Alexandria Engineering Journal (2022) 61, 10109–10118

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Alexandria Engineering Journal

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Airport terminal building capacity evaluation using queuing system

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Received 21 January 2022; revised 9 March 2022; accepted 21 March 2022
Available online 30 March 2022

KEYWORDS

Airport;
Capacity;
IATA;
Level of service;
Queuing theory;
Terminal building

Abstract Queues or waiting lines are a natural occurrence in the everyday lives of consumers and the process of every business. Being customers' first point of contact with the business, a customer's experience in the queue becomes a determining factor of their first impression of the business. Queuing provides the cornerstone of efficiency to businesses as they assist employees and managers in tracking, prioritising, and ensuring the delivery of services and transactions. Inefficiencies in queues are undesired as they can result in substantial losses to a business, such as bad reputation and loss of customers due to balking or reneging behaviour.

Previous research has shown that the application of queuing theory enables businesses to analyse their queuing system and the trends of demand for their services. This allows the business to effectively identify measures to improve their queuing system and serve demand at the desired level of service.

In this paper, where it examined Cairo International Airport (CAI)'s existing departure queue system and benchmarked it against the optimum wait time suggested in the International Air Transport Association's (IATA) Level of Service (LoS) concept. The application of Kendall-Lee's Notation is applied to describe the existing queuing system of the airport. It also suggested areas of improvement after the analysis and recommended that the CAI focus on improving service time for its Check-in, Security, and Boarding process. Although the Immigration process has met IATA's recommended optimal wait time, training could be provided to employees to enable them to progressively work towards a better service time and prepare for the future higher traffic volume.

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

https://doi.org/10.1016/j.aej.2022.03.055

The team has also suggested for CAI to introduce autonomous technology for the departure process and software which analyses passenger flow and projects a forecast value based on the airport growth trends.

1. Introduction

Queues exist across all businesses, whether visible or not, and the airport is no exception. The Terminal Building Capacity (TBC) refers to the maximum number of inbound and outbound passengers that the terminal can accommodate with its existing facilities. Two indicators measure it, i.e., the number of passengers it can serve during peak hours or year and the number of passengers who pass through the terminal in an hour or year respectively [1]. However, the capacity of the terminal building can be affected by the efficiency and capability of the queuing system. Inefficient service facilities or an insufficient number of service facilities provided can result in severe bottlenecks, affecting overall terminal capacity ([17]).

Previous research has shown that the application of queuing theory enables businesses to analyse their queuing system and the trends of demand for their services. This allows the business to effectively identify measures to improve their queuing system and serve demand at the desired level of service.

Furthermore, terminal capacity is finite, making inaccurate planning to meet demand result in a high cost to the airport. In the context of an airport, such costs may include delay costs or bad reputation, which leads to loss of customers for the airlines. Additionally, under the condition where increasing capacity is spatially viable, upgrading the service facilities is also expensive. Hence, an accurate evaluation of the queuing system to identify potential bottlenecks is vital to help airport management improve the queuing system and ensure maximum utilization of available terminal space ([17]).

The time that customer spends in a queue strongly correlates with his or her level of satisfaction [1]. Furthermore, customers form a first impression of the company through their first contact with the company, therefore, evaluating terminal building capacity is essential to enhance the Level of Service (LoS) performance and boost the efficiency at which an airport can operate [1] (ref.). The purpose of this paper is to explore and examine the existing queue system of Cairo International Airport (*CAI*) during the passenger departure process using queuing theory and, in turn, suggest improvements that can be made to the system to minimize the passenger delays and at the same time maintain the same LoS as recommended by IATA.

2. Literature review: queuing theory and its applications

Through the past decades, many queuing models have been developed, these models can be categorized into three categories: Macroscopic (strategic), Mesoscopic (Managerial), and Microscopic (Operational), these three levels of queuing models are developed to explore the relationship between the capacity and demand in terms of three essential performance measure, aircraft movement, number of passengers, and amount of cargo. These models may be either deterministic or stochastic, the main results of queuing theory and its applications are obtained under steady-state conditions. Agner K. Erlang, a Danish mathematician and engineer, pioneered the research of the queuing theory in 1909. He began developing the theory after realising the application of his project to reduce wait time for a phone service company could be expanded to other fields . Studies have demonstrated the correlation between wait time and customer satisfaction; the longer the wait time, the lower the level of customer satisfaction . Therefore, the application of queuing theory is important to help allocate available resources to serve the demand in a timely and cost-efficient manner. The study on queuing theory aims to minimise customers' wait time in queues and optimise utilisation of limited resources. Using queuing theory, analysis of a business's expected queue length, frequency of the queue system being in certain states as well as the customer expected wait time can be derived [17].

