*Proceedings of the 2024 Winter Simulation Conference*
*H. Lam, E. Azar, D. Batur, S. Gao, W. Xie, S. R. Hunter, and M. D. Rossetti, eds.*

# CROSS-TRAINING POLICIES FOR ENHANCED RESILIENCE IN EMERGENCY DEPARTMENTS

Moustafa Abdelwanis[1], Eman Ouda[1], Andrei Sleptchenko[1], Adriana F. Gabor[2], Mecit Can Emre Simsekler [1], and Mohammed Omar[1]

[1] Department of Management Science and Engineering, Khalifa University, Abu Dhabi, UAE
[2]Department of Mathematics, Khalifa University, Abu Dhabi, UAE

## ABSTRACT

This paper investigates cross-training policies to enhance emergency department resilience in managing patient demand surges. We evaluated operational performance under varying patient flows using a simulation model based on an emergency department in Abu Dhabi, UAE. Results demonstrated a significant increase in patient length of stay in the triage room due to a shortage of available nurses during surges. Conversely, nurses in other areas (adult zone, pediatrics, and fast-track) were less affected. Two cross-training policies were investigated: pooling nurses from the triage and adult zones and expanding the pool to include the pediatrics section. The first policy reduced patient length of stay in the triage by 91.71%. The second policy further improved flexibility, leading to reductions in length of stay. Additional experiments revealed the limitations of the second policy when subjected to higher surge levels; therefore, further research is needed to explore a broader range of policies and contexts.

## 1 INTRODUCTION

In recent years, resilience has gained significant attention owing to the escalation of disruptive occurrences, ranging from geopolitical tensions to pandemic outbreaks (Saulnier et al. 2021). Among the sectors profoundly impacted, the healthcare industry stands out, particularly susceptible to the consequences of such crises. The emergence of the COVID-19 pandemic exemplifies this vulnerability, as evidenced by the unprecedented surge in patient influx into emergency departments. Under normal circumstances, emergency departments contend with issues of overcrowding and the resultant strain on healthcare providers due to inadequate layout design, staffing levels, and resource distribution (McKenna et al. 2019). The consequences of overcrowded emergency departments extend beyond the immediate challenges faced by healthcare personnel, such as high workload, profoundly affecting the quality of care administered to patients. Increased length of stays in the emergency department can result in adverse health outcomes, including loss of life in extreme conditions (Colella et al. 2022).

One of the primary catalysts for increasing resilience lies in workforce flexibility (Burau et al. 2022). This adaptability gives facilities a strategic advantage, allowing managers to reallocate and schedule resources in response to sudden fluctuations in demand. Recognizing the pivotal role of workforce flexibility, managers across various industries have underscored the importance of cross-training initiatives, encompassing upskilling and reskilling strategies (Agnihothri et al. 2003). Such cross-training strategies have demonstrated the effectiveness of optimizing resource allocation and staffing efficiency across diverse industries. Different levels of cross-training, as highlighted previously (Qin et al. 2015), are shown in Figure 1. Notably, the levels range from dedicated servers, where each server specializes in one service, to full cross-training, wherein all servers are proficient in processing every service type. Additionally, clustering (pooling) means having multiple groups, each characterized by internal full flexibility, without cross-training between groups. Conversely, in chaining, each adjacent servers possess identical qualifications, enabling them to handle identical types of demands.

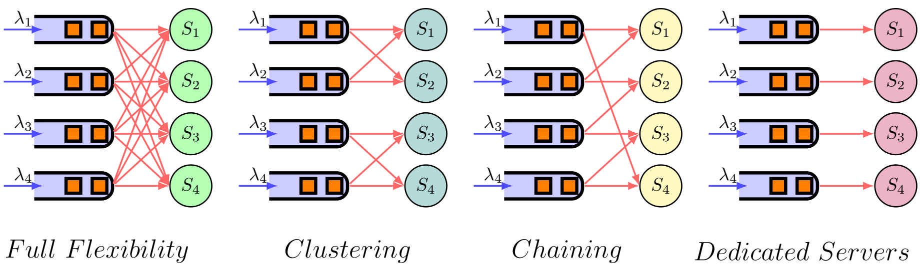



Figure 1: Different configurations of cross-training.

This study investigates the impact of different cross-training strategies on the resilience capabilities of emergency departments in absorbing sudden surges in patient flow. Given the nature of emergency departments, catering to a diverse array of patient needs, the duration of patient wait times within these settings holds significant implications for their probability of survival. A simulation model for a real emergency department in the UAE is used to analyze how different levels of cross-training can mitigate the surge in demand in emergency departments. The remainder of the paper is organized as follows. Section 2 presents different models that study resilience in healthcare and cross-training. Section 3 presents the simulation model and the flow of patients inside the emergency room, while Section 4 presents the experiments conducted to study the effect of different cross-training policies to mitigate the consequences of demand surges. Section 5 presents the conclusion of the work and highlights future research directions.

## 2 LITERATURE REVIEW

This study combines two research areas: cross-training strategies and healthcare resilience. Therefore, we explore different resilience models in healthcare and cross-training applications to improve systems performance. Resilience within the healthcare domain is measured through different qualitative and quantitative models. Regarding qualitative methodologies, Blanchet et al. (2017) underscore resilience in healthcare as the system's ability to adapt, absorb, or transform in response to sudden events, thereby preserving its inherent structure and functionality. They further emphasize the critical role of information management and data collection in anticipating and managing such events to foster resilience. Barasa et al. (2017) introduce the concept of everyday resilience in the aftermath of the Ebola outbreak, stressing the imperative role of resilience capacities in extending beyond crisis response and being readily available for routine operations. This is particularly relevant given the recurrent challenges health systems encounter, such as brief labor strikes or healthcare worker shortages, particularly in rural areas.

