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Estimation of the innovative technologies influence on passengers processing procedures at the airport

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Abstract

In the period of coronovirus pandemic, a particularly important tasks of the airport are to reduce the time of passengers processing at check-in counters, baggage drop-off points and passport control counters, as well as to minimize contacts between people. All this can be achieved due to the implementation of the self-service check-in systems for passengers and their baggage, automatic boarding, self-service kiosks for reporting about lost baggage, etc. Insufficient number of processing points leads to forced delays, formation of passengers congestion at restricted areas. The article demonstrates how to use the queuing theory models to estimate the impact of the newest technologies on passengers processing at the airport. The automatic passengers check-in system has been considered as an example of the innovative technology for air passengers processing. Efficiency of the automatic passengers check-in system with self-service bag drop points implementation at the largest international airport of Western Ukraine Danylo Halytskyi International Airport Lviv has been proved, using queing systems models.

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Keywords: airport; passengers processing; conventional check-in; self-service check-in; queuing theory; modeling; efficiency

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1. Introduction

In recent years, passengers processing at the airport have been constantly changing due to the implementation of different innovative technologies. According to the SITA forecast (SITA, 2020), in the next decade, air passengers will have unlimited access to the latest technologies - from self-service check-in kiosks, self-service bag drop points, automated border control systems to “smart” airports with their own intelligent systems (Abdullah, 2016). Almost all airport systems are expected to undergo major changes.

Currently, in the period of coronavirus pandemic, the most popular newest technologies during passengers processing at the airport are those that minimize contacts between people, i.e.:

- Automatic passengers check-in systems with self-service bag drop points, which allow to uniformly redistribute passengers in the Air Passenger Terminal, avoiding passengers congestion in separate terminal areas, to decrease the airport formalities time. Combining airlines’ web (on-line) check-in, check-in at the conventional check-in counters, mobile check-in and self-service check-in kiosks, the airport gets the opportunity to manage queues, time of airport formalities, and optimal usage of terminal areas.
- Automatic boarding gates in order to decrease time of airport formalities during check-in and boarding operations.
- Self -service kiosks for reporting about lost baggage.

Unfortunately, not all airports in Ukraine are equipped with such automated technologies. However, their implementation will allow the airport, airlines and passengers to gain a number of significant benefits (see Fig. 1).

