Hybrid Modeling Approach to Investigate the Impact of Boarding Patients on Unit Performance

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***Abstract*— Overcrowding of Emergency Departments (EDs) is an issue that adversely affects patient safety, quality of care, and patient experience. In attempt to mitigate this risk, the National Acute Medicine Program (AMP) in Ireland has introduced a fast track medical unit, namely Acute Medical Units (AMU), designed to accommodate medical patients presenting to the ED with certain severity levels. Surprisingly, less than 50% of ED medical patients can get access to this unit. In partnership with a leading Irish hospital in Dublin, a hybrid simulation model has developed to investigate the underlying factors that limit patients' access to AMU. Discrete event simulation is used to model the process while cross-boundary interactions with other neighbor units such as ED and inpatient wards are explained using a system dynamics approach. Integrating the two simulation approaches show that boarder patients (i.e., patients waiting to progress) slow performance significantly. Decisions regarding capacity expansion are not the answer to this problem! Staffing and adequate resource leveling seem to have a better impact on patient flow.**

Keywords - Hybrid simulation; Boarding patients; AMAU; Healthcare management.

I. INTRODUCTION

Healthcare organizations worldwide are challenged to meet growing demands on Emergency Departments (EDs). Extra pressures are due to reduce costs, improve outcomes, and be more patient-centered while controlling the cost.

ED overcrowding is a serious issue that adversely affects patient safety, quality of care, and patient satisfaction[1]. One of the main identified factors to ED overcrowding is boarding, in which admitted patients from the ED spend long periods awaiting the availability of inpatient beds [2]. Consequently, less ED resources are available for new emergency patients [3]. The bottleneck of inpatient boarding naturally will increase Patient Experience Time (PET) for both admitted and discharged patients [3]. As a result, the quality of care, patient safety and satisfaction goals are affected by ED boarding and crowding. Hospital management is ultimately looking for ways to reduce ED overcrowding and boarding patients [4], however due to system complexity, they worry about the impact of any interventions on patient flows and equally budget.

Discrete Event Simulation (DES) modeling approach has a proven track record of success when it comes to system variability understanding. The boarding problem is multi-dimensional and has macro and micro impactful decisions. DES models are effective to simulate the process in details while incorporating the patient-resource relationships [5]. Nevertheless, this problem requires higher-level modeling capabilities. Hybrid Simulations (HS) seem to provide better insights into complex systems because they offer a more holistic approach to system analysis [6]. This means less assumptions and better accuracy to outcomes [7]. Therefore, this paper is presenting an integration of two simulation approaches in a unified framework to support decision-makers in the partner hospital [8]. Literature has indicated that HS can contribute to significant improvement of patient scheduling in outpatient clinic setting [9], redesigning and implementing new healthcare facilities [10], and model the complexities of emergency department [11]. Simulation models have been used to study patients boarding problems and their implications on patient experience. The trade off between increasing physical capacity of the ED and reducing admitted patient boarding times was examined in [12], while impact of inpatient boarding on the ED efficiency was explored in [13]. Reports from literature have revealed that not many studies have considered the hybrid approach between System Dynamic (SD) and DES in healthcare applications.

This paper presents a hybrid simulation model (i.e., DES-SD) to investigate the impact of patients boarding problem on the ability of patients to access other units in the hospital such as the Acute Medical Assessment Unit (AMAU). The proposed hybrid model considers the horizontal integration to the up/downstream departments (i.e., intra-departmental and inter-departmental interactions). DES model offers a better representation of the process complexity in details including patients flow, AMAU operations, and underlying relationships with other supporting units in the hospital. On the other hand, SD model is responsible for the cross-boundary interactions outside the AMAU, which allows a holistic view to represent the interaction among system components.

The remaining sections of this paper is organized as follows. A background about the project is given in the next section. A detailed description of developing the hybrid model then follows. Data collection, analysis and experimentation are presented. Finally, section VI concludes the paper.

II. Project Background

The Hospital under study is a public, adult teaching hospital that holds more than 520 beds. The hospital has a 24-hour "on-call" Emergency Department (ED) that serves over 45,000 adult patients annually. The department has officially, 23 monitored trolley space. Recently, the hospital has opened two more new units to offer possible alternative treatment routes for patients: An Acute Medical Assessment Unit (AMAU) and a Short Stay Unit (SSU). The capacities of the AMAU and SSU are 11 trolleys and 24 beds respectively. The AMAU works as a 12-hour unit; it opens from 9:00 – 21:00, but only accepts patients till 18:00 to allow beds to be available for the next day. The SSU works as a short stay ward, on a 24/7 basis, for acute medical patients who need to be admitted to the hospital, and whose length of stay is estimated to be less than five days.

