1, 2, and 3

	Decision Variables		
	Access Block	Physical capacity (number of trolleys)	physician shifts
Base Line	Yes	13	-
Scenario 1	Yes	19	-
Scenario 2	Yes	13	1 SHO [9pm to 7am]
Scenario 3	No	13	-

The principle variables introduced had increased clinical assessment capacity (extra 6 trolley cubicles), increased clinical assessors (1 Senior House Officer shift at night), and absolute compliance with the national 6 –hour admission target for ED boarders. These scenarios were suggested by the ED senior managers to evaluate the intended new extension of the hospital which will include rebuilding of key parts of the hospital including the ED. Expanding the capacity of the ED may eventually necessitate a corresponding increase in the staffing levels. Therefore, the hospital managers showed their interest to evaluate the impact of capacity expansion and increasing the staffing levels against the effect of unblocking the "access block" from the ED to the hospital.

4.3 Results Analysis

The results of the simulation model showed that adoption of the scenario 3, which is absolute enforcement of the national 6-hour admission target (Table 5) had the greatest impact on the patients average LOS (ALOS) at every stage of the patient journey through the ED, especially amongst patients who are ultimately discharged directly from ED care (48% improvement in avg. LOS).

Table 5: Simulation results of scenario 1, 2, and 3

Key Performance Indicators (KPIs)		Base Line	Capacity Expansion (Scenario 1)		Increasing Staff (Scenario 2)		Zero Tolerance (Scenario 3)	
			O/P	▲▼	O/P	▲▼	O/P	▲▼
Patient Throughput	A.W.T Doctor (hrs)	2.96	2.50	15%	2.80	5%	1.80	39%
	Avg. LOS Dis. Pts. (hrs)	10.23	8.40	18%	9.80	4%	5.30	48%
	Avg. LOS Adm. Pts. (hrs)	21.30	18.20	15%	19.80	7%	5.70	73%
Resource Utilization	Doctor Utilization	81%	84%	4%	73%	10%	86%	7%
	Nurse Utilization	82%	87%	7%	83%	1%	74%	10%
	CPR Utilization	91%	86%	6%	91%	0%	87%	5%
	Majors Utilization	94%	82%	13%	92%	2%	85%	10%
	ACU Utilization	93%	75%	19%	94%	2%	83%	11%
Layout Efficiency	Avg. Doctor Distance (km/d)	3.24	3.63	12%	2.83	13%	3.91	21%
	Avg. Nurse Distance (km/d)	6.48	7.32	13%	6.55	1%	5.34	18%
ED Productivity	Patient : Doctor Ratio	7.34	7.52	2%	7.14	3%	7.9	8%
	Patient : Nurse Ratio	9.84	10.22	4%	10.16	3%	10.8	10%
	% Patients Treated	83%	85%	2%	90%	8%	96%	16%

O/P: Simulation output ▲▼: Increase/decrease relative to the baseline scenario

Scenarios 1 and 2 resulted in minimal improvements and these changes were not clinically significant or palatable for patients. Scenario 3 reduced an over-reliance on overstretched nursing resources, whilst improving the utility of physicians as well as expected improving the LOS of boarders (i.e. patients waiting to be admitted). The more potentially expensive change Scenarios 1 and 2 had a negligible impact on ED boarding times.

Analytic hierarchy process (AHP) was then used to evaluate these scenarios considering the ED decision makers preferences. The AHP comparison matrix for the four main performance criteria of the ED and their corresponding weights are represented in Table 6. For simplicity, LE was given as an abbreviation for Layout Efficiency, PT for Patient Throughput, PR for ED Productivity and RU for Resource Utilization.

Table 6: Comparison of KPI Performances

a- The comparison matrix for the main KPIs in ED performance criteria

	LE	PT	PR	RU	Resulting AHP Weight
LE	1	0.125	0.167	0.25	0.046
PT	8	1	3	6	0.581
PR	6	0.33	1	3	0.285
RU	4	0.167	0.33	1	0.116

b- The comparison matrix for the KPIs of the Patient Throughput criterion

	ALOS Dis.	ALOS Ad.	A.W.T Doc.	AHP Weight
ALOS Dis.	1	0.33	4	0.304
ALOS Ad.	3	1	3	0.575
A.W.T Doc.	0.25	0.33	1	0.121

A comparison matrix for each criterion in Figure 4(b) was then constructed to obtain the weights of individual KPIs (i.e., the leaves of the performance value tree). Table 6a shows the comparison matrix for the three KPIs that represent the Patient Throughput criterion and their AHP weight. The same process of pair comparison among KPI's for each main criterion was repeated until the last level was reached. Figure 5 shows the final weights for all the levels in the performance value tree.

