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A DISCRETE-EVENT SIMULATION STUDY FOR EMERGENCY ROOM CAPACITY MANAGEMENT IN A HONG KONG HOSPITAL

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ABSTRACT

It is very common for patients to face a long journey after the first physician visit in many emergency service care models. This affects the service quality of accident and emergency departments (AEDs). In this study, we developed discrete-event simulation models to mimic the complex health service system of a 24-hour AED in Hong Kong. We assessed how changing the number of emergency department physicians or the patient journey influenced AED performance achievement, which was quantified as service achievements for patients (SAP). We observed that reducing the time spent on subsequent treatments (after the first physician visit) among semi-urgent patients was comparatively sensitive to improving the overall AED outcomes. There was an increase in mean service achievements from 69.29% to 79.30% (95% confidence intervals were 1.28% and 0.98%, respectively). The proposed model is helpful in making decisions about emergency resource planning when there is a sudden surge of emergency patients.

1 INTRODUCTION

1.1 Background

The ‘patient journey’ refers to the sequence of clinical care events that patients experience from the point of entry (due to sickness) until they are discharged from the hospital unit, or they die. Long patient journeys have become a common issue faced by many of the world’s accident and emergency departments (AEDs). According to a recent study that compared the crowding problems of emergency systems worldwide (Pines et al. 2011), AED crowding associated with long patient wait times (Choi et al. 2006; Guardian 2015; Lauks et al. 2016) and prolonged processing times are commonly observed. The door-to-doctor time is an extremely important measure for emergency departments. In a busy AED that takes care of both emergency and non-emergent patients, the latter may experience a long AED waiting time (Sing Tao Daily 2013). The term ‘non-emergent’ typically refers to patients who do not urgently need AED services. Failure to discharge patients may result in disruptions to emergency services, as the internal healthcare systems and resources are closely linked and associated with complex health service systems. This can negatively affect emergency care service quality, patient safety and experience, staff morale and the ability to respond to unexpected surges, such as infectious disease outbreaks, unpredictable disasters and winter weather-related health problems.

Simulation models have been used as a pragmatic approach to enhance AED operation management (Junwen et al. 2012, Saghafian et al. 2015, Wiler et al. 2011, Zgaya et al. 2014). To the best of our knowledge, very few studies have paid particular attention to the effects of modifying clinical processes under the complex AED service system. A long patient journey after the first physician visit is actually common in emergency service care models. The subsequent treatment (medical treatment procedures after first physician visit such as medication, electrocardiography (ECG), blood sample taking, x-ray imaging, etc.) and reassessment (second and/or third physician visits after subsequent treatment) processes inevitably increase the workloads of AEDs' human resources (both physicians and nurses), lengthen the time to first physician treatment of new patients, increase the number of patients' work-in-progress and affect the overall total length of stay.

1.2 Objective

Typical AED simulation studies use simulation to mimic emergency department patient flows without considering the complicated healthcare service processes. It is unclear how much prolonged patient journeys influence AED outcomes in practice. This study assesses how modifying (1) the path of the AED clinical process after the first physician visit and (2) the level of physician resources affects AED performance. The remainder of this paper is organised as follows. Section 2 presents the research materials and methods. Section 3 provides the validated model and sensitivity analysis results. Section 4 discusses the effects of these changes on overall AED service operation improvement, and Section 5 concludes the study's outcomes, limitations and implications to provide future research directions.

2 METHODS

A typical systematic approach to conducting a simulation study includes formulating the subject problem, collecting data, constructing a model, calibrating the developed model, designing and running experiments and analysing the output results (Abo-Hamad and Arisha 2013). In the following sub-sections, we focus on the design and development of the AED discrete-event simulation model.