Kruk et al. (2017) introduced a resilience index designed to assess resilience within healthcare facilities, drawing insights from three distinct real-life scenarios: the Syrian refugee influx in Lebanon, Liberia's Ebola crisis, and natural disasters in Indonesia. Their index underscores the critical significance of healthcare systems in understanding their resource landscape, including resource allocation and the population's vulnerability to risks. Moreover, they advocate for healthcare systems to effectively cultivate diversity in addressing a spectrum of health needs.

For the quantitative models and the role of operational research (OR) in hospital resilience, Farahani et al. (2023) presents various OR applications in resource allocations, facility location, and capacity planning in future pandemics. Farahi and Salimifard (2021) modeled an emergency department using a Discrete event simulation (DES) model with distinct crisis scenarios. They proposed a simulation-based optimization approach to minimize the additional resources required to withstand the crisis. Resources include various nurses, general physicians, and receptionists.

Basaglia et al. (2022) developed two DES models that imitate the operations of a hospital under routine conditions and post-earthquake scenarios. Employing these models to simulate a small hospital's response in Italy, their findings indicated that delayed treatment was the primary contributor to patient mortality during seismic events, highlighting the importance of managing patients' length of stay during demand surges.

Cimellaro et al. (2017) developed a DES model to assess hospitals' resilience during disaster scenarios, with patient waiting time as the primary response metric. Utilizing a hospital in Turin as the basis for their simulation, the study evaluated the effectiveness of the hospital's emergency plan, which had not been previously implemented at the time of the investigation. Results indicated a reduction in patient waiting times following the emergency plan implementation compared to baseline conditions. Additionally, the study explored various sensitivity scenarios to analyze the impact of augmenting resources on the hospital's resilience.

While existing literature encompasses numerous models examining healthcare resilience across diverse scenarios, there remains a gap in studies investigating the influence of cross-training and multi-skill resource allocations on improving healthcare resilience, which is the primary focus of this study. Cross-training and multi-skill queueing models have been explored across different domains, including manufacturing and call centers, with the aim of enhancing operational efficiency. However, cross-training in healthcare has been limited, especially in studying its impact on improving resilience within emergency departments, highlighting the contribution of this study.

Altendorfer et al. (2021) investigated the effectiveness of cross-training among production workers as a strategy to mitigate the adverse impacts of unforeseen employee absences on service levels. Employing a simulation-based optimization model, their findings revealed that cross-training aids in mitigating the impact of absences; however, maintaining high service levels amidst absences necessitates full cross-training of servers. In the healthcare sector, Paul and MacDonald (2014) explored cross-training between two hospital departments: the surgery and the emergency department. They developed an optimization model to minimize the total cost of the hospital while optimizing the number of nurses required in a chaining design. Harper et al. (2010) developed a stochastic programming approach to optimize nurse staffing levels and skill configurations in hospitals, leveraging a case study to demonstrate the importance of stochastic modeling in accommodating demand variability. Furthermore, Gnanlet and Gilland (2014) investigated three cross-training policies using two-stage stochastic programming, unveiling a threshold beyond which the benefits of cross-training may diminish, depending on training costs. They also emphasized that cross-training can facilitate cost savings in staffing strategies.

In the call center industry, Munoz and Bastian (2016) analyzed the impact of various cross-training configurations aimed at minimizing the total cost of a multi-skill call center. Their study, utilizing a DES model, revealed that employing a chaining strategy outperformed having dedicated servers or implementing full cross-training in terms of total cost while still maintaining a certain service level. Additionally, Kilincli Taskiran and Zhang (2017) proposed a two-stage approach to minimize staffing levels through the utilization of cross-trained servers in call centers. Their results emphasized the pivotal role of cross-training in reducing staffing costs while also highlighting its superiority over hiring part-time shift servers to manage fluctuations in service types.

Despite the abundance of studies analyzing the influence of cross-training on enhancing operational efficiency across diverse domains, to our knowledge, no investigations have studied how cross-training can be leveraged to improve resilience in emergency departments, thereby mitigating the repercussions of sudden surges in patient demand. Improving resilience is assessed by improving the robustness of the system and enhancing the ability to recover from sudden surges. Consequently, we measure resilience based on the emergency department's capacity to manage a sudden patient surge without affecting patients' length of stay, as Cimellaro et al. (2017) and Basaglia et al. (2022) identified that prolonged length of stay was the primary factor contributing to patient mortality during such surges. The current study aims to fill the gap in the literature by examining the significance of cross-training between different sections within emergency departments in improving its robustness to mitigate the impact of a general surge in patient flow. We employ a discrete event simulation model developed based on the actual operations of the emergency department.

## 3 PROBLEM STATEMENT AND METHODOLOGY

This study investigates the performance of an emergency department in Abu Dhabi, UAE, under a high level of overall demand surge spanning a 12-hour period. A simulation model is developed to mimic the actual operations of the emergency department and evaluate its performance under different new scenarios. We evaluate the impact of demand surges on patient service, particularly in terms of patient's length of stay across different stages within the emergency department. Cross-training policies between distinct sections within the emergency department are investigated as a mechanism to enhance the department's capacity to manage heightened patient demand effectively. The length of stay of patients and resource utilization are assessed when pooling nurses from different sections of the emergency department to test the effectiveness of the new policies in enhancing resilience. To ensure the robustness of the numerical experiments comparing two different cross-training policies, the simulation model was replicated until either a significant difference in the length of stay during surge between the policies was detected or the maximum number of iterations was reached. The significance test was conducted with a 90% confidence level, and the maximum number of iterations was set to 15.