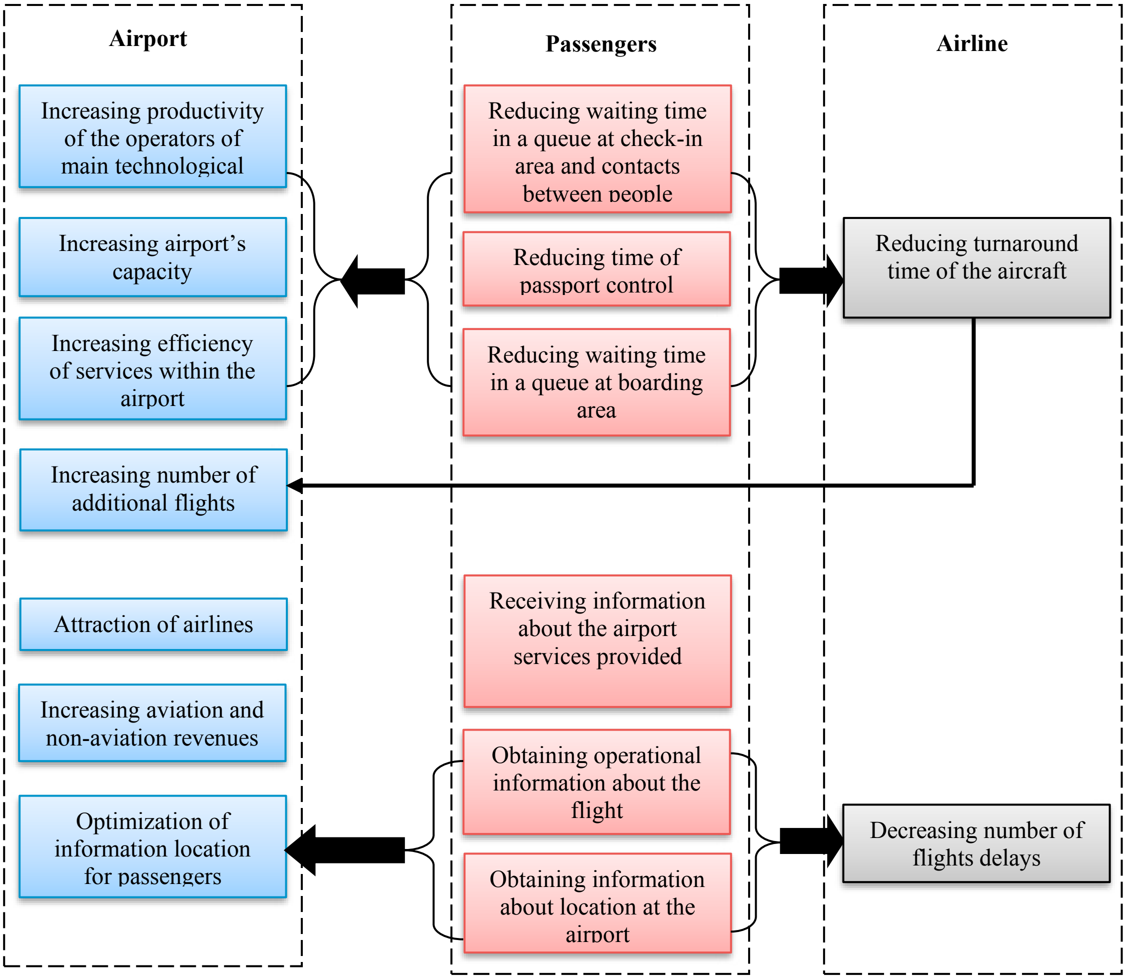

Fig. 1. Possible effects from implementation of self-service technologies during passengers processing at the airport

Analysis of the conducted researches (Yudin et al., 2020; Savchenko et al., 2020) shows that after the coronovirus pandemic all check-in services for the flight will take place either on-line or using automatic check-in systems with a self-service bag drop points. Currently, these technologies are very relevant for Ukrainian airports, which lag behind in this field. That's why, it was decided to show the efficiency of the innovative technologies implementation during passengers processing at the airport on the example of the automatic passengers check-in system with self-service bag drop points, using models of queuing theory.

2. Passengers processing technology at the airport: comparison of conventional and automated systems

Passengers processing system at the airport (Ashford et al., 2013): - is a set of technologies, equipment, means of automation and mechanization, as well as personnel, performing passengers and their baggage check-in, baggage handling, passport control and other operations, related to passengers processing.

Conventional passengers processing process is rather simple: a passenger buys a ticket, then at the airport proceeds to the check-in area, where he receives a boarding pass and delivers his baggage, passes passport control and goes on boarding (Fig. 2a). Even 10 years ago, this process looked quite normal for passengers. However, currently, especially during the coronavirus pandemic, the opinions and expectations of passengers, airport and airline management have been changed. More and more airports are replacing the traditional passengers processing technology by the automated self-service points or corridors, because of these technologies reduce face-to-face contacts during passing through all procedures at the airport.

The stages of the automated passengers processing process at the airport are shown on the fig. 2b. As it is visible, thanks to the latest automated technologies, a passenger, having checked-in at the self-service kiosk and dropping his baggage at the self-service bag drop points, can immediately go to passport control and boarding. Such technologies will reduce queues, allowing to pass through all airport formalities before flight during 10 minutes (Gualandi et al., 2018).