A model of airport congestion which has received considerable attention in which the demand process and the service process are approximated as a Poisson process and an Erlang process respectively. Given the computational intractability of this dynamic model, a numerical approximation called DELAYS has been developed and algorithmically implemented.

Queueing model simulation can enable rapid model development and is often able to produce a more accurate representation of the situation and the inputs involved [7]. The queuing system refers to the process by which a customer enters the queue, waits for the service, and then exits the system after receiving it. It should be noted that queuing system elements have been categorised differently by different sources. However, the basic queuing system elements are covered in the categorisation of Bhat, namely the Arrival Process, Service Mechanism, System Capacity, and Queuing Disciplines ([17]).

The arrival or Input Process is the first element of the queuing system. When designing the queue structure for an airport, it is essential to account for all information related to the number of arrival passengers in the airport at various time intervals, also known as the arrival rate. This information can be categorised into three categories, i.e., Source, Time, and Number of customers. Source decides if customers originated from finite or infinite populations. Time defines the known or random intervals between the incoming traffic. Known intervals are categorised as deterministic models and described as probability or Poisson distribution. Whereas, the final category, number of customers, determines if customers arrive individually or collectively as a group ([5]).

Service Mechanism or Service Process is another element in the queuing system. It comprises two aspects, i.e., the structure of the service system and the speed of service. The layout of the service facilities is referred to as the Service System Structure, which can adopt any of the following four service system structures. Firstly, a Single Service Facility is a single service model in which customers arrive and are served by a single server. Secondly, Multiple, Parallel Facilities with Single Queue is a facility with multiple servers providing the same type of service but employs a multiple, parallel service structure. Third, the Multiple Parallel Facilities with Multiple Queues indicates that there is more than one server, each with a different queue, performing the same type of task and that there are multiple customer lines despite a single line. The last service structure is Service Facilities in a Series. In this system, a customer enters the first service station, receives a portion of a service there, then moves on to the second station to receive another portion of the service, and so on. When the entire service is completed, the customer exits the system.

Speed of Service refers to the speed with which the service is provided to the customer when he enters the queuing system. This can be expressed in two ways, i.e., Service Rate and Service Time. The Service Rate is the number of customers served in a given time period. The Service Time, on the other hand, refers to the amount of time required to serve a customer. Service time and service rate are reciprocals of each other ([24]).

System capacity refers to the maximum number of customers that can wait in the queue at a single time (Bhat, 2010). Capacity is usually finite as once full capacity is reached, customers are rejected from receiving the service. Since increasing capacity is not always economically or spatially feasible, effective planning is essential to ensure customers are served at the desired performance level. However, an accurate prediction of capacity is implausible without extensive historical data of the performance and analysis of trends using linear regression [1]. Capacity can also be infinite, which is assumed in the models where there is no physical queue, such as in a call centre (Green, 2011).

Queue Disciplines is an element in the queuing system. which refers to the order in which customers are selected from the queue for service [19]. In this paper, five queue discipline models will be highlighted. However, the most frequently used system is First Come First Served (FCFS), whereby customers are processed in the order of arrival. FCFS is regarded as the system performed with the highest level of fairness [21]. However, a failure to evaluate the service time and importance of consumers often results in high-priority clients being let go when capacity is reached. Therefore, the Priority Queuing (PQ) system resolves this problem by ranking customers based on their level of importance. FCFS is often integrated into PQ, where multiple queues are formed to cater to customers of different classes of priority (Peterson & Davie, 2012). The Shortest Processing Time First (SPTF) model can be an alternative model to help boost level of satisfaction and reduce frequency of full load capacity through improving queue efficiency. In SPTF, with minimal time required for service are rendered services before others. However, if service time cannot be determined, SPTF cannot be implemented [21]. Last Come, First Served (LCFS) refers to when the service is provided to customers who arrive last. In the LCFS discipline of service, it removes the incentive provided to arrive early in FCFS. It also eliminates the inefficiencies of having to observe queues to identify which customer has arrived first (Ting, 2015). According to Jounin (Jounin, 2012), the LCFS model is often implemented to serve the baggage loading and offloading to/from aircrafts, also impatient customers or those with higher urgency. He illustrates this in the form of aircraft in a holding pattern upon landing; an aircraft facing technical issues or are about to enter fuel exhaustion will be attended first when a long queue has formed in the landing pattern. Service In Random Order (SIRO) is a discipline model whereby selection and services are rendered to customers at random and not subjected to the arrival time of the customer [20].

2.1. Customer behavior in queuing theory

Depending on the customer's experiences in the queue, it could promote three types of queuing behaviour. Firstly, Balking occurs when the queue is too long, and the customer is unable or unwilling to join the queue upon their arrival. Secondly, Reneging refers to the behaviour of customers who become impatient and eventually opt to abandon the queue. Lastly, the provision of multiple channel facilities may encourage Jockeying behaviour, which occurs when customers move from one queue to another in an attempt to receive faster service [23].