### 3.1 Patient Flow in the Emergency Department

Patients arrive at the emergency department with varying levels of severity. This paper focuses exclusively on patients with mild-severity conditions, constituting approximately 70% of those seeking treatment in the emergency department. It is important to note that patients with life-threatening conditions follow a different flow than the one modeled in this study. Figure 2 illustrates a simplified flow chart outlining the trajectory of patients with mild-severity conditions. Upon arrival, patients proceed to the registration phase before advancing to the triage area of the emergency department. It is assumed in this study that 70% of patients undergo triage conducted by specialized triage nurses, while 30% of the patients go to their departments without triage. The timely completion of the triage process is crucial to facilitate the proper allocation of patients to their respective departments based on their condition.

Three distinct sections are identified within the emergency department: pediatrics, fast-track, and adult zone. The pediatrics section caters to infants and patients under the age of 18, while the fast-track area facilitates rapid diagnosis and treatment of patients with minor injuries. Patients not directed to the pediatrics or fast-track areas proceed to the adult zone for further assessment and treatment. Approximately 50% of patients triaged are directed to the adult zone, while 20% are directed to the pediatrics zone, and the remaining patients are routed through the fast-track area. Conversely, among patients who do not undergo triage, approximately 75% are directed to the adult zone, 20% to the pediatrics zone, and 5% to the fast-track area.

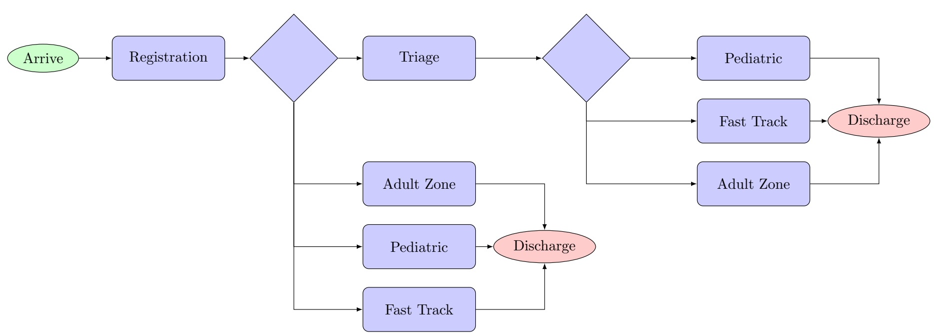



Figure 2: Patients flow inside emergency department.

### 3.2 Simulation Model

A simulation model was implemented in Anylogic to imitate the operations in the real emergency department. The simulation model was validated in a previous study (Ouda et al. 2023), ensuring its validity in replicating the operations of the actual emergency department within the hospital. Real-time data from the hospital, including timestamps, were collected and integrated into the simulation model. The OptQuest Optimization Engine was employed to fine-tune various parameters within the model, aligning its behavior closely with that of the actual emergency department.

### 3.3 Resources in Emergency Department

Each section within the emergency department is equipped with its own dedicated resources, including nurses, beds, and doctors. Nurses and doctors are allocated to specific areas and do not work outside of their assigned departments due to the distinct skill sets required for each area. For instance, nurses stationed in the triage area necessitate rapid assessment skills and proficiency in operating within a fast-paced environment. Similarly, fast-track nurses are expected to possess the ability to promptly assess and treat patients. Conversely, nurses assigned to the pediatrics section must demonstrate proficiency in conducting age-specific assessments and effectively communicating with young patients and their families. Table 1 provides an overview of the nurse staffing schedule during 8-hour shifts across various areas within the emergency department. The emergency department has 26 beds for the adult zone, 11 for pediatrics, and one bed for fast-track. The number of scheduled physicians is 5, 2, and 1 in the adult zone, pediatrics, and fast-track, respectively.

Table 1: Number of nurses scheduled in different areas in the emergency department.

| | Triage | Pediatrics | Adult Zone | Fast-track |
|---|---|---|---|---|
| Shift 1 | 3 | 4 | 9 | 1 |
| Shift 2 | 2 | 4 | 9 | 1 |
| Shift 3 | 3 | 4 | 9 | 1 |

### 3.4 Cross-training Nurses in Emergency Department

In this study, we explore cross-training policies, as illustrated in Figure 1, with a primary focus on clustering (pooling) nurses stationed in the triage area and other departments within the emergency department. Pooling enables nurses from two distinct departments to perform tasks assigned to both types of nurses, as patients coming in will seize any nurse from the nurse pool according to FCFS policy. By pooling resources across both departments, nurses can effectively respond to surges in patient flow, enhancing the department's overall capacity to manage increased demand. This approach is especially advantageous in scenarios where one section experiences higher utilization than the other, as it enables the redistribution of resources as needed.

## 4 NUMERICAL EXPERIMENTS

In this section, we conducted experiments to analyze the impact of a sudden surge in patient demand in the emergency department and to evaluate cross-training policies and their influence on the hospital's resilience in addressing demand surges.

### 4.1 Surge in Patients Flow

In this subsection, we investigate the effects of a sudden surge in patient demand within the emergency department over a 12-hour period, spanning from 7 a.m. to 7 p.m. The surge simulated in this study represents a general influx of patients distributed across different department sections based on typical distribution percentages, as outlined in Subsection 3.1. Figure 3 illustrates the surge in incoming patient rates (shown in red) side by side with normal rates (shown in blue). Our analysis involves comparing the emergency department's performance during the demand surge to its performance under normal conditions. We selected the length of stay in the emergency department (from arrival to departure) as the primary metric for measuring the impact of the patient surge on service delivery. The simulation model was executed with the influx of patients during the surge, and the resulting length of stay for patients was compared to that observed under normal conditions. Various performance indicators were collected from the simulation model to evaluate resource utilization during the surge. Additionally, we examined the length of stay across different sections within the emergency department to identify potential bottlenecks in service delivery.