2.1 The AED Service System

This study features a 24-hour AED that provides emergency care to community members. AED patients are classified with respect to their severity level, from Category (Cat) I (Critical) to V (non-urgent). One of the service achievements for patients (SAP) monitored by the management authority is based on the time between registration and first physician visit. In the featured AED, the service target to treat emergency patients (Cat I and II) is easily achieved, as higher priorities and designated resources are assigned to such cases. Most of the time, the AED encounters difficulty in meeting the service pledges of semi- to non-emergent cases (i.e., Cat III-IV). Taking the period of July through September 2009 as an example, only 71% of Cat IV patients were treated within 120 min, which fell below the targeted rate (75% of Cat IV patients being seen within 120 min). There are frequent reassessments and medical treatment activities among Cat III-V patients. Thus, many patients crowd the waiting areas and cubicles waiting for treatment, laboratory tests, treatment results, reassessment, etc. In our previous study, the waiting time and length of stay of non-emergent patients increased by 14.9% and 10.8%, respectively, if manpower resources were commandeered to resuscitate emergency patients (Xu et al. 2013). The current study specifies non-emergent patients as those who do not urgently need AED services (i.e., Cat IV and V). The clinical ethics approval number of this study is KW-EX-13-008(59-08).

The AED healthcare operation flow is displayed in Figure 1, and our model is based on the displayed flow and the subsequent arrangement. Every patient undergoes admission, triage, a physician visit and discharge (exit time). Patients with higher urgency and degree of severity are prioritised to use the resources (including physicians, nurses and resuscitation rooms) before non-emergent patients. Separate physician resources are reserved for Cat I-III, IV and V patients. However, all AED physicians may support resuscitation if needed.

The queuing for Cat IV and V follows a first-come-first-served basis. According to the standard operating procedure, the care of Cat V patients has a 30-minute delay compared with Cat IV patients. During the consultation period, physicians may order medical treatment procedures according to the patient's condition. The reassessment/treatment procedures path may be repeated 1-2 times based on the patient's actual condition. However, the majority of non-emergent patients (73% for Cat IV and 84% for Cat V) are discharged home.

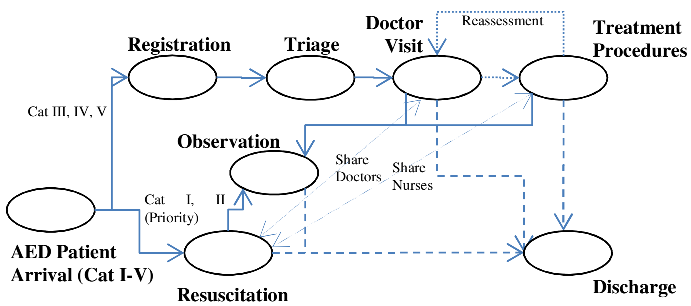


Figure 1: AED healthcare flow.

2.2 Data from the Clinical Management System

Our simulation input and calibration data were obtained from Hong Kong Hospital Authority's institutional database (June 2009 - June 2010, total number of patient visits: 139,910) – a centralised clinical information system used in all of the region's public hospitals. It provides rich patient flow information on registration time, triage time, first physician visit and discharge time. Retrospectively, patient records were manually reviewed to quantify the occurrence of major medical treatment procedures. Time studies were conducted and we measured the time required by each major treatment procedure using multiple trial setups established by experienced clinical staff members. We also obtained a roster and roles for the physicians and nurses, resource availability (number of available resuscitation rooms, cubicles and consultation rooms) and facilities layout for the study period. All of the data collected were cleaned and pre-processed by omitting the missing data before we built up the model. Means, variances, chance of occurrences, fitted distributions and relative errors were obtained as appropriate for building up the model.

2.3 Patient Arrivals

We modelled patient arrival in a piecemeal fashion on weekly and hourly bases (Figure 2). It was assumed that the inter-arrival time within each hour followed exponential distributions (McCarthy et al. 2008). We adopted a piecewise-constant rate method to model patient arrival patterns, i.e., making the assumption of constant arrival rate within a time interval (hr). The AED hourly arrival rate by the hour of the day and day of the week factors were used.