2.2. Industrial application of queuing theory

As mentioned, the queuing theory developed could be applied to different fields ranging from retail to healthcare (Green, 2006), which also includes the aviation industry. Walden and Rouse (1978) aimed to study the pilot's sequence of action when multiple errors were detected concurrently to better allocate decision-making tasks between the aircraft automation and the pilot. In this case, the queuing theory was applied, with the different types of errors acting as "customers" and the participating pilots acting as "servers". In a separate study, Lange et al. [16] applied the queuing theory and simulation model to investigate the possibility of virtual queuing of security immigration to increase operational efficiency at the airports.

3. Research problem and case study characterization

The aviation market is expanding, and passenger traffic at many international airports has increased from year to year. With ever-increasing passenger numbers, airports face the challenge of ensuring consistency in service quality while also attempting to improve it using pre-existing resources. Customer satisfaction and cost-effectiveness have emerged as critical objectives for airport operations. These two objectives are critical in the passenger departure process as it marks the beginning of the passenger journey and is the first point of contact of the customers to the airport. Therefore, this paper focus on the passenger departure process, where this process includes the following touchpoints: Check-in, Security checkpoints, Immigration, and Boarding.

In recent years, automatic check-in facilities have gained popularity. Traditional check-in counters, however, continue to exist due to factors such as security, convenience, operational issues, and passenger preference for human interaction. Check-in counters are a scarce resource in many airports. During peak hours, the number of check-in counters is insufficient to meet total demand, resulting in long wait times for passengers. Efficient use of check-in counter resources in airport terminals is a major issue for airport managers and airlines.

Inadequate utilization and inefficient use of resources such as check-in counters and staff have become major factors affecting passenger congestion and delays in the departure process (ref.). Passengers on departing flights are typically expected to arrive 2 to 3 h before their departure time. The check-in counters are usually open for two hours and close 30 min prior to the scheduled departure time.

The airport also established a number of security checkpoints to ensure the personal safety of passengers. This increases the likelihood of bottlenecks occurring due to a surge in the number of people arriving at the security checkpoint. Therefore, resolving the bottleneck at the security checkpoint is critical to eliminate impending issues such as such as the delay of some flights.

Passengers proceed to immigration after passing through the check-in and security checkpoints, which is an important part of the departure process. However, due to limited capacity, queues may form during peak hours. Our case study is focusing on Cairo International Airport, Egypt, this airport has 3 parallel runways and having three Terminal Buildings (TB), TB1, TB2, and TB3 with different capacities as follows 7.5, 7.5 and 11 million passenger per year respectively, terminal building 1 is dedicated for Low-Cost Carrier (LCC), terminal building 2 is dedicated for one world, sky team, and the Arab group airlines, while terminal building 3 is dedicated for Star Alliance Members. Fig. 1 describes the departure process for every facility in the airport during the passenger movements.

According to a Skytrax review, and experiencing difficulties managing immigration queues, resulting in long wait times of up to 25 min [25,28]. Space constraints and inefficient queue disciplines are two factors that contribute to this ineffective process. The boarding gate usually opens 30–45 min before the flight departure time, and the service counter must handle a large number of passengers in a short period of time. Thus, there are often queues during the boarding process.

With airlines being the airport operators' largest and most important customer, ensuring the aircraft's on-time departure and the passenger experience and convenience at the airport would be the operators' top priority. One of the criteria used to judge the efficiency of an airport would be the availability of operational facilities and the LoS provided. In relevance to that, it is important to note that everyone has different perspectives on service and that each experience is heterogeneous.

Due to high airport traffic volumes (up to 350 aircraft movements per year 2019) (ref.), airline passengers are more susceptible to increased levels of congestion, which are caused by three interrelated problems. The first problem is the fluctuation of demand in different seasons, events, and time periods. The second problem is the airline network in the airport. With more airlines, the airport will be more prone to long lines and congestion as more passengers arrive. The third problem is flight scheduling. When there is an overlap in flight schedules, passengers from multiple flights will meet, potentially resulting in longer lines, and the most important are the two waves of flights, early morning for departure, and early evening for arrival.

The most common queueing model that has been considered for airport congestion is the M(t)/Ek(t)/1 queuing system, where the four essential facilities in the airport during the passenger's departure process are depicted in Fig. 2, and the arrival rate and service rate for every facility should be estimated.

