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Simulation Model for Airport Disruption Management

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ABSTRACT

Ensuring the regularity of flights is one of the key tasks of the airline. Three main components of effective functioning of the air transport system comprise ensuring flight safety, regularity and high quality of the services provided, that is, the service component of the air transportation process.

At the same time, it is worth paying attention to the fact that regularity or punctuality of flights is the basis for ensuring safety, the rhythmic implementation of the daily plan allows strictly adhering to the standards for timely maintenance and preventive inspections of aircraft. And flights operated with significant delays nullify all the efforts of air carriers to show a high level of service on board and when servicing passengers at airports. Violation of regularity of flights implies airline's losses and significant reputational damage. The traditional reasons for flight delays are unfavourable weather conditions, technical reasons, late arrival of the aircraft. But the indicator of delays in departures and arrivals of flights of some Russian air companies increases from time to time due to the congestion of airports, the congestion of airport waiting areas, disruptions in the rhythm of the execution of the daily planning.

Every flight delay creates a disruption. The issue of disruption management has always been a topic for scientific discussions and research. The object of research presented in the article is to study the model of managing an airport disruption, the task was to study options for decision-making in the form of a queue of aircraft for departure and analyse the results of these decisions, where the objective function will be to minimise losses from delay.

For decision-making, it is proposed to use a simulation model of a conditional disruptive situation.

Keywords: air transport, airport, flight regularity, disruption, airline losses, simulation model.

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INTRODUCTION

The regularity of flights for each airline is a key indicator for evaluating its performance. If we adhere to international standards for assessing regularity (punctuality), then a flight that is fifteen minutes late upon arrival or departure will be considered delayed. Then, according to the OAG (Official Aviation Guide), the punctuality of Russian airlines' flights is from 53 to 72 %[1]. In 2019, OAG named the most punctual airports and airlines. «Tokyo Haneda has become the leader in punctuality among major airports that serve more than 30 million departing passengers per year. It is followed by Atlanta Airport (USA); Changi Airport (Singapore); Denver Airport (USA); Los Angeles Airport (USA).

In the main airports category (20–30 million departing passengers per year), Moscow Sheremetyevo Airport was ranked first. The most punctual small airport (2,5–5 million flights per year) was the air transport hub of Minsk.

Top 10 most punctual airlines in the world were Copa Airlines (Panama); airBaltic (Latvia); Hong Kong Airlines (China); Hawaiian Airlines (USA); Bangkok Airways (Thailand); Qantas Airways (Australia); LATAM Airlines (Chile); Azul (Brazil); Qatar Airways (Qatar); KLM (Netherlands).

Of the Russian air carriers, S7 company was included in the ranking of the most punctual mainline airlines (18th place) and the most punctual carriers in Europe (sixth place)»[2].

Besides studying the statistics of regularity of flights, an important area of research is management of the process of resolving a disruptive situation at the airport. Information systems with nested algorithms for solving the problem of disruption in regularity, artificial intelligence in managing the flow of passengers and flights will not be able to replace the experience, intuition and skills invested in the «live» mind of an experienced operator for a long time to come. It is only necessary to create an environment for decision-making, to predict, which is very important, the economic effect. The simulation model does not offer an optimal solution but helps to better understand validity of management decisions.

The object of study describe in the article is the process of choosing a solution to manage a disruption, which consists in the fact that the researcher is invited to build a queue for departure from flights delayed at the airport with minimisation of airline losses associated with disruption of flight regularity.

The *objective* is to study the model of managing a disruptive situation. The task is to study options for decisions in the form of a queue of aircraft for departure and analyse the results of these decisions, where the objective function will be to minimise losses from delay.

RESULTS

Approaches to the Study of the Research Problem

«For the cost-effective functioning of an airline in a competitive environment, one of the most important factors is the problem of regularity of flights. Failure to meet the deadlines for departure and arrival of flights implies additional costs for carrier associated with penalties paid to passengers, consignees, and consignors, as well as to airports if flight delays occur through the fault of the airline, which is usually associated with management errors. Regularity of flights of civil aviation aircraft includes the concept of regularity of departures of aircraft and regularity of flights. Regularity of flights characterises the work of civil aviation enterprises in delivery of passengers, baggage, and cargo in accordance with the contract for transportation. Regularity of flights is the ratio of the number of flights performed without delay to the total number of flights, expressed as a percentage. This is one of the most important indicators of quality of functioning of air transport enterprises» [1]. The above quote from an article by a young researcher D. A. Naumova is relevant for all times of the commercial use of air transport. Apparently, only the conservatism of the approach to determining the regularity of flights determines the fact that until December 2020, the main document intended for determining and calculating the regularity of flights was a document entitled «Guidelines for ensuring and accounting for regularity of flights of civil aviation aircraft of the USSR», approved by order of the MCA dated January 10, 1990, No. 6[3], which was cancelled by Order of the Ministry of Transport of Russia dated December 4, 2020, No. 541

[1] Russian Airlines had lost punctuality by the end 2021 [*Rossiyskie aviakompanii k kontsu 2021 goda rasteriali punktualnost'*]. [Electronic resource]: https://www.vedomosti.ru/business/articles/2022/01/13/ 904695-aviakompanii-rasteryali-punktualnost. Last accessed 13.01.2023.