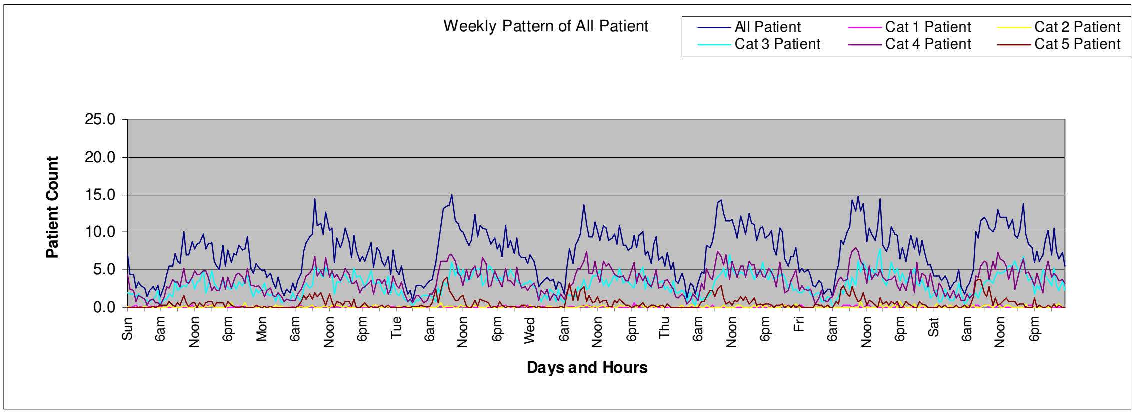


Figure 2: Weekly patient arrival pattern by triage categories.

2.4 AED Physician Resources

In this study, we focused on the capacity level of day shift physicians, of which there are two types: Cat I-III and Cat IV and V. Cat I-III physicians take care of critical to urgent patients from triage level Cat I-III, and their working mode is based on priority in accordance with urgency. The main role of Cat IV and V physicians is to handle non-emergent patients, i.e., Cat IV and V patients. However, if necessary, they can be appointed to handle emergency patients. In reality, it is common for AED physicians to simultaneously deal with multiple tasks. However, in this simulation study, we assumed that the physicians only worked on a single clinical task in each simulation time point, according to the task priority.

2.5 Processing Time and Route

The operation times of the major tasks and routes for AED processes and medical procedures were quantified via the institutional database, expert interviews, a retrospective review of AED patient records and an on-site time study. Based on the institutional data, we were able to obtain patient arrival patterns, arrival and discharge destinations (such as ambulance and walk-in cases, and discharge routes) and observation path by category. The operation times of critical AED processes were largely obtained through staff interviews. Considering individual AED staff differences and case variations, the senior AED staff members (manager grade or above) provided the minimum, most likely and maximum operation times for registration, triage and consultation times; that is, triangular distributions, which are normally used as subjective descriptions of populations with limited sample data. In September 2013, extensive time studies were conducted to determine the processing times for major medical treatment procedures (including CT scans, dressing, medication, urine testing, intravenous therapy). The time studies were conducted across various AED shifts so that the results would reflect the different AED settings between shifts. One hundred samples were taken, and the results were further organised to classify medical treatments into groups of ‘within 5 min’, ‘5-10 min’, ‘10-15 min’ and ‘15 min or above’.

2.6 Performance Measures

(Abo-Hamad and Arisha 2013) noted that AED performance is measured by patient throughput and AED efficiency, which include wait time, length of stay and resource use. In the featured AED, the length of time to first physician visit by category was the major performance indicator. As Figure 3 shows, the current institutional data provided major AED outcome measures in terms of the SAP, length of stay (LOS), time to consultation (TTC) and time to triage (TTT).

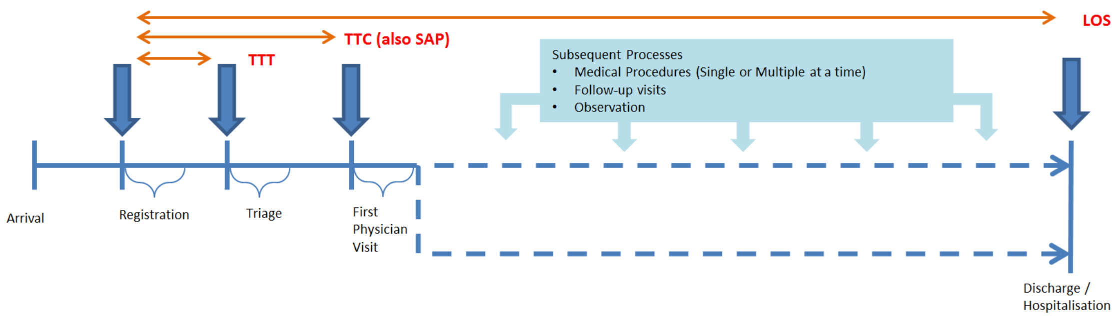


Figure 3: Time points from institutional data (dark blue arrows).