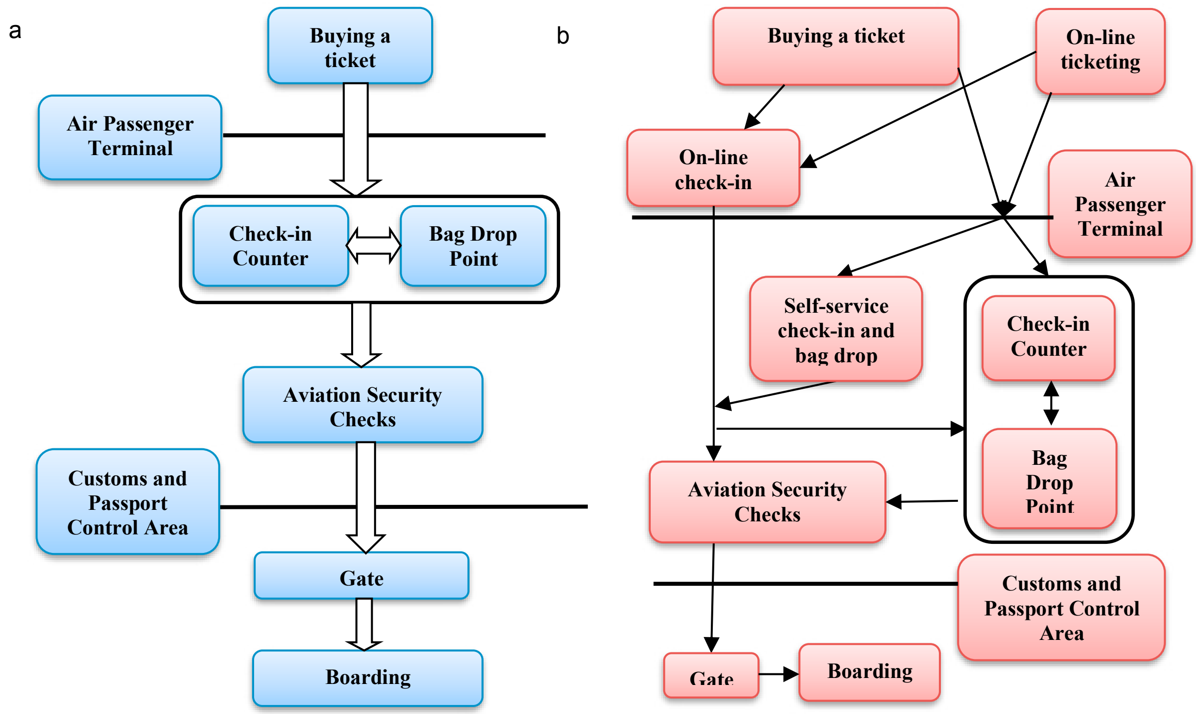

Fig. 2. (a) Conventional passengers processing process; (b) Automated passengers processing process.

3. Modeling of airport work as a queuing system

In order to represent the operation of an airport at different parameters, it is proposed to consider it as a queuing system (QS), which has a number of servers and all key characteristics of QS (Yudin et al., 2020; Savchenko et al., 2020; Ivannikova, 2013; Kryvonozhko et al., 1999).

Queuing systems (Kleinrock, 1975) are systems, the arrival flow of which is a random flow of similar customers (events), served by one or more similar servers.

A characteristic of the arrival flow is an important element during the modeling (Martel et al., 1991). From the standpoint of systems theory, an airport is a complex dynamic stochastic system, which obtains non-stationary flows of aircraft, passengers, etc. The expressed cyclic fluctuations of the arrival flows intensity are caused by the wave character of passengers arrival and flights departure (Tsymba, 1994).

The important task of an airport is to reduce the departure passengers processing time at check-in, baggage claim and passport control areas (Wensveen, 2007; Pavelko, 2014). In order to solve this problem, it is necessary to introduce the latest self-service technologies in the passengers processing procedures at the airport.

Insufficient number of service points leads to forced delays and queues of passengers. The lengths of such queues are limited by the Air Passenger Terminal capacity and other parameters.

3.1. Case study: Danylo Halytskyi International Airport Lviv (Ukraine)

Danylo Halytskyi International Airport Lviv is one of the four leading airports in Ukraine (see Table 1). It is the largest international airport in the Western Ukraine, according to its routes network and passenger traffic, which has been grown from 600,000 to 2.2 million pax. during three years. That's why, Lviv is often compared with the airports of Krakow, Lublin and Ryashev.

Table 1. Passengers flows through the main airports of Ukraine (Source: State Service of Statistics of Ukraine, 2020).