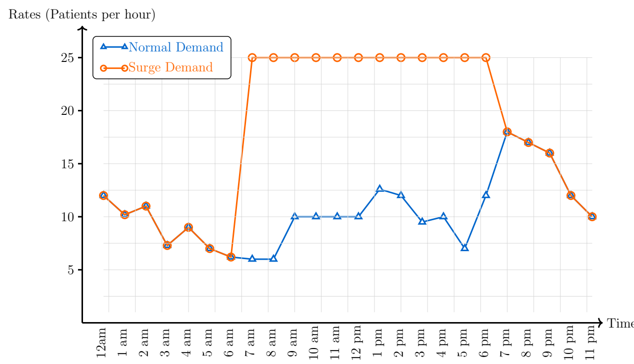


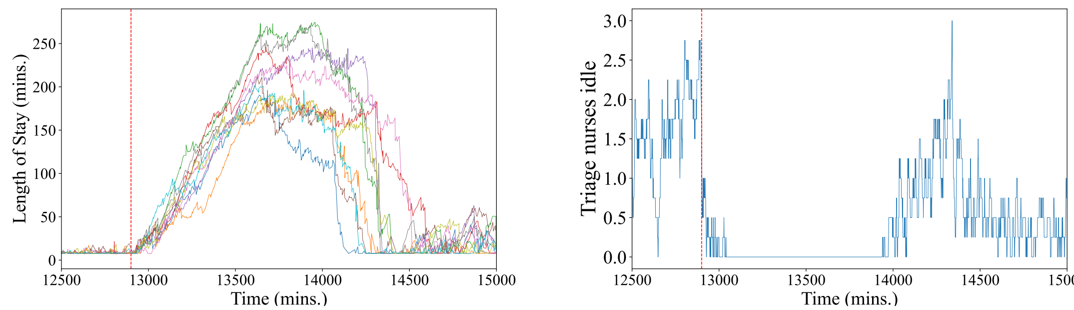

Figure 3: Surge in the demand of patients compared to the normal rates of patient arrivals.

We compare the average length of time in the normal scenario with the length of stay averaged over a day and a half after the start of the surge. Our findings revealed a notable increase in the length of stay for patients during the surge, amounting to a surge-related increase of 96.16% (approximately 268.74 minutes compared to approximately 137 minutes). This underscores the profound impact of demand surges on emergency departments, potentially compromising the quality of patient care and, in severe cases, leading to loss of life.

Furthermore, we examined various timestamps across different directions of patient flow to illustrate the surge's effects on different areas within the emergency department. Our analysis revealed a substantial increase in time spent in the triage room, soaring by 622.3% (approximately 105.25 minutes compared to approximately 14.57 minutes) due to the surge in patient flow. Additionally, the average length of stay of patients passing through the adult zone, pediatrics, and fast-track areas increased by 91.1%, 161.33%, and 95.43%, respectively, during the surge period. These findings underscore the significant implications of demand surges on emergency department operations and patient outcomes.

Additionally, we examined the average utilization of resources during the surge event, particularly focusing on the number of idle nurses in each area within the emergency department (triage, adult zone, pediatrics, fast-track). Our analysis revealed that triage nurses were the most heavily utilized during the surge period. Specifically, the average number of available nurses during the surge in the triage area was 0.348, whereas the available nurses in the adult zone, pediatrics, and fast-track were 7.191, 3.543, and 0.864 nurses, respectively. These findings underscore the critical impact of demand surge on the triage room and the need for efficient resource allocation and management during periods of heightened demand within the emergency department. On the other hand, the number of available doctors in the adult section and pediatrics were found to be 0.406 and 0.635, respectively. The variability in nurse availability across different areas compared to doctors suggests that cross-training among nurses would be a more effective solution than cross-training between triage nurses and doctors.

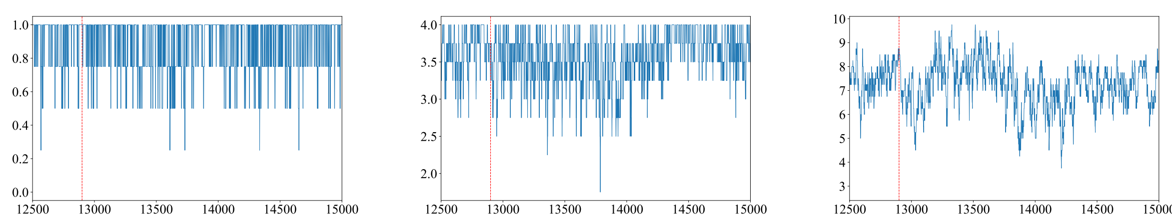
Triage is one of the most important functions of the emergency department as it classifies patients based on their severity. Delays in the triage area can affect patient care significantly before they meet a physician. Figure 4 shows the length of stay of the patient in the triage room (on the left) and the number of idle triage nurses during the surge (on the right). The figure illustrates a sharp rise in the length of stay for patients immediately following the surge event (indicated by the red dashed line). Furthermore, the right graph shows that the number of idle triage nurses decreased significantly, approaching zero, after the surge event. These observations highlight the substantial impact of the surge on the utilization of nursing resources within the triage area. Figure 5 shows the number of idle nurses in other areas in the emergency room (pediatrics, adult nurse, and fast-track). The graphs show that sections other than the triage were less affected by the surge in terms of resource utilization.