2.7 Study Design

Our preliminary studies (Wong et al. 2011, Xu et al. 2011) documented part of the core model design and provided the technical details for the simulation model development. In this study, we built up the AED model using a system simulation package called *Arena*® (Automation 2015). We emulated the AED baseline situation from 1 July to 30 November 2009 and several AED outcomes by triage category. Patient volume, SAP, LOS, TTC and TTT were used to calibrate the model. The outcomes covering the entire patient journey thereby increased the validity of the calibrated model. Sensitivity analysis is a systematic method for examining the effects of a range of scenarios on a model's results. We used a one-way sensitivity analysis to examine the effects on the model's conclusions caused by changes in parameters. In this study, we considered the level of available physicians and occurrence of reassessment and treatment procedures as factors. According to the capacity level, we adjusted the level of medical doctor resources by 1-4 units of doctor capacity (4 hr/unit) in 4 time periods (early morning, late morning, early afternoon and late afternoon). We increased and decreased the rate of the occurrence of subsequent processes after the first physician visit by 5% or 10%. By changing the abovementioned factors one at a time, in total, 142 experimental settings were designed and the model outputs were evaluated based on the changes in SAP, LOS, TTC and doctor utilisation level (DUL). We focused on TTC and DUL when we altered the physician resources level and path of patient journeys after the first physician visit, respectively.

3 RESULTS

3.1 The Model

The model comprised the entire AED patient journey including critical aspects of AED operations, such as patient arrival patterns, patient flows by category, priority based on triage level, patient/staff interactions and rules, resource schedules and capacity, main AED processes and operation times, disposition routes and decisions on medical treatment(s) and reassessment. The conceptual model was calibrated manually with respect to actual AED outcomes and adjusted the simulation input parameters within the defined plausible ranges. We matched the simulation outcome by triage categories using SAP, LOS, TTT and TTC with the real data to ensure that the baseline model was a trustworthy representation of the real AED system. Table 1 shows the used time distributions of major AED processes.

Table 1: Simulation input parameters.

Time distributions of major AED processes	
Process	**Time distributions (min)**
Resuscitation visit Cat I	TRIA (45,60,80)
Registration	TRIA (1.8,2,2.2)
Cubicles visit	TRIA (20,30,50), TRIA (12,14,18)
Triage processing Cat V	TRIA (3,4.5,5.5)
Consultation room visit	TRIA (10,11.5,15), TRIA (8,11.5,15)
Less than 5 min procedures	CONSTANT (7.5)
5 to 10 min procedures	CONSTANT (12.5)
10 to 15 min procedures	CONSTANT (17.5)
More than 15 min procedures	TRIA (17.5,25,35)
Nurse briefing discharge	TRIA (0.5,0.75,1)
Nurse briefing hospitalisation	TRIA (0.5,0.75,1)
Triage processing Cat III	TRIA (4,5,6)
Resuscitation visit Cat II	TRIA (20,30,50)
Triage processing Cat III/IV	TRIA (3,4,5)
Intensive observation Cat I	TRIA (20,30,60)
Consultation room reassessment	TRIA (9,12,14)
Consultation room 2nd reassessment	TRIA (8,10.5,13)
Cubicles reassessment	TRIA (5,6,10)
Cubicles 2nd reassessment	TRIA (5,6,10)

Subsequent clinical processes after the first physician visit for non-emergent patients. Each of the following cells represents the proportion of patients from the previous process					
Cat	**1st Physician Visit**	**1st Set of Medical Treatment**	**2nd Physician Visit**	**2nd Set of Medical Treatment**	**3rd Physician Visit**
III	100.00%	95.00%	90.00%	40.00%	80.00%
IV	100.00%	70.00%	80.00%	30.00%	15.00%
V	100.00%	50.00%	50.00%	10.00%	0.00%

A comparison of the baseline model outcomes and the actual AED situations during the study period is provided in Figure 4. We compared the simulated mean values of patient volumes, SAP, LOS, TTC and TTT with the actual values, and most of them fell within 95% confidence intervals (CIs) of the corresponding observed AED mean values. Understanding the real AED time capturing introduces potential measurement errors, and we accepted relative errors below 0.2 and all the simulated values fell into the range. For the baseline scenario, the simulated mean for Cat IV patients' SAP reports was within 69.29% ± 1.28% (95% CIs). For the baseline simulation, we ran the model based on the period from 1 July through 30 November 2009. A 7-day warm-up period was set to achieve steady-state simulation outcomes. A replication–deletion approach was used and the simulation outcomes were recorded for 153 simulation days. We repeated each scenario to generate 20 replications.