Airport name	**Passengers flow**					**Specific weight of airports in the total volume of air passenger traffic in 2019**
	2015	**2016**	**2017**	**2018**	**2019**	
Boryspil International Airport	7277443	8650000	10554757	12603757	15260000	63%
Kyiv International Airport	944 305	1127500	1851700	2811700	2617900	11%
Odessa International Airport	949 100	1033560	1228102	1598102	1694022	7%
Danylo Halytskyi International Airport Lviv	***570 570***	***738000***	***1080000***	***1446000***	***2217400***	***9%***
Kharkiv International Airport	373 625	599700	806200	962200	1340000	5%

However, Lviv Airport lacks self-service technologies. It is not equipped with self-service check-in kiosks and biometric systems for efficient, fast and safe passengers processing, which is especially important in the coronavirus pandemic period and the post-COVID period.

3.2. Models and calculations

Let's analyze the efficiency of the automatic passengers check-in system with self-service bag drop points implementation at the Danylo Halytskyi International Airport Lviv with the help of queuing system models.

The queueing system has been considered on the example of flights from Lviv, performed on November, 18, 2020, which correspond to the average number of flights per a day for the autumn season at the airport. The average payload factor of these flights was 80%, corresponding to 840 pax.

It was found that during the survey, 10% of the total number of passengers traveled without checked baggage and checked-in for their flights on-line. In total, on November 18, 2020, the airport processed 756 passengers (see Table 2).

Our case study considers check-in process at two conventional check-in counters, operated from 6:00am (first flight) up to 4:55pm (last flight). In the Lviv International Airport check-in of passengers and their baggage on international and domestic flights is started from two hours to forty minutes before the scheduled time of departure.

So, the total working time of the conventional check-in counter is 11 hours. According to the international aviation standards, the service time of one passenger at a traditional check-in counter is 2 minutes.

Table 2. The list of flights from the Danylo Halytskyi International Airport Lviv on November 18, 2020 (average day for the autumn season).

Time	Flight	Direction	Aircraft	Economy Class	Business Class	Total number of passengers at payload factor 100%	Total number of passengers at payload factor 80%
08:00	7W 166	Kyiv	ATR 72-600	72	0	72	58
08:50	PQ 8345	Hurghada	Boeing 737-800	189	0	189	151
09:50	TK 0442	Istanbul	Boeing 737-800	135	20	155	124
12:25	7W 162	Kyiv	ATR 72-600	72	0	72	58
14:25	LO 766	Warsaw	Embraer ERJ-175	68	14	82	66
15:00	7W 6061	Hurghada	Airbus A321	218	0	218	174
16:15	PC 421	Istanbul	Boeing 737-800	189	0	189	151
17:35	7W 164	Kyiv	ATR 72-600	72	0	72	58
			Total:	**1015**	**34**	**1049**	**840**

Check-in process at the Lviv International Airport can be considered as a multi-server queueing system with a waiting time and unlimited queue, i.e. a system without restrictions on its own capacity as well as capacity of the source, generating customers $(M/M/n):(FCFS/\infty/\infty)$, where M is the Markov (Poisson) distribution of the moments of passengers arrival or departure from the system (i.e. equivalent exponential distribution of time intervals between moments of successive arrivals or durations of passengers processing); n - number of servers, working in parallel; FCFS - queue discipline: first come - first served (Hamdi, 2007).

It is proposed to use the following indexes for calculation of the queuing system efficiency indicators:

λ – arrival flow intensity;

μ - servicing intensity of each server;

A – absolute capacity of the queueing system (average number of customers, served by the QS per the unit of time);

q - relative capacity of the queueing system (the probability of arrival customers servicing);

$P_{failed} = 1 - q$ - probability of failure, i.e. the probability that the customer will not be served;

$\bar{r}$ - average number of customers in a queue.

Let's consider passengers check-in process as $n-$server queueing system with a queue, which receives a flow of customers with intensity λ. Servicing intensity of each server is μ. The time intervals between the moments of customers' arrival to the system are random variables, which are distributed according to the exponential law with an average value $\frac{1}{\lambda}$ seconds.

Since the queue in the queueing system is unlimited, each customer will be served and therefore we will have the following conditions (Ponomarenko et al., 2008):

$$P_{failed} = 0\,,\ q = 1 - P_{failed} = 1\,,\ A = \lambda \cdot q = \lambda\,. \tag{1}$$

In our case study flow intensity will be equal to $\lambda = \frac{756}{11} \approx 68\ customers/hour$.