[2] OAG Aviation Worldwide ranked the most punctual airlines and airports in the world. [Electronic resource]: https://www.aex.ru/news/2019/1/6/192271/. Last accessed 13.01.2023.

[3] Order of the Ministry of Civil Aviation of the USSR dated January 10, 1990, No. 6 «On approval and implementation of the Guidelines for ensuring and accounting for regularity of flights of civil aviation aircraft» (the document has ceased to be valid). [Electronic resource]: https://base.garant.ru/70198590/. Last accessed 13.01.2023.

«On recognition of certain acts of the USSR, their individual provisions, as well as letters, instructions and instructions issued by central authorities of state administration of the USSR as invalid on the territory of the Russian Federation, and as invalidated some acts of the RSFSR, their individual provisions, as well as letters, instructions and directives issued by the central bodies of state administration of the RSFSR, in the field of transport»[4].

An information appeared in some open sources that: «The Ministry of Transport has begun to develop new standards for accounting for regularity of flights. They should replace the rules that have been in force since the times of the USSR, [newspaper] *Izvestia* was told in the department. In particular, it is proposed to detail the reasons for flight delays and clearly indicate the culprit – the airport, airline or ground handling operator. This will allow identifying bottlenecks in the work of these structures and increase the punctuality of carriers – passengers will not have to sit at airports for hours waiting for a flight, experts say. But it will not be easy for market participants to agree on a single methodology»[5]. At present, flight delays are entirely the responsibility of the air carrier, although many of the problems with ensuring the timely departure of a flight or ensuring its arrival are created by airport operators. It is precisely for this reason that there are a huge number of projects and even local regulations to ensure and calculate the regularity of aircraft flights. The Ministry of Transport received drafts of regulatory documents from the Airport Association, and the main operators of Sheremetyevo and Domodedovo airports. Local documents that consider the regularity of flights have different names, for example, for Domodedovo Airport, the Domodedovo Airport User Guide[6] has been developed, which has a section on accounting for punctuality of flights. However, even the definition of «punctuality of flights» is absent therein. The «Guidelines for ensuring and accounting for regularity of flights of civil aviation aircraft of the USSR (RRP GA-90)» details the concept of «flight regularity». «Regularity of flights of civil aviation includes the concept of regularity of departures of aircraft and regularity of flights. Regularity of flights characterises the work of civil aviation enterprises and departments and the industry as a whole in delivery of passengers, baggage and cargo in accordance with the contract for transportation»[3]. The definition emphasises the social significance of the process of performing flights by civil aviation aircraft. Probably, the lack of a single approach to regulating flight departure delays and determining the responsibility of a specific person responsible for this delay leads to a loose interpretation of significance of failures in regular flight operations resulting in information that flight delays and cancellations are beneficial to airlines[7]. Especially if the flight is operated with a load less than planned, then the flight can be cancelled or combined with another flight with the same low load. As a result, the airline will save on refuelling, airport taxes and ground handling. In fairness, it must be said that on the contrary a missed flight will incur losses from the uncovered fixed costs of the airline, the largest of which is the lease payment. It is possible to perform a simple calculation of the amount of such losses: the cost of leasing an A-320 aircraft is approximately estimated at 350–380 thousand dollars per month. If there are 720 hours in a month, then the cost of leasing is 527,77 dollars per hour, or about 37000 rubles at an exchange rate at the moment of writing the article. The daily flight time on an aircraft, in leading airlines, is 12 hours, that is, the airline already, according to the plan, incurs losses from leasing in the amount of 444000 rubles per day.

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[4] Order of the Ministry of Transport of Russia dated December 4, 2020, No. 541 «On recognition of certain acts of the USSR, their individual provisions, as well as letters, instructions and instructions issued by central authorities of state administration of the USSR as invalid on the territory of the Russian Federation, and as invalidated certain acts of the RSFSR, their individual provisions, as well as letters, instructions and instructions issued by the central bodies of state administration of the RSFSR, in the field of transport». [Electronic resource]: https://www.consultant.ru/document/cons_doc_LAW_375322/. Last accessed 13.01.2023.