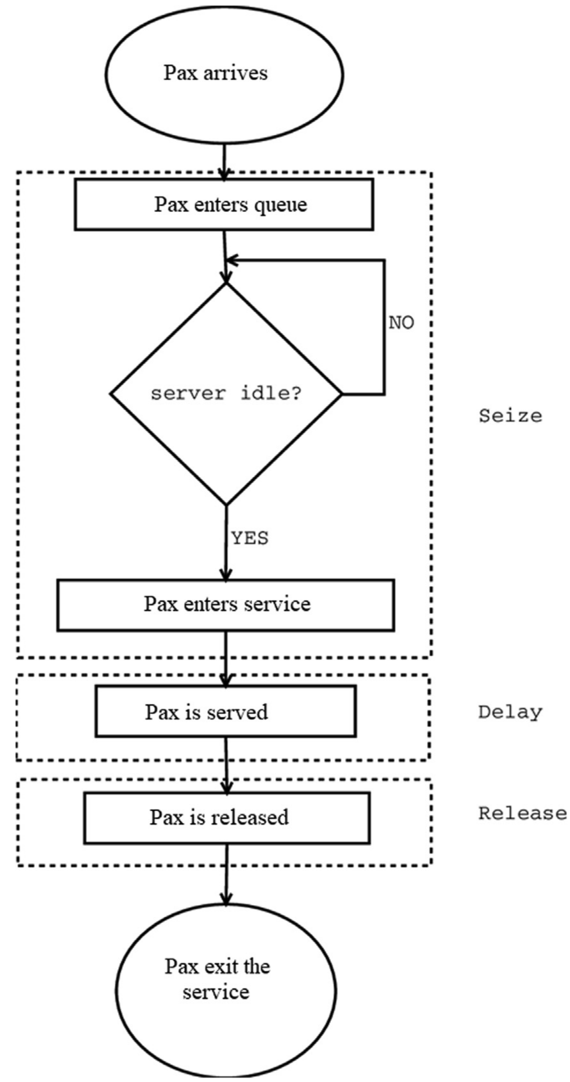

Fig. 1 Departure process of passengers.

According to "Kendall-Lee Notation" we can describe the queuing system of *CAI*'s departure process as in Table 1.

3.1. Check-in sub-system

The entire check-in sub-system consists of passengers waiting in line, accepting check-in consignment services, and ending check-in consignment operations. The terminal check-in counter queuing discipline is random due to the irregularity of passenger arrival time and counter service time. *CAI* adopts a combination of FCFS for economy passengers and PQ for other passengers in first, business or premium economy classes. The origin of the passengers is known as there is a passenger list to follow at the check-in counters.

3.2. Security check sub-system

An airport's security check sub-system comprises two types: centralised security screening and decentralised security screening. The security sub-system at *CAI* utilises centralised screen-

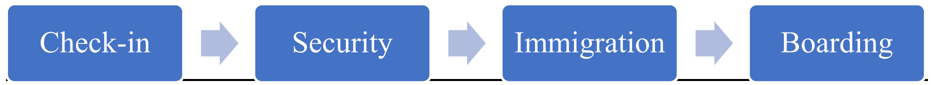

Fig. 2 Passenger Departure Process.

Table 1 Airport terminal building passenger departure sub-systems.

	Airport terminal building sub-systems			
	Check-in	Security Check	Immigration	Boarding
Nature of Arrival Process	M	M	M	M
Nature of Service Time	M	G	G	G
No. of Parallel Server(s)	s	s	s	s
Queue Discipline	GD	FCFS	GD	GD
Maximum allowable customers in the system	N	∞	N	N
Size of the population	N	∞	∞	N
Queuing model	M/M/s/GD/N/N	M/G/s/FCFS/∞/∞	M/G/s/GD/N/∞	M/G/s/GD/N/N

Where (according to Kendall's notation):
M: Markovian or memoryless.
G: General distribution.
FCFS: First Come First Serve.
N: Normal Distribution.

ing. The arrival and service process for centralised screening is irregular as the service time varies according to the time taken by the security checks machines and different security officers. The system consists of many service lanes, based on the terminal building, each serving different number of gates. The queue discipline is FCFS. The maximum number of allowable customers and the population size are both infinite, implying that customers can come from any origin. Since the security counter lacks the passengers' information sheet, they have no idea where the passengers are from.

3.3. Immigration sub-system

CAI adopts a centralised immigration system to serve all its passengers. The arrival process is deemed as irregular due to different flight timings. For eligible passengers, *CAI* immigration has implemented a self-service machine, while others can use manual counters. This unique process results in the general distribution of service time. The queue discipline is a mix of PQ and FCFS. Due to space constraints, the immigration's queue sub-system capacity is limited. The passenger population is infinite because it includes all passengers departing the airport.