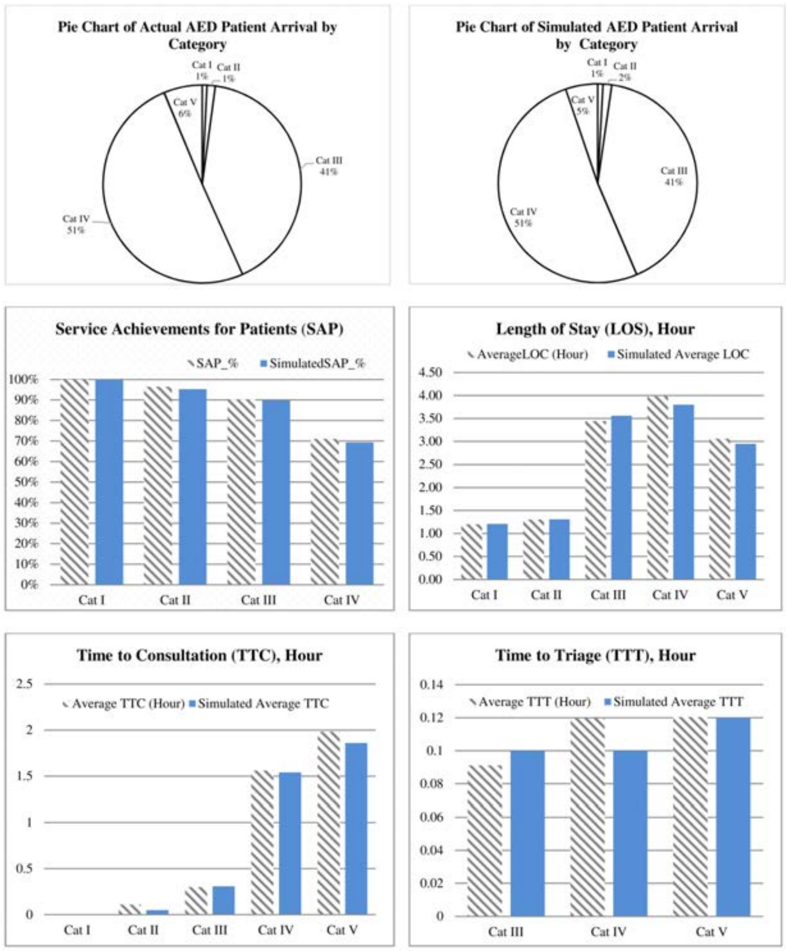


Figure 4: Graphical displays of simulation results against actual AED situations.

3.2 The Effects of Changes in Physician Level and Patient Journey

We varied the level of medical doctor resources by adding and subtracting 1 or 2 doctors by 1-4 units of doctor capacity (4 hr/unit) in various time periods in the daytime. The 4-hour increment/deduction strategy was designed based on the standard physician half-shift duty, which is practical and potentially implementable. It was found that reducing the manpower of Cat I-III doctor(s) had an obvious negative effect on AED outcomes for Cat III patients (including SAP, LOS, TTC), and the situation was similar when adjusting Cat IV and V doctors' levels. However, adding physicians (in both Cat I-III and Cat IV and V cases) did not significantly improve AED outcomes (including SAP, LOS and TTC). Figure 5 displays the effects of varying two types of doctors on Cat V patients' SAP. When we varied the number of Cat IV and V doctors, it was found that reducing the number of medical doctors had stronger absolute effects on AED outcomes than adding medical doctors. It was noted that the percentages of changes in Cat IV-SAP were -36.84% (-2 doctors * 8 hr) and 1.85% (2 doctors * 8 hr).