AMAUs are resourced by physicians and a dedicated multidisciplinary medical and support teams and the only access to the AMAU is through the ED [14]. After patients are triaged and assigned a triage category according to the Manchester Triage System (MTS) that uses a five-level scale for classifying patients per their care requirements [15]. The triage nurse usually contacts the AMAU consultant or registrar so that they can accept or reject the case. Patients routed to the AMAU are those medical patients triaged as category 2 or 3 (i.e., very urgent and urgent patients respectively) who do not require resuscitation or isolation facilities. These patients only transferred to the AMAU if a trolley is available. Patients presented in these units will get to see a senior medical doctor, who should be able to treat and/or discharge patients, within almost one hour of admission. The two units along with the emergency department share resources among them, and share some resources with the hospital. When the AMAUs were first introduced, an improvement was witnessed in the increase of the proportion of patients discharged within 24 hours and also by decreasing length of stay and overall medical bed day usage [14]. However, AMAU unit under this study is facing two types of boarding problems: ED boarding and internal boarding. In ED boarding case, patients had occupied between one to six AMAU trolleys for maximum 12 hours. On the other hand, internal boarding occurs when patients in AMAU require a hospital bed in another downstream unit (e.g., medical words or SSU) for further treatment. AMAU unit opens from 9am to 6pm. Over a 6-month period, the number of medical patients presented to the ED with triage category 2 and 3 is 3753, however only 40% of these patients got access to the AMAU with an average patient experience time (i.e., The total time from patient entrance to AMAU until s/he exit the unit) of 4.45 hours. Therefore, a collaborative study was conducted with the hospital and the national acute medical program to investigate the underlying factors that restrict patients' access to AMAU specially patients boarding issues.

III. Hybrid Model Conceptualization

Analysing the patient boarding problem in AMAU necessitate integrating with downstream and upstream facilities that show high interdependency, in particular, ED and in-patient wards. A better understanding of the problem and its implications could be accomplished when system integration is to considered. Therefore, a hybrid simulation model between SD and DES is developed to address the consequences of patient boarding problem in the AMAU. The upstream component is the ED, which is the demand source of the AMAU while the downstream components model the patient disposition. In fact, patient disposition refers to two cases in AMAU: First, the patients who are waiting for beds in other units to release AMAU trolleys. Second, patients have been transferred to the AMAU overnight in order to free-up ED's blocked trolleys. Patient's flow in the AMAU is modeled using a DES in order to simulate the the unit activities and processes in details, taking into account the resources interaction. Downstream and upstream hospital operations are explained in SD model, which enables manager to envisgae the impact of changes using feedback loops between the different activities. The two simulation models are running simultaneously (Figure 1), and the information is exchanged from both models in the run time with a parallel interaction.

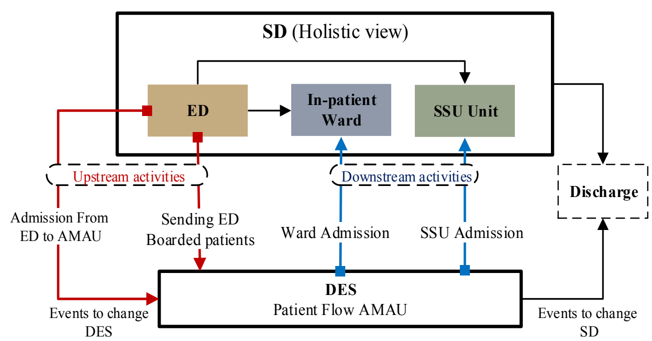

Figure 1. The interaction between the DES and SD models.

A. *AMAU patient flow(DES)*

Upon arrival at the ED and registration, walk-in patients (self-referral or GP referral) remain in the waiting area to be triaged. When a patient's name is called, depending on triage staff availability, the patient is assessed by a triage nurse. Based on patient condition and triage assessment by MTS criteria, each patient is assigned a clinical priority (triage category). Then, based on their severity level, medical patients can be directed to either the ED or the AMAU. A medical patient is eligible for the AMAU path if s/he arrives between 9:00 a.m. and 6:00 p.m. (i.e., the unit's admission hours) and if the patient is triaged either a category two or three. Once these requirements are met, the triage nurse calls the AMAU's consultant to check the availability of a trolley for the patient. The patient goes back to the ED path if a trolley is unavailable. The majority of patients in the AMAU are medical patients, accounting 96% of patients presented to the unit.