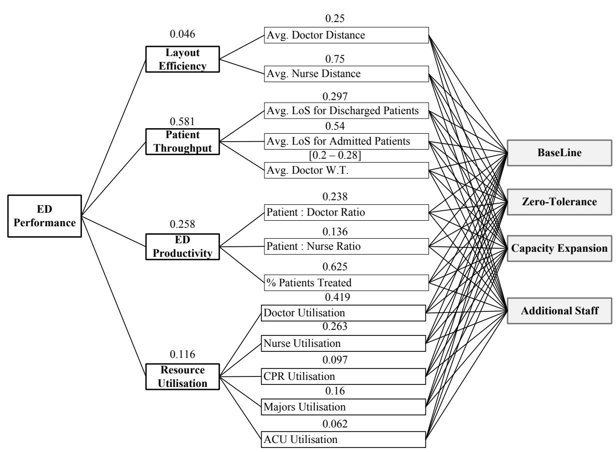


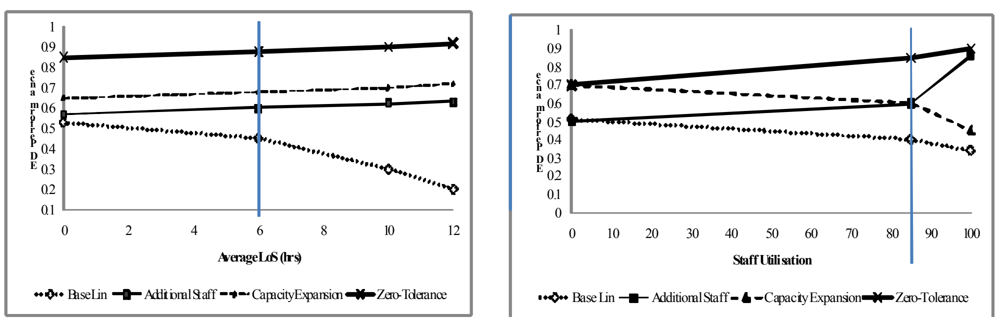
Figure 5: AHP weighted value tree

Upon the determining the weights, the acceptable range for each KPI was determined by the ED manager. For example, the utilization of staff – for nurses or doctor – had a range between 50% and 85%. This is to avoid the burnout level of the staff (85%) and at the same time avoid under-utilization of resource. Similarly, the LOS KPI specified a range between 0 and 6 for both admitted and discharged patients; this is to measure the achievement level of each scenario taking into consideration the HSE target (6-hours maximum LOS). Following assigning acceptable ranges, a value function was then used for each individual KPI to describe the importance and desirability of achieving different performance levels of each KPI based on its measurement level from the simulation model. The implementation of the "zero-tolerance" strategy had the greatest impact on the throughput of patients, and on the overall ED performance. Accordingly, the zero-tolerance scenario is clearly a recommended strategy for the ED.

The "zero-tolerance" scenario can be implemented by moving patients, who are waiting to be admitted, to a short stay unit or improving the admission/discharge cycle within the hospital. Consequently, any improvement strategy that will not address the access blockage (i.e. scenario 3) will not lead to the desired performance targets. Based on these insights, the hospital senior managers have prioritized improving the admission/discharge planning activities across the hospital over the other expensive solution alternatives.

4.4 Sensitivity Analysis

Recognizing the aspects to which the decision is sensitive enables the ED manager to concentrate on, or possibly reconsider the issues, which may cause changes in the decision. Accordingly, a sensitivity analysis was conducted to explore how the ED performance may change according to each strategy and how sensitive each strategy is to variations in performance measures. Figure 6 shows the sensitivity of proposed scenarios to the variation in ALOS and staff utilization respectively. The increase of the ALOS for the current ED above 6-hrs will deteriorate the performance of the current ED at all levels, which necessitates the addition of more staff and the expansion of the ED at this stage. However, enforcing the 6-hrs target (i.e., zero-tolerance scenario) outperformed these more expensive scenarios (i.e., capacity expansion and additional staff) as shown in Figure 6a. The performance of the current ED will become worse if staff members are over-utilized because they have reached their burnout level (Figure 6b). As indicated in the figure, staff burnout (85% utilization) can be better mitigated by increasing the staffing level on the ED than expanding the physical capacity which does not decrease the staff work load.



(a) (b)

Figure 6: (a) The change in ED performance with average LOS for all scenarios (b) ED performance with the burnout level of staff

CONCLUSION

The developed integrated framework brought together scientists and clinicians to resolve many challenges that face healthcare providers and managers at different levels of the decision making process. Through the development of a detailed and comprehensive model that duplicated a real process, managers used a '*what if*' analysis approach to examine solutions. In this way they can enhance decision making by simulating situations that are too complicated to be modeled mathematically. The integrated framework has successfully provided real-time strategies for emergency departments to improve patient care, by improving their internal processes. By applying and analyzing the results, a number of potential performance bottlenecks have been identified. One of the main performance bottlenecks in healthcare systems and especially in hospitals is the access blockage from the ED to the inpatient facilities within hospitals. The lack of coordination among hospitals units resulted in unbalanced utilization of hospital resources which in turn affects the whole care delivery process. Moreover, the prolonged waits for admission from EDs increase total hospital ALOS and also impacts the morbidity of elderly patients. Increasing medical staffing at busy periods might seem intuitively beneficial to overall patient LOS. However, the reduction in LOS for patients awaiting admission is on average of 7%. This potentially expensive change has limited impact on ED boarding time. Similarly, the impact of increasing the clinical assessment capacity was negligible (15%

decrease) compared to the synchronization of patient flow through the hospital (i.e., enforcing the maximum boarding time from ED to hospital beds). Resolving this performance blockage can free valuable resources (e.g., doctors, nurses, and trolleys) consumed by patients waiting for hospital admission, which in turn reduced ALOS by 48 %. Moreover, the average waiting time was reduced by 39% for patients waiting to be seen by ED clinician, while reducing the over-reliance on overstretched nursing resources, and improving the utility of doctors and nurses by 7% and 10% respectively. The combination of MCDA tools along with simulation and BSC contributed significantly in the decision making process by explicitly dealing with priorities and trade-offs between different performance indicators. Such integration resulted in building a better understanding about the problem structure, the implications of potential corrective actions prior to their actual implementation, and selecting appropriate and informed decisions. Consequently, the integration between simulation modeling, BSC, and MCDA has brought new insights to inform and support the different stages of the decision making process. Therefore, the proposed framework provides a safe and non-disruptive management environment to assess potential process strategies without unnecessary disruption to the healthcare delivery process. Consequently, potentially expensive unsuccessful strategies can be detected prior to their actual implementation.

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