3.4. Boarding sub-system

The final stage of the passenger departure process is boarding. The arrival and service processes are inconsistent. The ground handling staff check, scans, and tear boarding passes during the boarding process. The queue discipline is general discipline. The boarding procedure differs from airline to airline. Priority boarding is available on some airlines for frequent flyers, alliance members, passengers with special needs, and first-class passengers. The maximum allowable customers in the sub-system and customer population are identical. These are restricted to the number of passengers on the flight.

4. Case study assumptions, application and solution

The passenger arrival rate is an uncontrollable factor to an airport or any service provider, which is also variable across different times of the day. In practice, the service time is often dependent on the type of service the customer requires, for instance, a customer requesting to check-in extra baggage will take a longer time than an ordinary process passenger. Due to the heterogeneity of these factors, an airport's queue system encounters varying performance levels across different times of the day. Therefore, several assumptions have to be set before simulating the model as follows:

1. The paper has scope down to focus on the departure process from all three terminal buildings since they are similar in departure rules and patterns.
2. The calculations are based on a full year departure passenger 19,604.000 and around 84,350 flights based on the top movements for year 2019 statistics before Covid-19 hits, totalling 177 counters. Check-in counters open 3 h before the scheduled departure time.
3. **Stage 1:** It was assumed that each flight would have approximately 130–350 passengers, the arrival rate of the check-in process is estimated to be approximately 850 passengers per hour. This is calculated by taking the calculated average passenger on each flight (2 2 0), multiplied by the number of average daily flights (3 5 0), divided by the hours the check-in is opened for these flights (5 h):

$$350 \times 220\tilde{A} \cdot 24 = 3208 \quad passenger \quad per \quad hours$$

1. **Stage 2 & 3:** Each terminal building in *CAI* features centralised security and immigration process. The security area features different numbers of counters.

2. **Stage 4:** *CAI* features decentralised boarding gates and passengers move onto the assigned gates. Boarding gate will commence 40 min before flight departure

The POM-QM software has been used to solve this case, and the system service rate must be higher than the arrival rate. System service rate is computed by:

$$System\ \ servicerate = service\ \ rate \times no\ \ of\ \ servers \tag{1}$$

When the arrival rate surpasses the system service rate, it implies that customers are joining the queue at a faster rate than servers are processing them. This would mean that the servers would require to operate at over 100% capacity to reduce the queue. Since this is not feasible, this results in a long queue length and a never-ending or "infinite" queue. Given that it is common for servers to process a load demand higher than their handling capability during peak periods, computation using the POM-QM software may not always be feasible for peak period calculation. The simulations formulated such as M/G/s. It should also be noted that despite the computed probability of the system being empty in different scenarios are zero or just 0.11. This is expected given that the researchers are computing for the peak period scenarios and the input values are as such. The model is also be using the optimum wait time suggested in the Level of Service (LoS) concept developed by the International Air Transport Association (IATA) as a benchmark for the existing and proposed queue performance (Fig. 3).

4.1. Check-in process

As depicted in Table 1a, the actual scenario of *CAI* arrival rate at check-in is estimated to be 1020 passengers per hour using and a service time of 4.5 min per passenger ([2]). Given the service time of 4.5 min, the service rate derived is 1067 passengers per hour.

Despite this, frequent travellers have observed that less than half of the counters were utilised even during peak periods. Therefore, the servers available will be assumed as four per check-in row. With the assumption that the peak period check-in process handles 26 flights using four check-in rows, the number of servers will be 80. As server numbers are too low, the system service rate is significantly lower than the passengers' arrival rate.

Aforementioned, the system would not be able to compute this scenario whereby the server utilisation value is more than one.

According to the IATA's LoS Concept, the optimal check-in wait time is between one to five minutes. Attempts to achieve the recommended wait time as suggested by IATA lead to three possible scenarios as follows:

(1) Increase the number of servers, (2) Improve the service time, and (3) Both Scenarios 1 & 2 simultaneously (Refer to Table 1b).

Although Scenario 1 was able to achieve the wait time in the queue system of 4.99 min through increasing the number of servers, the 10 additional manpower required will significantly drive costs up. It also has the lowest server utilisation rate of the three proposed solutions. Hence, this scenario is unfavourable. Through improving service time, Scenario 2 was able to deliver the best results; the queue system wait time was the shortest while the server utilisation rate was the highest. It also reflects the shortest system queue length of the three solutions. However, the service time is to be lowered to 2.9 min, and such a considerable improvement in service time may not be achievable in the short term. In Scenario 3, it was suggested for 20 additional servers to be added and improvement of a more attainable service time of 3.5 min. This proved