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Following the triage process, a patient who is directed to AMAU will be registered in the AMAU's system, interviewed by a nurse where his blood pressure and vitals are measured then s/he would wait for a doctor to assess the patient. Next, the AMAU doctor will discuss the case with the unit's consultant who would then either ask for more tests, request an opinion, or decide whether the patient needs to be admitted or discharged. AMAU's consultant from a medical/surgical speciality doctor can confirm whether a patient should be admitted or not. Alternatively, the consultant may wish to refer the patient to a colleague for a second opinion based on the medical condition. These are the primary care stages, which are relevant for all AMAU's patients, whether they are discharged from or admitted to hospital. Secondary patient stages are steps involved in the care of some, but not all patients such as diagnostics (e.g. MRIs and CTs). In the flowchart of AMAU steps (Figure 2) is shown.

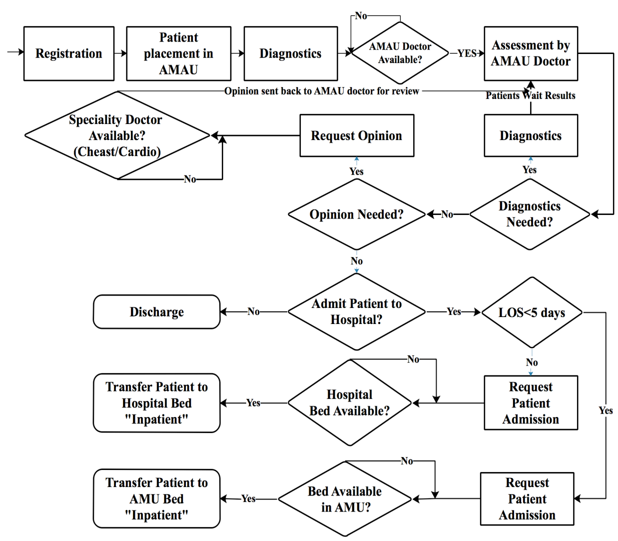

Figure 2. Patient's flow in AMAU

B. SD model

The casual loop – developed by Vensim software (Figure 3) – can be conceptualized regarding two main areas: the community area and the hospital area (ED, AMAU, and inpatient wards). Regarding the community, patients are presented to the ED from the surrounding catchment area and then discharged back to the community. The rate of patient arrivals depends on a variety of factors and characteristics of the surrounding catchment area. The rate of discharge back to the community depends on the bed occupancy, which is a function of the patient's length of stay (LOS) in the hospital. The factors affecting both arrival rate and the average LOS are not considered in this model, and they are represented as aggregate parameters. To reduce the pressure on the ED, medical patients can be dispatched to the AMAU pathway subject to the AMAU's trolley availability. The majority of the patients (75%) presented to the ED are discharged back to the community after receiving their treatment. If further inpatient care is required, patients wait in the ED for an inpatient bed. The rate of admission depends on the bed management and hospital bed occupancy. Due to the high bed occupancy of inpatients beds, patients that need inpatient care are boarded (delayed) in the ED while blocking ED trolleys.

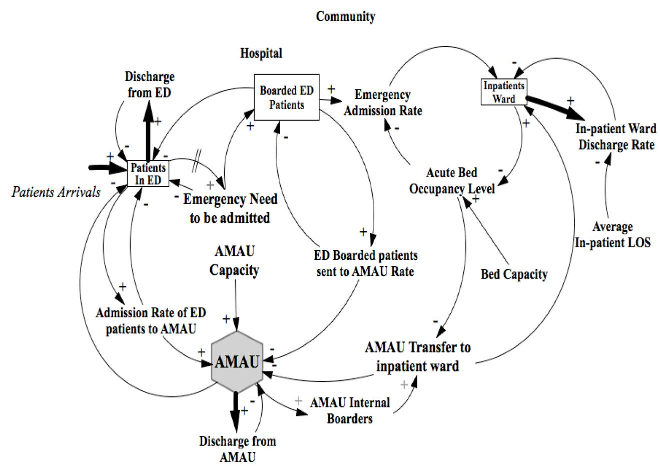

Figure 3. A Simplified causal loop diagram

A similar situation occurs in the AMAU when patients require further stay in the hospital and needed to move to other downstream units such as the SSU or inpatient beds. To free-up ED's blocked trolleys, the ED management transfers some patients to the AMAU overnight. This management practice moves the ED bed blocking partially from ED to the AMAU. Consequently, the AMAU has an average of 3.2 blocked trolleys due the transferred ED boarded patients. The situation becomes worse when it combined with the AMAU boarded patients. In turn, these limit access to the AMAU and subsequently increase the pressure on the ED.