Unlike physician's level increments, increasing the occurrence of reassessment/additional treatments could increase LOS and DUL while decreasing SAP, and vice versa. We examined the changes in these patient paths by adding or subtracting 5% or 10% from the baseline condition. Taking the minus 5% Cat

IV case as an example, the percentages of changes in Cat IV patients' LOS and Cat IV and V patients' DUL decreased by 11.55% and 4.47%, respectively, and the Cat IV patients' SAP underwent 11.36% improvement. This implies an increase in the sample mean of SAP for Cat IV patients from 69.29% to 79.30% (half-widths were 1.28% and 0.98%, respectively). Figure 5 displays the effects of varying reassessment/additional treatments rates on AED SAP. For Cat III patients, an effect on SAP is not apparent. Altering the percentages for Cat IV patients (both increasing and decreasing) had a greater effect on SAP changes than for Cat V and Cat III patients. This may be primarily due to the fact that the majority of patients (more than 50%) were Cat IV patients. It is noted that the half-width is relatively large when the scenarios are unfavourable to the service outcomes (such as the scenarios of reducing two Cat IV and V physicians – the dedicated resources for Cat IV patients – and increasing the reassessment rate for Cat IV patients). This indicates a larger variability contributed to SAP by the unfavourable than by the favourable scenarios.

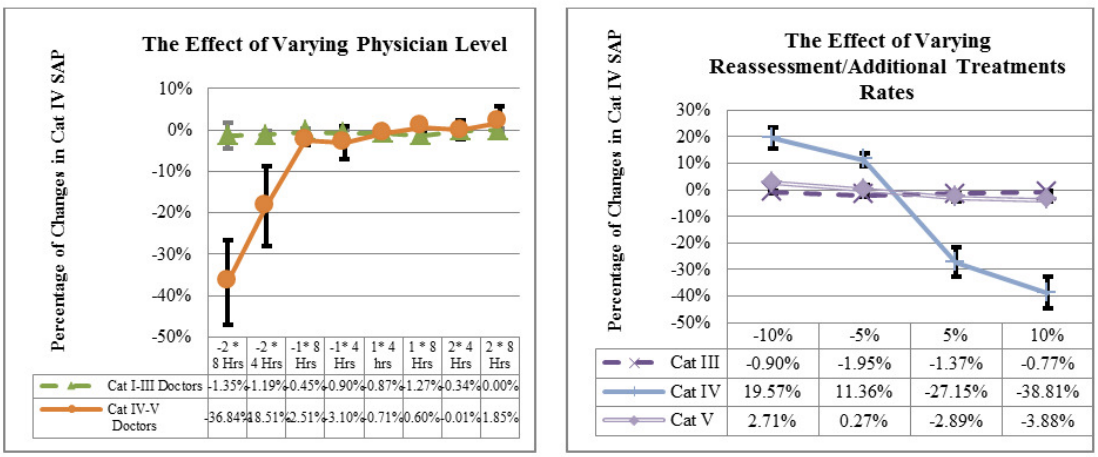
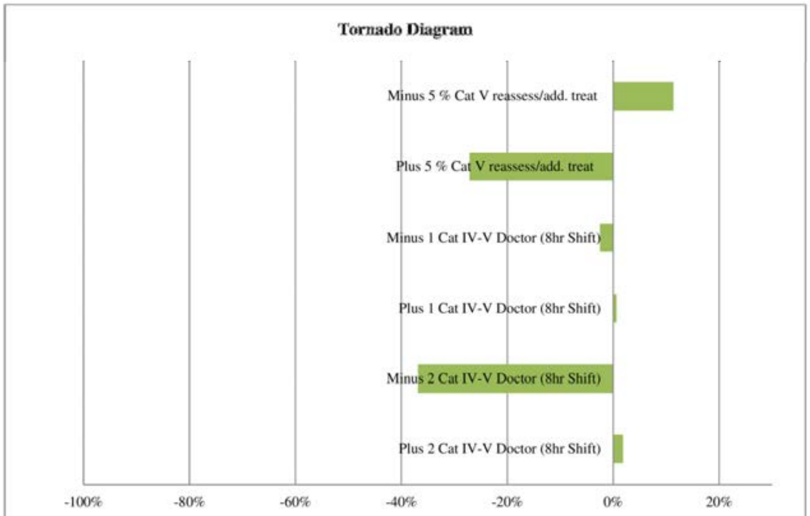


Figure 5: Effect of changes on AED Cat IV patients' SAP (with 95% CIs).