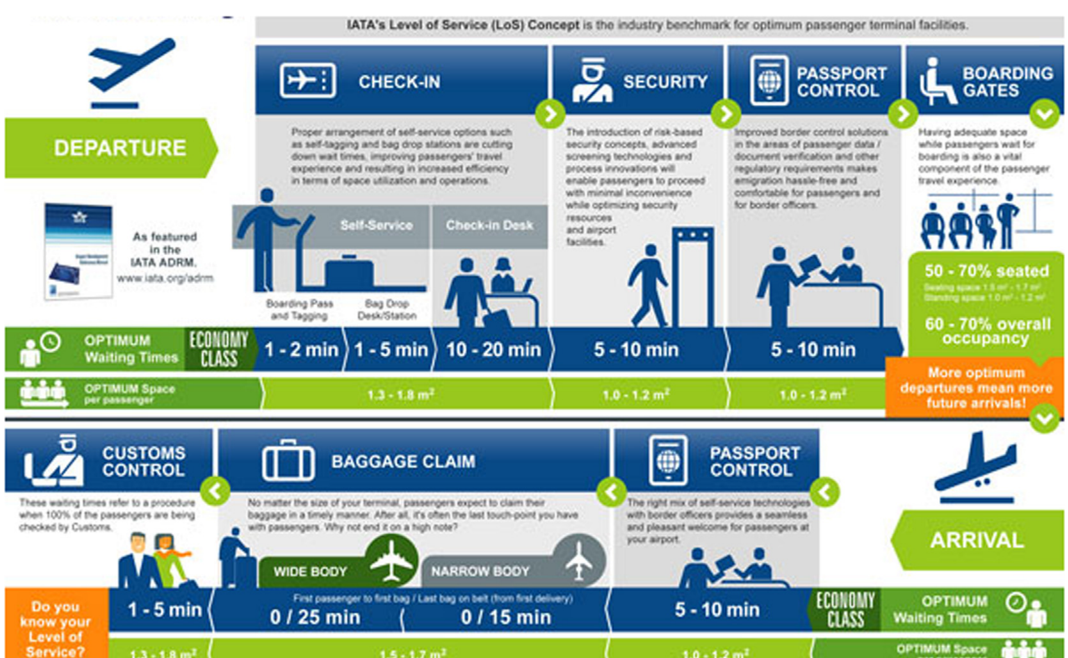

Fig. 3 The IATA LoS Concept - Wait time.

Table 1a Actual Scenario for Check-in Process for Cairo International Airport.

Arrival rate (Pax/h)	Service time (min/pax)	Service rate (pax/h)	No. of servers	Server utilization
1020	4.5	1067	80	> 1 (1.41)

Table 1b Proposed solutions for Check-in Process for Cairo International Airport.

Check-in (Per hour) - proposed solution										
Scenario #	Arrival rate (Pax/h)	Service time (min/pax)	Service rate (pax/h)	No. of servers	Server utilization	Queue length in line *Lq*	System queue length, *L*	Wait time in line, *Wq* (min)	System wait time, *W* (min)	Probability (% of time) system is empty
1	1020	4.5	1200	90	0.87	2.42	24.93	0.48	4.99	0
2	1020	2.9	1467	110	0.91	5.93	20.43	1.19	4.09	0
3	1020	3.5	1714	100	0.92	7.49	25	1.5	5	0

Note. The values highlighted are the numbers that changed.

to be the most physically and economically feasible solution which the airport should adopt in the short term.

Despite this, the airport should expect to see a longer queue length than the two other solutions and the queue system wait time to only achieve the bare minimum of the IATA's recommended wait time.

As a result, the research recommends *CAI* management to consider adopting Scenario 3 while training its employees to improve the service time and build up capabilities towards the goal of Scenario 2.

4.2. Security

The arrival rate at the security process is computed differently from the check-in process, where it is computed using the output of the previous queue of the check-in system. Hence, the arrival rate is 350 passengers per hour.

$$\text{Arrival rate}_{\text{queue2}} = \text{service rate}_{\text{queue1}} \times \text{no. Of servers}_{\text{queue1}}$$

Given that the service time, in reality, is 5 min, the service rate is 12 passengers per hour. Despite the peak, the airport only assigned 35 servers, leading to an infinite queue as depicted in server utilisation (Refer to Table 2a).

Similarly, when computed security numbers using the three scenarios listed in Table 2b. IATA's recommended wait time at security is between five to ten minutes. Attempts to achieve IATA's recommended wait time leads to three possible scenarios:

(1) Increase the number of servers, (2) Increase the number of servers and improve service time, (3) Improve service time while maximising usage of the existing 35 counters.

In Scenario 1, the service time was kept at five minutes while the number of servers was increased to 40. Through this, it was able to improve system wait time to 8.05 min and a high server utilisation rate of 0.94.