Servicing intensity of each server equals $\mu = \frac{1}{M[T_{proc}]}$, where $M[T_{proc}] = 2\min = \frac{1}{30} hour$; $\mu = 30\ cust/hour$.

Let's calculate the coefficient of queueing system loading: $\rho = \frac{\lambda}{\mu} = \frac{68}{30} = 2.27$.

Then, we will have: $\frac{\rho}{n} = \frac{2.27}{2} = 1.13$.

Since 1.13 ≥ 1, the servicing process will not be a stationary one. The average queue length and the average waiting time for passengers processing will be increased in the system.

In this case, for effective passengers processing, it is necessary to introduce an additional check-in counter for passengers and their baggage check-in. Popular among business class passengers would be a self-service check-in kiosk with a 30 seconds service time. So, in our case study, we will have one self-service check-in kiosk ($n_1 = 1$) and two traditional check-in counters.

So as, usage of self-service check-in kiosks decreases check-in time, this service can be also interested to the economy class passengers. According to the survey results at the investigated airport, it was found that 10% of the total number of passengers would pay for the self-service check-in. Then, we will have for $n_1 = 108$ passengers and for $n_2 = 648$ passengers. Let's calculate the main processing indicators of the multi-server queueing system for two schemes of the passengers' check-in system at the airport.

Self-service check-in system:

$$\lambda_{n1} = \frac{108}{11} \approx 10 \; customers/hour;$$

$$\mu_{n1} \approx 120 \; customers/hour;$$

$$\rho_{n1} = \frac{10}{120} \approx 0.08;$$

$$\wp_{n1} = \frac{\rho_{n1}}{n_1} = \frac{0.08}{1} \approx 0.08.$$

Conventional check-in system:

$$\lambda_{n2} = \frac{648}{11} \approx 59 \; customers/hour;$$

$$\mu_{n2} \approx 30 \; customers/hour;$$

$$\rho_{n2} = \frac{59}{30} \approx 1.97;$$

$$\wp_{n2} = \frac{\rho_{n2}}{n_2} = \frac{1.97}{2} \approx 0.985.$$

where $\wp_{n1}$ – loading coefficient of a self-service check-in kiosk; $\wp_{n2}$ - loading coefficient of a conventional check-in counter, correspondently.

Loading coefficients $\wp_{n1} = 0.08$ and $\wp_{n2} = 0.985$ show the degree of consistency of the arrival and departure customers flows of the servicing server and determine the queuing system stability.

Since the load intensity is 0.08 <1 and 0.985 <1, the servicing processes will be stationary ones. The graph of the model with multiple parallel servers and unlimited queue is presented in Fig. 3.

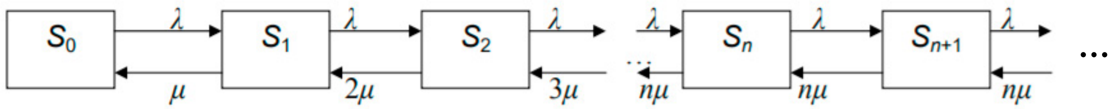

Fig. 3. Graph of the multi-server queueing system with *n* servers and unlimited queue.

This is the scheme of «death and birth». Queueing system $(M/M/n):(FCFS/\infty/\infty)$ can be represented as a system with $n+m$ states, when $m \to \infty$.

S_0 - all servers are free;

S_1 - one server is used, others are free;

……………………………………

S_k - *k* servers are used, others are free;

……………………………………………

S_n - all *n* servers are used, there are no queues;

S_{n+1} - all *n* servers are used, one customer is in the queue;

……………………………………………………

S_{n+m} - all n servers are used m customers are in the queue;

………………………………………………………………...

In this case the probabilities of the system states S_k in the stationary regime are determined by the formula:

$$p_0 = \left(1 + \frac{\rho}{1!} + \frac{\rho^2}{2!} + ... + \frac{\rho^n}{n!} + \frac{\rho^{n+1}}{n \cdot n!} \cdot \frac{1}{1-k}\right)^{-1}, \text{ where } \wp = \frac{\rho}{n} \quad (2)$$

For the self-service check-in kiosk, using the formula (2), we obtain the following probability:

$$p_{0n1} \approx \frac{1}{\frac{0.08^0}{0!} + \frac{0.08^1}{1!} + \frac{0.08^1 + 1}{1!(1-0.08)}} \approx 0.92 .$$

So, 92% of time during the hour the server will not be used, downtime will be equal to $t_{dt} = 55.2\,\text{min}$.