IV. Data Collection and Analysis

A. Data sources

The data collected for this project utilized both quantitative and qualitative data types. The quantitative data are collected from the historical data of ED logs, electronic patient records (EPRs) from the ED's IT system, and direct observation. The direct and indirect time per activity and staff Rota are not stored in the IT system and were collected from interviews and observations. The qualitative data such as patient pathways, conceptual modeling have been gathered through observation, interviews, and focus groups.

B. Data analysis

Data are collected retrospectively for six months for patients who are presented to ED and AMAU between January 1^{st,} 2014 and June 30^{th,} 2014. A total of 20,493 anonymous patient records from ED and 1,520 anonymous patient records from AMAU have been collected through the hospital's information system, which is used by the staff (e.g., administrators, doctors, and nurses) to record data about each patient through the stages of their care. 23% of the patients arrived by ambulance, and 77% are walk-in patients. Of the total patients, 90% of patients are new patients, and 10% are unscheduled return. Referral from GP with a letter represents 70% of patients while 23% are self-referred.

Patients differ according to the medical complaints and severity of their care needs, so it is essential to understand their different arrival patterns to reflect the characteristics and needs of various groups of patients. In this study, the patients are clustered based on the triage category to be able to differentiate those patients who will be directed to the AMAU path. As mentioned previously, the AMAU in this study facing two kinds of boarding: ED boarding and internal boarding. In ED boarding, patients occupy between one to six AMAU trolleys (Figure 4) for maximum 12 hours.

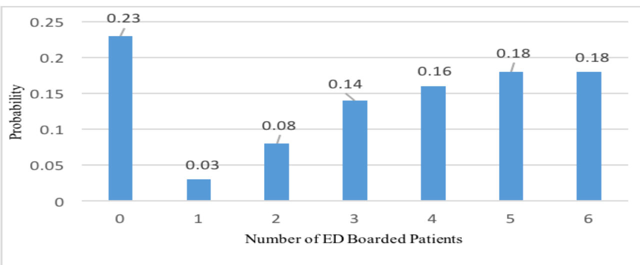

Figure 4. Distribution of ED boarded patients in the AMAU.

In internal boarding case, patients in AMAU are waiting to get inpatient ward beds or SSU beds in order to release AMAU trolleys.

C. *Verification and validation*

Conceptual models for both patient flow and causal loop diagrams have been documented and validated by hospital's senior clinicians and senior nursing staff. The validated conceptual models along with the analysis of empirical data were used to develop the hybrid simulation model using AnyLogic software platform. Once the models are completed, the verification and validation were carried out all the way through the development phases of the model. Visual tracking was used to verify the model logic to ensure that patients follow the correct care path as expected. The following Key Performance Indicators (KPIs) were used for the AMAU: the average of total patient experience time (PET), the average of total waiting time (TWT) and patient access (i.e., the total number of patients enter the AMAU). The main reason for choosing patient access as one of main KPIs is that increasing patients access to the AMAU can mitigate overcrowding in ED [14]. The simulation model is validated (Table. I) using face validation and comparison testing. This is to ensure that the actual PET within the AMAU is reflected by the model when it runs for twenty-four weeks period.

TABLE I. MODEL VALIDATION

KPIS	Base Scenario	Real Data	Difference%
Avg. PET(Min)	276.79	267.6	3.4
Avg. Patient access	1710	1520	11.1

V. SCENARIO ANALYSIS AND DISCUSSION

The simulation results of the baseline model show that on average 1710 patients could access to AMAU unit at any six months. In fact, in the current situation, AMAU works on 9 hours/ 5 days; from 9:00 am to 6:00 pm. According to the baseline only 40% of medical patients of ED could access to AMAU. However, the target of ED managers is to increase the flow percentage in order to absorb most if not all medical patients who attend to the ED during its opening hours. The average PET of the baseline – presented in Table II – is currently 276.8 minutes and patients normally wait 98.2 minutes in AMAU.

TABLE II. SIMULATION RESULTS FOR BASE SCENARIO

KPIS	Baseline Scenario
Avg. PET(Min)	276.79
Avg. TWT (Min)	98.24
Avg. Patient access	1709.80

A. *Scenario Design*

The simulation scenarios are designed (Table. III) to identify the factors that contribute to PET and patient access to AMAU and consequently ED overcrowding. Three factors are considered: ED boarded patients, internal boarded; and the number of trolleys in the AMAU.