However, *CAI* management would require to invest a considerable amount of funds in hiring more employees or to consider that while they are planning for the fourth terminal building as a strategic plan or the planned renovation for terminal building 1. If this scenario was adopted, the long queue length and wait time compared to Scenario 3 would not justify the significant cost and terminal operation disruptions involved with the renovations. Hence, this solution is unfavourable. Scenario 2 demonstrates the results when the service time was reduced to 4 min while server numbers increased to 50. This helped attain a high server utilisation rate of 0.95 and an average wait time of 8.32 min, which meets the IATA recommended LoS standard. Similarly, this proposed scenario encounters the same problems as Scenario 1, while delivering worse results with a longer wait time and queue length of 29.66. Seeing the high capital involved to implement this solution and the least improvement to the existing queue problems, this proposed solution displays is the least favourable of the three. In Scenario 3, the service time was reduced to 3 min and the number of servers was maintained as 35 to maximise the usage of existing security counters. This scenario achieved significant improvement to the average system wait time as

Table 2a Actual scenario for security process for cairo international airport

Arrival rate (Pax/h)	Service time (min/pax)	Service rate (pax/h)	No. of servers	Server utilization
350	5	420	35	> 1 (2.23)

Table 2b Proposed Scenario for Security Process for Cairo International Airport.

Scenario #	Arrival rate (Pax/h)	Service time (min/pax)	Service rate (pax/h)	No. of servers	Server utilization	Queue length in line Lq	System queue length, L	Wait time in line, Wq (min)	System wait time, W (min)
1	350	5	480	40	0.94	10.89	28.72	3.05	8.05
2	350	4	750	50	0.95	15.4	29.66	4.32	8.32
3	350	3	700	35	0.89	5.05	15.75	1.42	4.42

Note. The values highlighted are numbers that changed.

well as queue length, reflecting improvement to 4.42 min and 15.75 respectively. Even with a minuscule reduction in server utilisation rate when compared to the previously recommended solutions, it is the most cost-effective of the three; the airport will incur the cost of four more labour costs if there is no additional employee that can be deployed to the security process.

4.3. Immigration

The arrival rate is computed using the output of the security process. Therefore, the arrival rate is 700 passengers per hour. In reality, the number of servers can be estimated to be 60 and the average service time as 5 min.

As a result of the service time, the service rate is 12 passengers per hour (Refer to Table 3a). IATA recommends passport control wait times be between five to ten minutes. Although, the computed average system wait time of 6.02 min meets IATA's recommendation for passport control. The analysis perceives that the current service time could be further improved.

The paper has proposed to improve service time to 4.5 min while server numbers remain unchanged (Refer to Table 3b). By doing so, the system wait time would be improved to 4.91 min, which reflects even better results than IATA's suggested wait time.

We understand that IATA developed the LoS concept to encourage airports to optimise service levels while minimising situations of over-performance and preventing excessive investment of limited airport resources [13]. The service time suggested in the proposed solution, however, would only require airport staff service training which is already implemented in most airport training procedures. It would permit the airport immigration team time to progressively work towards the suggested service time; foresight and action in preparation for it are especially essential to the airport environment, where passenger volume is rapidly growing.

4.4. Boarding

Aforementioned, the arrival rate is computed through using the output of the previous queue with the consideration that boarding commences 40 min before flight departure; immigration process and is denoted to be 120 passengers per hour. With a service time of 1 min, the service rate can process 60 passengers per hour. The boarding process also has two servers. Despite the short service process of the boarding process, the server utilisation is 100%, effectively creating an infinite queue (Refer to Table 4a).

According to IATA's LoS concept, there is no recommended wait time allocated for the boarding process. The criteria, however, states to ensure that 50% to 70% of the passengers are to be seated in the boarding room and a more optimal departure boarding process will result in more future arrivals. To ensure that the boarding process can reduce the infinite queue and strengthen the airport's capabilities for the future, simulations using two different scenarios, increase the number of servers, and improve the service time (Refer to Table 4b).

Scenario 1 was able to achieve a wait time of 1.44 min and a queue length of 2.89 pax by introducing an additional server to the process. However, the addition of one server drove the server utilisation rate down to 0.67. Furthermore, the airport will have to spend a considerable amount of money to remodel or expand the boarding gates to accommodate the new counter. Therefore, this solution is unfavourable. Scenario 2 sought to maintain the number of servers constant while enhancing server performance, as seen by the shorter service time. The derived average system wait time was 2.22 min with a queue length of 4.44. The solution, however, was deemed more favourable as training employees to improve service time is more beneficial in total cost incurred as compared to the addition of a new server as proposed in Scenario 1. As a result, the team would recommend CAI to adopt scenario 2 and focus its efforts on training its employees to improve the service time.

Table 3a Actual Scenario for Immigration Process for Cairo International Airport.