For the conventional check-in counters, using the formula (2), we obtain the following probability:

$$p_{0n2} \approx \frac{1}{\frac{1.97^0}{0!} + \frac{1.97^1}{1!} + \frac{1.97^2}{2!} + \frac{1.97^{2+1}}{2!(2-1.97)}} \approx 0.0084 .$$

Thus, 0.84% of time during the hour the server will not be used, downtime will be equal to $t_{dt} = 0.5\,\text{min}$.

Let's calculate the probability P_* that two conventional check-in counters will be used, when the passenger arrives to the check-in area at the airport. The probability P_* is equal to the probability of the following events:

- two conventional check-in counters are used, there is no queue;
- two conventional check-in counters are used, one passenger in a queue;
- two conventional check-in counters are used, two passengers in a queue and so on:

$$P_* = p_2 + p_3 + p_4 + ... = 1 - p_0 - p_1 . \quad (3)$$

$$P_{*2} \approx 1 - 0.0084 - \frac{1.97}{1!} \cdot 0.0084 = 0.975 .$$

Let's calculate the probability P_*, that the self-service check-in kiosk will be used, using the formula (3):

$$P_{*1} \approx 1 - 0.92 - \frac{0.08}{1!} \cdot 0.92 = 0.0064 .$$

The probability of a queue formation is calculated, using the formula: $P_q = \frac{\rho^{n+1}}{n!(n-\rho)} p_0$.

elf-service check-in kiosk:

$$P_{q_{n1}} = \frac{0.08^{1+1}}{1!(1-0.08)} \cdot 0.92 = 0.0064 ;$$

Conventional check-in counters:

$$P_{q_{n2}} = \frac{1.97^{2+1}}{2!(2-1.97)} \cdot 0.0084 = 0.959 .$$

The probability that no queue will be formed is calculated, using the formula: $P_{a.q} = 1 - P_q$.

Self-service check-in kiosk: *Conventional check-in counters:*

$P_{a.q_{n1}} = 1 - 0.0064 = 0.994$; $P_{a.q_{n2}} = 1 - 0.959 = 0.041$.

Average number of customers in a queue is calculated, using the formula: $\overline{r} = \dfrac{n}{n - \rho} \cdot P_q$.

Self-service check-in kiosk: *Conventional check-in counters:*

$\overline{r}_{n1} = \dfrac{1}{1 - 0.08} \cdot 0.0064 = 0.00696$; $\overline{r}_{n2} = \dfrac{2}{2 - 1.97} \cdot 0.959 = 57.53$.

Average downtime of the queueing system is calculated using the formula: $T_q = \dfrac{L_q}{A}$

Self-service check-in kiosk: *Conventional check-in counters:*

$T_{qn1} = \dfrac{0.00696}{10} = 0.000696\ hour$; $T_{qn1} = \dfrac{57.53}{59} = 0.975\ hour$.

Thus, based on the calculations, we can conclude that conventional check-in counters worked almost continuously (downtime was 0.5 min/hour). At the same time, the self-service check-in kiosk could take more passengers, because its arrival flow was much smaller (downtime was 55.2 min/hour). So, implementation of the self-service check-in kiosks would give possibility to significantly increase the number of passengers and flights, which can be processed at the airport. Self-service devices are able to process the same number of passengers as two conventional check-in counters, but in four times faster. It means that 648 passengers could pass through the self-service check-in kiosk during 3 hours and 15 minutes, instead of 11 hours at two conventional check-in counters.

The considered multi-server system with unlimited queue is just one of many others systems, that can be used during the analysis of passenger processing technology at the airport. The *M/M/m/K/M* model is also applicable (Kleinrock, 1975) for this purpose. This system more adequately analyzes the whole process of passengers processing, because it takes into account the fact that there is a restriction on the number of passengers per a flight and sources of their arrival. However, this model is the most complicated among all other queueing system models.