TABLE III. SIMULATION VARIABLES FOR BASE SCENARIO,

	Control Variables		
	ED Boarders	***Internal Boarders***	***Number of trolleys***
Base Scenario	Yes	Yes	11
Scenario 1	Yes	Yes	17
Scenario 2	No	Yes	11
Scenario 3	Yes	No	11
Scenario 4	No	No	11

For the first two factors, a value of 'Yes' and 'No' means the existence or the absence of the corresponding factor respectively. For example, Scenario 1 is similar to the baseline with both ED boarding and internal boarded patients considered, however, AMAU trolleys are increased from 11 to 17. This is to investigate the effect of increasing the physical capacity of AMAU only. On the other hand, Scenario 2 is designed to examine the effect of having no ED boarders while keeping other variables the same as the baseline (i.e., same number of trolleys with internal boarders).

B. *Result Analysis*

Increasing the AMAU physical capacity (Scenario 1) results in 30% increase in patient access with an insignificant effect on PET (increased by 0.7%) and TWT (increase by 7%). Despite adding extra trolleys (Table. IV) improve the

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patient access, it has insignificant effect on PET and TWT. On the other hand, unlocking ED boarders (i.e., Scenario 2 is assuming constant inpatient beds availability for ED patients) has resulted in a significant increase patient access to the AMAU by 25.9% (i.e., 1710 to 2152 patients). Such increase is attributed to an increase of availability of AMAU trolleys as patients do not have to wait in the unit. However, there is no significant change in PET for AMAU patients (1.9% decrease).

TABLE IV. SIMULATION RESULTS FOR SCENARIO 1 AND SCENARIO 2.

KPIS	Base	Scenario 1		Scenario 2	
		O/P[a]	*+/- (%)*	*O/P[a]*	*+/- (%)*
Avg. PET(Min)	276.8	278.85	0.7	271.5	-1.9
Avg.TWT(Min)	98.2	105.08	7.0	96.8	-1.4
Avg. Patient access	1710	2224.0	30.1	2152	25.9

a. O/P: simulation output; +/- : percentage of increase/decrease relative to the base scenario.

Scenario 3 seems more effective in comparison to Scenario 2 (Table. V), in which patient access increase from 1710 patients to 2337 patients and TWT decrease from 98.2 minutes to 51.8 minutes as well as 9.2% reduction in PET.

TABLE V. SIMULATION RESULTS FOR SCENARIO 3 AND SCENARIO 4.

KPIS	Base	Scenario 3		Scenario 4	
		O/P[a]	*+/- (%)*	*O/P[a]*	*+/- (%)*
Avg. PET(Min)	276.8	251.4	-9.2	285.8	3.2
Avg.TWT(Min)	98.2	51.8	-47.2	87.5	-10.9
Avg. Patient access	1710	2337	36.7	3052	78.5

a.O/P: simulation output; +/- : percentage of increase/decrease relative to the base scenario.

Scenario 4 is the ideal situation in the system with no ED boarding and no internal boarding. In this scenario, there is a noticeable increase by 78.5% in patient access and 10.9% decrease in TWT. However, PET has increased by 9 minutes, which is mainly because the number of patients entered into the unit is doubled. All the internal queues in the AMAU were analyzed in order to gain insights regarding the increase in PET. Three main bottlenecks were discovered due to the increased number of patients who can access the AMAU: access to the SSU; the number of AMAU consultants; and finally, the number of required porters. As a result, different combinations of the four basic scenarios (Table. VI) were designed

TABLE VI. SIMULATION SETTINGS FOR SCENARIOS 5 – 11.

Scenarios	Control Variables				
	ED Boarders	*Internal Boarders*	*SSU beds*	*NP[b]*	*NC[c]*	*NT[d]*
Base	Yes	Yes	24	1	1	11
Scenario 5	No	Yes	36	1	1	11
Scenario 6	No	Yes	48	1	1	11
Scenario 7	No	Yes	24	2	1	11
Scenario 8	Yes	No	24	2	1	11
Scenario 9	Yes	No	24	3	1	11
Scenario 10	No	No	24	2	1	11
Scenario 11	No	No	24	1	2	11
Scenario 12	No	No	24	2	2	11

(b.NP: number of Porters, c.NC: Number of Consultants, d.NT: Number of Trolleys)