Arrival rate (Pax/h)	Service time (min/pax)	Service rate (pax/h)	No. of servers	Server utilization	Queue length in line Lq	System queue length, L	Wait time in line, Wq (min)	System wait time, W (min)	Probability (% of time) system is empty
700	5	13.33	60	0.80	1.64	9.64	1.02	6.02	0

Table 3b Proposed solutions for Immigration Process for Cairo International Airport.

Immigration (per hour) – Proposed solution									
Arrival rate (Pax/h)	Service time (min/pax)	Service rate (pax/h)	No. of servers	Server utilization	Queue length in line Lq	System queue length, L	Wait time in line, Wq (min)	System wait time, W (min)	Probability (% of time) system is empty
700	4.5	13.33	60	0.72	0.65	7.86	0.41	4.91	0

Note. The values highlighted are the numbers that changed.

Table 4a Actual Scenario for Boarding Process for Cairo International Airport.

Arrival rate (Pax/h)	Service time (min/pax)	Service rate (pax/h)	No. of servers	Server utilization
730	1	60	76	1.00

Table 4b Proposed solutions for Boarding Process for Cairo International Airport.

Boarding (per hour) – Proposed solution									
Arrival rate (Pax/h)	Service time (min/pax)	Service rate (pax/h)	No. of servers	Server utilization	Queue length in line Lq	System queue length, L	Wait time in line, Wq (min)	System wait time, W (min)	Probability (% of time) system is empty
730	1	60	3	0.67	0.89	2.89	0.44	1.44	0.11
730	0.8	75	2	0.80	2.84	4.44	1.42	2.22	0.11

Note. The values highlighted are the numbers that changed.

However, considering the current and future capacity-demand relationship, it is obvious that additional significant capacity is needed to accommodate the expected demand and to avoid the delay in passenger flow, Fig. 4 showing the predicted delays in passenger movement in case no additional capacity provided.

5. Conclusion and recommendation

Although Cairo airport is one of the three busiest airport, but he is not among the best 10 airports in Africa (Skytrax, 2021), though, based on this case study and problem formulation, the researchers believes that it is critical for *CAI* to consider the following suggestions for improvement:

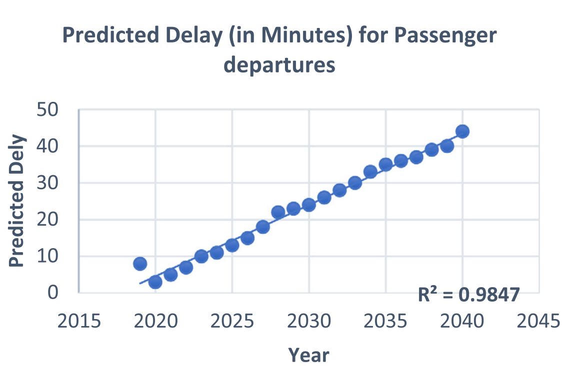

Fig. 4 The predicted delays in passenger movement.

1. Planning for additional capacity either by expanding the current terminal building/s or adding a fourth terminal building, the needed capacity supposed to be based on the annual rate of growth of aircraft movements, and/or the passenger movements. Adding more capacity means allowing more servers to reduce the waiting time and queue length.
2. Effective employee training is essential to enhance employee work performance which in turn allows them to deliver efficient and quality service to customers [12]. As employee performance plays a significant role in the airport's future growth. The content of training and assessments should be appropriate for each position and follow requirements set by IATA.
3. *CAI* can consider adopting a passenger flow forecast system to analyse the trends and allocate resources accordingly. For example, in 2008, Frankfurt Airport decided to develop a passenger flow management system where it measures the present passenger flow and projects a forecast of the future passenger flow based on airport growth trends. This system allows the airport to have an accurate forecast of the passenger flow and allocate resources effectively.
4. At last, but not least, *CAI* should consider investing in automation systems to improve the passenger departure processes. For instance, Changi Airport's Fast and Seamless Travel (FAST) system in Terminal 4 was able to substitute employees by adopting a full range of self-service kiosks and automated gates throughout the departure

process. As they can complete the entire departure process without human assistance, the entire process becomes faster. Changi Airport Group reported processing of 20 to 30% more passengers per hour using automated check-in and bag-drop kiosks (Teo, 2018). It also maintains the same service duration and performance across all passengers and spares passengers in long queues for service, increasing passenger convenience [9]. The airport could then reduce the manpower allocated to mundane tasks and utilise them in more complex roles. Despite the high initial investment, autonomous technologies will help improve service efficiency while reducing operating expenses in the long run.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors present their appreciation to King Saud University for funding the publication of this research through Researchers Supporting Program (RSP-2021/305), King Saud University, Riyadh, Saudi Arabia.

Funding statement

The Research is funded by Researchers Supporting Program at King Saud University,(Project# RSP-2021/305).

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