(a) Length of stay in the triage

(b) Average number of available Triage nurses

Figure 4: The performance of the triage room in the event of surge (red dashed line represents the start of the surge).



(a) Idle Fast-track Nurses

(b) Idle pediatrics Nurses

(c) Idle Adult Zone Nurses

Figure 5: The average number of idle nurses in different areas during the surge of patient flow (red dashed line represents the start of the surge).

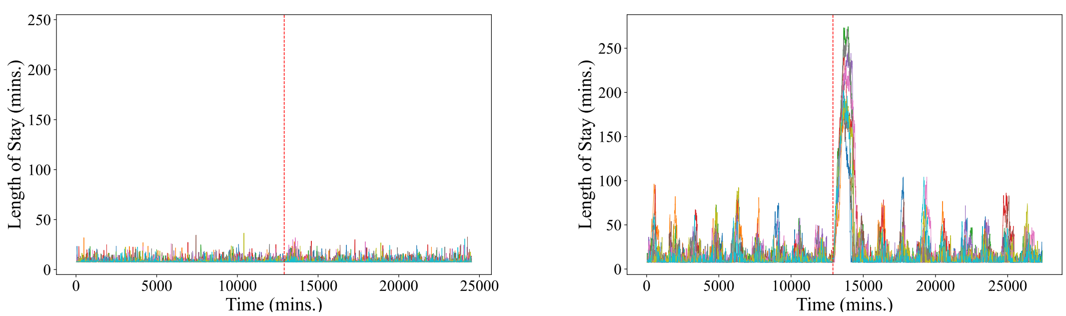
### 4.2 Cross-training Between Triage and Adult Zones

In this subsection, we examine cross-training policies between the triage section and various sections within the emergency department. The initial policy under investigation involves pooling nurses from two distinct sections: the triage section and the adult zone section. The triage section has been identified as the bottleneck and is most severely impacted by the surge in terms of available resources. Conversely, the adult zone section has the highest number of available nurses during the surge. Assuming that nurses from both the triage and adult zone areas are cross-trained and possess equal qualifications to fulfill duties in either section of the emergency department, the number of scheduled nurses according to the new schedule is outlined in Table 2. This revised schedule aims to enhance the system's flexibility in managing the surge in patient flow, capitalizing on the surplus of available idle resources in the adult zone compared to the triage section. Subsequently, this new configuration is implemented in the simulation model to evaluate the system's performance under the revised conditions during a surge in patient flow.

Table 2: Number of nurses scheduled in different areas in the emergency department after cross-training.

| | Triage + Adult Zone | pediatrics | Fast-track |
|---|---|---|---|
| Shift 1 | 12 | 4 | 1 |
| Shift 2 | 11 | 4 | 1 |
| Shift 3 | 12 | 4 | 1 |

After running the simulation model with cross-trained nurses between the triage and adult zone, we compare the length of stay of patients in both sections, the triage and the adult zone. Results revealed a significant 91.71% decrease in the average length of stay of patients in the triage room ($\sim$ 8.72 minutes compared to $\sim$ 105.25 minutes). The $t$-test after ten replications indicated a significant improvement with $t$-value of 13.748, and the $p$-value of $2.398 \times 10^{-7}$. Figure 6 illustrates the length of stay for patients in the triage during the surge, both with and without cross-training. Notably, a substantial reduction in the peak length of stay after the start of the surge is observed when nurses from both the triage and adult zones are pooled together as a unified group. Furthermore, a decrease in patient length of stay throughout the entire simulation time was observed, indicating that nurse pooling provides advantages to the emergency room not only during periods of patient surge but also during routine operations. This underscores the effectiveness of cross-training in mitigating the impact of surge events on patient flow dynamics within the emergency department.

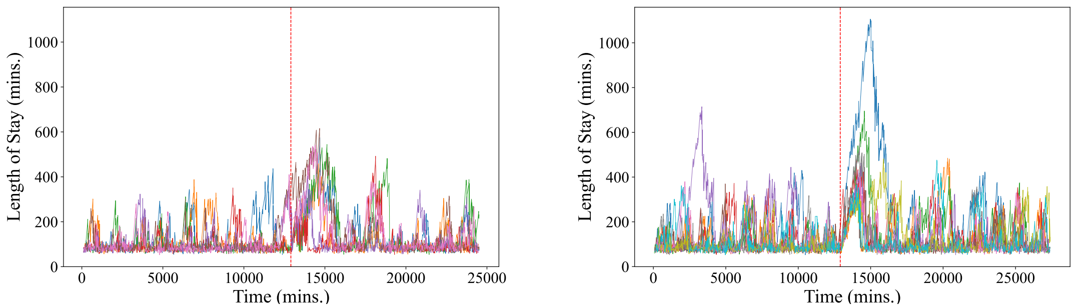



(a) With cross-training (b) Without cross-training

Figure 6: Comparison between the length of stay in triage with and without cross-training (red dashed line represents the start of the surge).

We also examined the length of stay for patients passing through the adult zone after the triage to assess the impact of cross-training on their journey. Results indicate that the length of stay for patients in the adult zone decreased by 24.27% with cross-training ($\sim$ 197.62 minutes compared to $\sim$ 260.97 minutes). The $t$-test based on fifteen samples also indicated a significant improvement, with a $t$-value of 1.926 and a $p$-value of 0.074. Figure 7 illustrates the length of stay for patients in the adult zone during the surge, both with and without cross-training. It is evident that there is a reduction in the peak length of stay following the surge in both the triage and the adult zone, attributable to the enhanced flexibility in patient capacity achieved by cross-training.