In Scenario 5 and 6 there are no ED boarders, and the number of SSU beds has been changed from 24 to 36 (50% increase) and 48 (100% increase) respectively. By increasing 50% of SSU beds, patient access from the ED to the AMAU has increased from 1710 patients to 2667 patients (Figure 5) with a slight increase in PET and TWT (Figure 6) compared to the baseline model. In Scenario 7, there are no ED boarders, but another porter added to the AMAU which resulted in a 30.9% increase in patient's access and 20.7% reduction in TWT. Therefore, increasing SSU beds is not as effective as increasing one porter to the AMAU. Scenario 8, is also designed to increase one porter with no internal boarder. The results of this scenario show that patients access increased by 51.2% along with a noticeable decrease in TWT by 74% (from 98.2 minutes to 25.5 minutes). Adding more porters (Scenario 9) does not have further improvement on the performance.

In Scenario 10, a full relaxation scenario (i.e., no ED boarders and no internal boarders) by adding another porter has resulted in a considerable decrease in TWT by 61.2%. In contrast, adding one more consultant to the AMAU with full relaxation (with only one porter) resulted in only 21.3% decrease in average TWT. In last relaxation scenario (i.e., Scenario 12) the combination of adding one porter and one consultant resulted in increasing the number of patients entered to the AMAU from 1710 patients to 3615 patients with an 81.5% decrease in TWT and 20.6% decrease in PET. To conclude, Scenario 12 seems to have the best impact on KPIs.

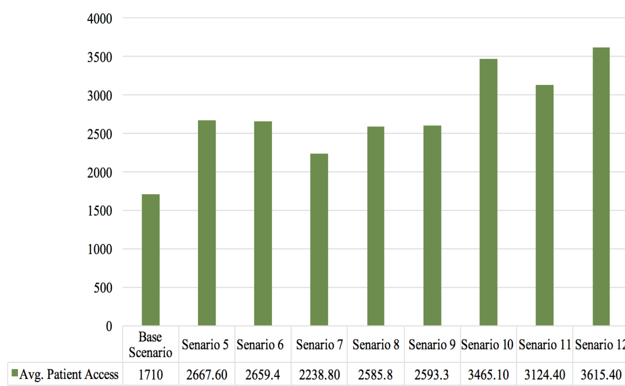

Figure 5. Comparing patient access in scenario 5 to scenario 12

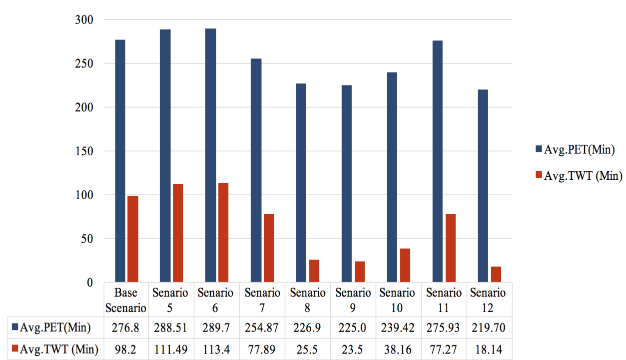

Figure 6. Comparing PET and TWT in scenario 5 to scenario 12

VI. CONCLUSION

Overcrowding is one of the key problems in Emergency Department (ED) of hospitals. It often has a negative effect on patients and unit performance. Acute Medical Assessment Units (AMAUs) is a new unit that is designed to reduce pressures on EDs by serving particular categories of ED patients. However, with time passing, this unit suffers from boarding issues – patients who are waiting for decisions.

A hybrid simulation model (DES-SD) has developed to examine the impact of boarding on AMAUs overall performance. The DES has used to model the patient flow in details incorporating AMAU and its relationships with other supporting units in the hospital such as ED, Wards and SSU. On the other hand, SD has looked at cross-boundary interactions outside the AMAU. Results show that improving the flow between up and downstream enhance patient access and resource utilization. Nevertheless, the original approach to this issue was to increase unit physical capacity. Adding AMAU's bed capacity will not have a significant impact on performance variables in comparison to adding extra staff. Particular resources (e.g., consultants and porters) seem to be impactful especially if less or no boarding problem exists.

Finally, the hybrid modeling approach has enabled the hospital managers to gain insights to the dynamism embedded in the system and also identify bottlenecks that hinder the performance. Future work intends to consider interaction between variables. In addition, Design of Experiment (DOE) module in order to examine factor sensitivity will be included.

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