3.3 Evaluation of Sensitive Factor

Figure 6 presents a tornado diagram to show which factors had a greater influence on SAP. It compares the effects that altering physician resources levels and patient journey paths after the first physician visit have on AED performance. Taking Cat IV SAP improvement into consideration, subtracting 5% Cat IV reassessment/additional treatment is a more sensitive factor than adding two Cat IV and V doctors.



	Plus 2 Cat IV-V Doctor (8hr Shift)	Minus 2 Cat IV-V Doctor (8hr Shift)	Plus 1 Cat IV-V Doctor (8hr Shift)	Minus 1 Cat IV-V Doctor (8hr Shift)	Plus 5 % Cat V reassess/add. treat	Minus 5 % Cat V reassess/add. treat
Cat IV	1.85%	-36.84%	0.60%	-2.51%	-27.15%	11.36%

Figure 6: Tornado diagram for changes in AED SAP (x-axis: percentage of changes in SAP; y-axis: scenarios).

4 DISCUSSION

In this study, we focused on improving AED performance for non-emergent patients. It might seem that increasing the physician level would potentially result in an increase in AED performance, and vice versa. However, based on our simulation results, this is not always the case, particularly in complex health service systems. If we want to maintain a stable AED performance for non-emergent cases, it is critical to dedicate a sufficient AED physician level to these patients. In terms of enhancing AED outcome performances for non-emergent cases, it is more sensible to consider the non-emergent patients' journey and subsequent processes after the first physician visit.

We used simulation methods and scenario analyses to model possible options that might improve the experiences of Cat III and IV patients. Our findings also demonstrated that a reduction in processes for a small number of patients can lead to improved times for a larger number. One of the examples is related to treatments for Cat IV patients. A small decrease in the patients' journey within the AED (affecting about 10 patients per day) could result in an achievement of overall Cat IV service target improvement. It is advised that AED management consider evaluating the clinical processes for non-emergent patients that tend to create bottlenecks.

Taking Hong Kong as an example, AEDs have been providing efficient emergency services to the public. However, the system must deal with a large volume of daily patient visits due to a low and same-for-all charging policy; specifically, the service charge for AEDs in Hong Kong is HK$100 per visit, which covers all clinical, laboratory and radiological assessments and treatments. Many patients mistreat AED services as general practitioner services and seek medical advice or prescriptions for non-emergent conditions, such as general influenza with mild symptoms or clinical urgency. Private care services cannot compete at the same service level and cost. It is commonly observed that the AED services have been depleted by non-emergent patients (Chung 2000, Graham 2015) who may have a prolonged stay in the AED due to subsequent treatments or reassessments. The high patient volume, especially due to non-emergent patients (more than 50%) in recent years, has exaggerated the common problems of long wait times, overcrowding, long LOS for AED patients and high turnover rates for AED physicians.

Similar to many developed countries, Hong Kong is one of the top territories in the world with an 85-year-old or above population portion projected to exceed 10% by 2060 (Bakker M 2014). An aging population is a serious concern, as it will inevitably increase future demands for emergency care services. By design, an AED's major function is to provide prompt life support to acute and critically ill patients. It also acts as the buffer, pending zone and satellite for other specialties. From a policy perspective, it is essential to re-think the role of AEDs in the entire healthcare system (such as in relation to primary care services) (Chung 2000) to ensure sustainable, robust and high-quality services for the community.

5 CONCLUSION

In this study, we developed an AED discrete-event simulation model for a typical 24-hour AED in Hong Kong, and investigated the effects that changes in clinical processes had on AED performance using a sensitivity analysis. This work demonstrates how we can use simulation methods to improve our understanding of complex health service systems. This study provides a guide to administrative leaders in evaluating optimal throughput practices and staffing. Indeed, we cannot turn patients away from AEDs. Instead we must balance urgency, create proper strategies for managing the non-emergent patients and understand their influence on overall emergency care services.

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