Since the triage room is common between the adult and pediatric zones, reducing patients' length of stay in the triage should reduce the overall length of stay for patients in the pediatrics section. Therefore, we examined the change in the length of stay of patients who pass through the pediatrics zone. Results indicated that patients' average length of stay in the pediatrics section was 50.8% lower than the length




(a) With cross-training (b) Without cross-training

Figure 7: Comparison between the length of stay in the adult zone with and without cross-training (red dashed line represents the start of the surge).

of stay without cross-training ($\sim$ 111.98 minutes compared to $\sim$ 227.683 minutes). The $t$-test based on fifteen iterations indicated a significant improvement with $t$-value of 5.107, and the $p$-value of $1.594 \times 10^{-4}$. These results highlight the significance of cross-training triage nurses as an improvement in the length of stay in the triage room during patient surge will translate into a comprehensive improvement in the length of stay in the emergency room.

### 4.3 Cross-training Between Triage, Pediatrics, and Adult Zones

In this subsection, we explore another cross-training policy to enhance flexibility and resilience across all primary areas of the emergency department. This policy expands the pool of cross-trained nurses to include those from the pediatrics area, triage, and adult zones. Subsequently, we implemented this new policy in the simulation model to evaluate system performance under the revised conditions.

The impact of the new cross-training policy was evaluated by measuring the length of stay for patients across various areas within the emergency department. Results indicate that during the surge period, the average length of stay for patients in the triage area was lower compared to scenarios where dedicated nurses were assigned or when cross-training was limited to the triage and adult zones. Additionally, the new policy reduced the average length of stay in both the pediatrics and adult zone areas compared to scenarios with dedicated nurses and limited cross-training between the triage and the adult zone. Table 3 compares the average length of stay in different areas of the emergency department. Overall, the new cross-training policy demonstrated improvements in the length of stay across various areas of the emergency department, attributed to the heightened flexibility in workforce allocation during surge periods.

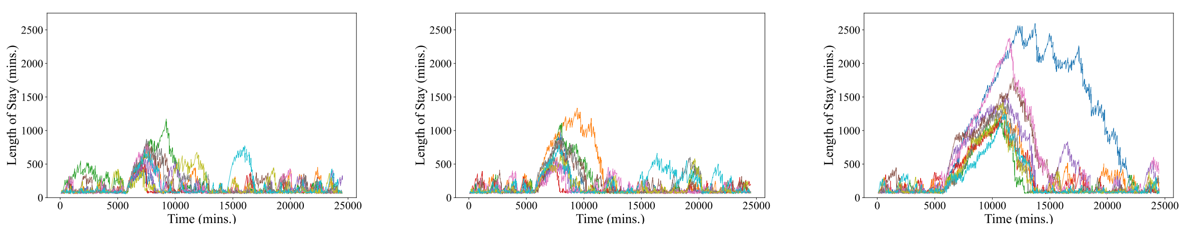
Table 3: The average length of stay (in mins.) in different areas in the emergency department under different cross-training policies (after 15 replications).

| | Triage | Adult Zone | pediatrics |
|---|---|---|---|
| Dedicated nurses | 101.649 | 260.97 | 227.68 |
| Triage and adult zone | 8.56 | 197.62 | 111.98 |
| Triage, adult zone, and pediatrics | 8.3 | 103.199 | 81.93 |

We also examined resource utilization under the new cross-training policy. Specifically, we measured the availability of resources, including nurses, beds, and doctors, during the surge in demand. Under the new cross-training policies, the average number of available nurses was approximately 11.07. These findings highlight the impact of the cross-training policies on the improved utilization of nurses during periods of heightened demand within the emergency department. Additionally, the number of available beds in the adult zone and pediatric sections during the surge was approximately 9.270 and 8.08, respectively. Furthermore, the number of available doctors in the adult zone and pediatric sections was found to be approximately 0.841 and 0.994 compared to 0.406 and 0.635 when having dedicated nurses, respectively.

### 4.4 Testing Robustness of Cross-training under Different Levels of Surges

In this section, we evaluate the impact of different levels of surges when cross-training the triage, adult zone, and pediatrics sections. Specifically, we tested two additional surge scenarios. The first scenario involves an arrival rate of 40 patients over a 6-hour period from 7 a.m. to 1 p.m., while the second scenario involves 100 patients over the same time frame. Figure 8 shows the length of stay for patients who pass through the adult zone under varying surge levels when cross-training is implemented. The results indicate that the cross-training policy yields a similar impact for surge levels of 20 and 40 patients, whereas the 100-patient surge significantly increases patient length of stay who pass through the adult zone. This finding highlights the limitations of the cross-training policy in accommodating extremely high levels of demand surges. High levels of surges necessitate better and more comprehensive resource management.




(a) 20 patients/hour for 12 hours (b) 40 patients/hour for 6 hours (c) 100 patients/hour for 6 hours

Figure 8: The length of stay of patients during different scenarios of surges.