In this system, there are a finite number of *M* customers, and the intensity of each customer arrival is equal to λ . In addition, the system has *m* service points, each of which is described by the parameter μ . There are also a limited number of places in the system's queue, which does not exceed *K*. It is assumed that $M \geq K \geq m$. Then, customers, arriving to the system, when it already has *K* customers, will be lost. This leads to the following parameters of the "death and birth" process:

$$\lambda_k = \begin{cases} \lambda(M - k), 0 \leq k \leq K - 1; \\ 0 \text{ in other cases;} \end{cases} \tag{4}$$

$$\mu_k = \begin{cases} k\mu, 0 \leq k \leq m; \\ m\mu,\ k \geq m. \end{cases} \tag{5}$$

Figure 4 shows a rather complicated diagram of the transition intensities.

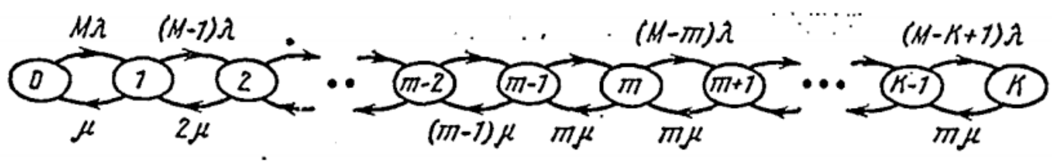

Fig. 4. Diagram of the transition intensities for the system *M/M/m/K/M*.

In order to find probability p_k for the stationary regime of operation, it is necessary to consider two areas. For the area $0 \le k \le m-1$, we obtain:

$$p_k = p_0 \prod_{i=0}^{k-1} \frac{\lambda(M-i)}{(i+1)\mu} = p_0 \left(\frac{\lambda}{\mu}\right)^k \binom{M}{k}, \quad 0 \le k \le m-1 . \tag{6}$$

For the area $m \le k \le K$, we obtain:

$$p_k = p_0 \prod_{i=0}^{m-1} \frac{\lambda(M-i)}{(i+1)\mu} \prod_{i=m}^{k-1} \frac{\lambda(M-i)}{m\mu} = p_0 \left(\frac{\lambda}{\mu}\right)^k \binom{M}{k} \frac{k!}{m!} m^{m-k}, \quad m \le k \le K. \tag{7}$$

where $\binom{M}{k}$ - binomial coefficients, which are determined as follows $\binom{M}{k} = \frac{M!}{k! \cdot (M-k)!}$.

In case of net losses in the system ($M \ge K = m$) stationary probabilities are determined by the formula as follows:

$$p_k = \frac{\binom{M}{k}\left(\frac{\lambda}{\mu}\right)^k}{\sum_{i=0}^{m}\binom{M}{i}\left(\frac{\lambda}{\mu}\right)^i}, \quad k = 0,1,2,...,m. \tag{8}$$

This distribution is called the Engset distribution.

4. Conclusions

Improving the technology of passengers processing at the airport, in order to reduce the duration of these processes at check-in area, baggage claim area and passport control area is an extremely important task for the airport authority, especially, today, in the period of coronavirus pandemic. Insufficient number of processing points leads to forced delays and passengers' queues. That's why, the article has been devoted to the explanation of the mathematical approach for assessment of the innovative technologies influence on passengers processing procedures at the airport, basing on the queueing theory models. The automatic passengers check-in system has been considered as an example of the newest technology for passengers processing at the airport. It has been demonstrated in the article how the optimal option of passengers and their baggage processing at check-in area in the largest international airport of Western Ukraine Danylo Halytskyi International Airport Lviv, when the service time decreases and the service quality increases, can be determined with the help of queuing systems models.

According to the results of calculations, it was found that implementation of the self-service check-in kiosks at the investigated airport will significantly increase the number of passengers that will be processed. This self-service device is able to process the same number of passengers as a conventional check-in counter, but in four times faster. Processing of one passenger at a traditional check-in counter takes up to 2 minutes, and in case of self-service check-in systems usage, it is reduced up to 30 seconds, which demonstrates the effectiveness of self-service check-in systems usage for the airport authority.

Further researches will be devoted to the collection of more data on passengers processing procedures at the airport and problem solution in the context of full operation of the airport, including self-service baggage handling, passport control, boarding, etc.

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