## 5 CONCLUSION AND FUTURE DIRECTIONS

This paper examined two cross-training policies for improving the resilience of an emergency department in Abu Dhabi, UAE, under a sudden surge in patient flow. A simulation model was developed in Anylogic to mimic the actual operations of the emergency department. Pooling strategies were implemented and evaluated using the simulation model for their impact on enhancing the department's ability to adapt and respond to a sudden increase in patient flow. Our findings revealed that pooling nurses with nurses from different sections significantly reduced the average length of stay for patients during surge events, thereby improving the resilience of emergency departments. Pooling triage and adult zone nurses significantly reduced the length of stay of patients after the surge by 91.57% in the triage room and 24.27% in the length of stay of patients that go into the adult zone. Furthermore, expanding the pool of cross-trained nurses to include pediatrics increased the overall flexibility and reduced patients' length of stay across the emergency department. Furthermore, we observed enhanced flexibility and resilience across the entire system, as the average number of available nurses increased to 11.07 compared to almost zero without cross-training. Overall, the results underscore the significance of strategic planning approaches such as cross-training in improving the resilience capabilities in the emergency department.

This study has several limitations that should be considered. The model assumes that nurses from various areas of the emergency department can be cross-trained to perform tasks interchangeably with no additional drawbacks. This, however, may not fully capture the variations in training time, learning curves, physical space limitations, and potential impacts on care quality. Moreover, this study only incorporates two cross-training policies and three levels of surges. The study does not explore the full range of possible scenarios and their long-term effects on staff morale, burnout, and employee retention. These limitations suggest avenues for future research, which should include a broader range of cross-training policies and aim to optimize the most suitable approach accounting for the inherent cross-training costs. Additionally, extending this research to encompass other departments in different countries would help validate the findings on a broader scale.

## REFERENCES


Agnihothri, S. R., A. K. Mishra, and D. E. Simmons. 2003. "Workforce cross-training decisions in field service systems with two job types". *Journal of the Operational Research Society* 54(4):410–418 https://doi.org/10.1057/palgrave.jors.2601535.

Altendorfer, K., A. Schober, J. Karder, and A. Beham. 2021. "Service level improvement due to worker cross training with stochastic worker absence". *International Journal of Production Research* 59(14):4416–4433 https://doi.org/10.1080/00207543.2020.1764126.

Barasa, E., K. Cloete, and L. Gilson. 2017, 11. "From bouncing back, to nurturing emergence: Reframing the concept of resilience in health systems strengthening". *Health Policy and Planning* 32:91–94 https://doi.org/10.1093/heapol/czx118.

Basaglia, A., E. Spacone, J. W. van de Lindt, and T. D. Kirsch. 2022. "A Discrete-Event Simulation Model of Hospital Patient Flow Following Major Earthquakes". *International Journal of Disaster Risk Reduction* 71:102825 https://doi.org/https://doi.org/10.1016/j.ijdrr.2022.102825.

Blanchet, K., S. Nam, B. Ramalingam, and F. Pozo-Martin. 2017, 04. "Governance and Capacity to Manage Resilience of Health Systems: Towards a New Conceptual Framework". *International Journal of Health Policy and Management* 2017:1–5 https://doi.org/10.15171/ijhpm.2017.36.

Burau, V., M. Falkenbach, S. Neri, S. Peckham, I. Wallenburg and E. Kuhlmann. 2022. "Health system resilience and health workforce capacities: Comparing health system responses during the COVID-19 pandemic in six European countries". *The International Journal of Health Planning and Management* 37(4):2032–2048 https://doi.org/10.1002/hpm.3446.

Cimellaro, G. P., M. Malavisi, and S. Mahin. 2017. "Using Discrete Event Simulation Models to Evaluate Resilience of an Emergency Department". *Journal of Earthquake Engineering* 21(2):203–226 https://doi.org/10.1080/13632469.2016.1172373.

Colella, Y., D. Di Laura, A. Borrelli, M. Triassi, F. Amato and G. Improta. 2022, 11. "Overcrowding analysis in emergency department through indexes: a single center study". *BMC Emergency Medicine* 22:181 https://doi.org/10.1186/s12873-022-00735-0.

Farahani, R. Z., R. Ruiz, and L. N. Van Wassenhove. 2023. "Introduction to the special issue on the role of operational research in future epidemics/ pandemics". *European Journal of Operational Research* 304(1):1–8 https://doi.org/https://doi.org/10.1016/j.ejor.2022.07.019. The role of Operational Research in future epidemics/ pandemics.

Farahi, S. and K. Salimifard. 2021, 11. "A simulation-optimization approach for measuring emergency department resilience in times of crisis". *Operations Research for Health Care* 31:100326 https://doi.org/10.1016/j.orhc.2021.100326.

Gnanlet, A. and W. G. Gilland. 2014. "Impact of productivity on cross-training configurations and optimal staffing decisions in hospitals". *European Journal of Operational Research* 238(1):254–269 https://doi.org/https://doi.org/10.1016/j.ejor.2014.03.033.

Harper, P., N. Powell, and J. Williams. 2010, 05. "Modelling the size and skill-mix of hospital nursing teams". *JORS* 61:768–779 https://doi.org/10.1057/jors.2009.43.

Kilinci Taskiran, G. and X. Zhang. 2017. "Mathematical models and solution approach for cross-training staff scheduling at call centers". *Computers & Operations Research* 87:258–269 https://doi.org/https://doi.org/10.1016/j.cor.2016.07.001.

Kruk, M. E., E. J. Ling, A. Bitton, M. Cammett, K. Cavanaugh, M. Chopra, , , , , , , , , , , *et al*. 2017. "Building resilient health systems: a proposal for a resilience index". *BMJ* 357 https://doi.org/10.1136/bmj.j2323.

McKenna, P., S. Heslin, P. Viccellio, W. Mallon, C. Hernandez and E. Morley. 2019, 07. "Emergency department and hospital crowding: Causes, consequences, and cures". *Clinical and Experimental Emergency Medicine* 6:189–195 https://doi.org/10.15441/ceem.18.022.

Munoz, D. A. and N. D. Bastian. 2016, dec. "Estimating cross-training call center capacity through simulation". *Journal of Systems Science and Systems Engineering* 25(4):448–468 https://doi.org/10.1007/s11518-015-5286-9.

Ouda, E., A. Sleptchenko, M. C. Emre Simsekler, and G. R. El-Eid. 2023. "Measuring Emergency Department Resilience to Demand Surge: A Discrete-Event Simulation Framework". In *2023 Winter Simulation Conference (WSC)*, 1018–1029: IEEE Press https://doi.org/10.1109/WSC60868.2023.10408059.

Paul, J. A. and L. MacDonald. 2014, apr. "Modeling the benefits of cross-training to address the nursing shortage". *International Journal of Production Economics* 150:83–95 https://doi.org/10.1016/j.ijpe.2013.11.025.

Qin, R., D. A. Nembhard, and W. L. Barnes. 2015. "Workforce flexibility in operations management". *Surveys in Operations Research and Management Science* 20(1):19–33 https://doi.org/10.1016/j.sorms.2015.04.001.

Saulnier, D. D., K. Blanchet, C. Canila, D. C. Muñoz, L. D. Zennaro, D. de Savigny, , , , , , , , , , , , , , , *et al*. 2021. "A health systems resilience research agenda: moving from concept to practice". *BMJ Global Health* 6(8) https://doi.org/10.1136/bmjgh-2021-006779.

## AUTHOR BIOGRAPHIES

**MOUSTAFA ABDELWANIS** is a Ph.D. candidate in the Department of Management Science and Engineering at Khalifa University. His research interests are in operations research and management, as well as data analytics in the healthcare sector. Moustafa's research focuses on developing algorithms to optimize resource allocation in stochastic systems, alongside exploring the applications of AI-powered technologies in the healthcare sector. His email address is moustafa.abdelwanis@ku.ac.ae.

**EMAN OUDA** is a Ph.D. candidate in the Department of Management Science and Engineering at Khalifa University. Her research interests lie in the design and analysis of stochastic simulations under input uncertainty, as well as the applications of data analytics and simulation-based optimization in operations management, with a focus on healthcare systems. Eman's work specifically focuses on developing mathematical models and algorithms for emergency departments with limited resources and uncertainty. Eman's work has the potential to significantly improve the efficiency and effectiveness of emergency department operations. The current email address of Eman Ouda is eman.ouda@ku.ac.ae, and her homepage is https://www.ku.ac.ae/college-people/eman-ouda-2.

**ANDREI SLEPTCHENKO** is an Associate Professor at the Department of Management Science and Engineering at Khalifa University. His primary research interests are in the modeling and optimization of various stochastic service systems with limited resources. Before joining Khalifa University, Dr. Sleptchenko served as a faculty member at the Department of Mechanical and Industrial Engineering at Qatar University. Prior to that, he worked for several years for different consulting companies in the area of Supply Chain and Transportation and as an Assistant Professor and a researcher at various Universities in the Netherlands and the USA. The current email address of Dr. Sleptchenko is andrei.sleptchenko@ku.ac.ae and his website is https://www.ku.ac.ae/college-people/andrei-sleptchenko.

**ADRIANA F. GABOR** is an Associate Professor in the Department of Mathematics at Khalifa University. She obtained a PhD in Applied Mathematics (Operations Research) from the University of Twente in The Netherlands. Prior to joining Khalifa University, she worked at Eindhoven University of Technology, Erasmus University Rotterdam in the Netherlands, and United Arab Emirates University in the UAE. Her research interests lie in developing algorithms and mathematical techniques for solving optimization problems, especially for applications in supply chain and telecommunication. In particular, she worked on location, inventory, and transportation problems. Her research has been published in well-established journals in her field, such as the European Journal of Operations Research, Computers and Operations Research, Transportation Science, Queuing Systems, and Discrete Applied Mathematics. Her email address is adriana.gabor@ku.ac.ae and her website is https://www.ku.ac.ae/college-people/adriana-gabor.

**MECIT CAN EMRE SIMSEKLER** is an Associate Professor at the Department of Management Science and Engineering at Khalifa University. He is also a visiting scholar at Boston Children's Hospital (Teaching Hospital of Harvard Medical School) and University College London (UCL) School of Management. Dr Simsekler's research interests span healthcare analytics and management to improve operational and safety outcomes and accelerate risk-based decision-making. He explores the role of systems thinking, business analytics, and disruptive technologies, such as artificial intelligence and machine learning, to leverage digital and sustainable transformation in building high-value health systems. The current email address of Dr. Simsekler is emre.simsekler@ku.ac.ae and his website is https://www.ku.ac.ae/college-people/mecit-can-emre-simsekler.

**MOHAMMED OMAR** is a Professor of Industrial and Systems Engineering at Khalifa University since 2012. Prior to joining KU he served as a graduate coordinator, and a founding faculty member of the Clemson University, CUICAR technology park, and the automotive engineering programs. Dr. Omar publishes on Engineering education and the future of work in the digital economy. His research is published in more than 180 journal manuscripts, textbooks, and four US and international patents. His research was awarded the SAE Foundation Manufacturing Award, the Murray Stokely Excellence Award, the SME Richard L. Kegg Manufacturing Award, among others. He is currently the editor-in-chief for the Journal of Material Science Research, and an associate editor for the Springer (Nature) Journal of Soft Computing. The current email address of Dr. Omar is mohammed.omar@ku.ac.ae and his website is https://www.ku.ac.ae/college-people/mohammed-omar.