[5] Volobuev, A., Tsyruleva, I. This is a flight: airlines will be prescribed punctuality. The Ministry of Transport is preparing a new method for accounting for flight delays. Izvestia, 22 April 2019. [Electronic resource]: https://iz.ru/870098/aleksandr-volobuev-irina-tcyruleva/eto-zalet-aviakompaniiam-propishut-punktualnost. Last accessed 13.01.2023.

[6] Domodedovo Airport User Guide (version 25). [Electronic resource]: https://business.dme.ru/files/doc/РУКОВОДСТВО%20ПОЛЬЗОВАТЕЛЯ%20АЭРОПОРТА%20(версия%2025).pdf. Last accessed 13.01.2023.

[7] Volobuev, A., Tsyruleva, I. Excellent position: who benefits from massive flight delays. Izvestia found out how Russian carriers make money on bad weather. Izvestia, 1 February 2019. [Electronic resource]: https://iz.ru/840013/aleksandr-volobuev-irina-tcyruleva/otmennaia-pozitciia-komu-vygodny-massovye-zaderzhki-aviareisov. Last accessed 13.01.2023.

And the cancellation of the flight and the subsequent return of the flight to the daily flight plan will take at least eight hours, then the losses will increase to 740000 rubles. So, the cost savings on refuelling will be exactly reduced to zero. Without going into details of calculating the required amount of fuel for a two-hour flight of an A-320 aircraft, it can be calculated that with a fuel consumption of 3,2 tons per flight hour and considering the fuel reserve, about ten tons of aviation kerosene will be needed to go to a nearby alternate airfield. The average cost of a ton of kerosene according to FAVT (Federal Air Transport Agency) is 67173 rubles[8]. Consequently, the cost of refuelling will amount to at least 671730 rubles. That is, the amount of fixed costs not covered by the flight performance is even greater than the sum of variable costs for refuelling the aircraft.

In this regard, it is rather difficult to say what is more beneficial for the airline – cancellation of a delayed flight or its operation after the delay time has passed.

According to European experts, the cost of restoring the schedule after a disruption in 2010 amounted to 1,25 billion euros, about 81 euros per minute of delay [2]. Which costs will be more: uncovered fixed costs or variable costs during the flight? As a first approximation, the specific component of variable costs is approximately 72 % of the amount of operating costs, fixed costs in their composition constitute, respectively, 28 %. But mentioned 72 % of the costs are spent during flights, that is, 12 hours a day, and 28 % are spent around the clock. As already noted, when a flight is delayed, operating costs that do not pay off bring losses. But there is the second component of losses in case of flight delays – these are additional expenses for payment of compensation to passengers, expenses for food and drinks for passengers, hotel accommodation, transfers, expenses for transferring passengers to flights of other airlines with an interrupted flight manifest. In 2007, direct operating costs associated with schedule delays in the US market were estimated by US experts to be about 8 billion dollars. The cost of delays for passengers was estimated by the same authors at four billion dollars a year [3].

[8] Federal Air Transport Agency. Rosaviation. Prices for avia fuel in 2022. [Electronic resource]: https://favt.gov.ru/dejatelnost-ajeroporty-i-ajerodromy-ceny-na-aviagsm/?id=8788. Last accessed 13.01.2023.

The most difficult is the issue of managing a disruption, especially in case of massive flight delays. Scientific research on this issue is dedicated not only to management of delays caused by force majeure, but also to systemic issues of airport development. The intensification of their activity results in more and more situations that lead to a violation of punctuality of flights.

An increase in intensity of air traffic leads to a delay of aircraft in the landing waiting area. The intensity of air traffic at the airports of large metropolitan areas leads to the fact that 60–65 take-off and landing operations per hour becomes an insufficient rate and, naturally, any one-minute delay in landing or taking off an aircraft leads to a malfunction and formation of a queue for departure. And the delay is followed by extra fuel costs and an impact on the image of an airline.

A serious problem that limits the rhythm of the airport is the take-off and landing speed of different types of aircraft. Aircraft with slower rates of climb or descent increase the time interval for the aircraft to stay on the runway. This problem is analysed in detail in [4]. The creation of buffer, excess time for schedule alignment is explored in [5].

Other studies are looking at the more common causes of flight delays. The work [6] examined several causes determining flight delays at Newark International Airport (EWR) using an integrated approach. The results show that adverse weather conditions, low ceilings (lower edge of the clouds) and poor visibility greatly affect flight delays. Similarly, the work [7] explored the main causal factors for flight delays by ranking various factors using an analytical hierarchy process. The authors found that technical disruption and data entry delay were two most influential factors. Based on the identification of causal factors, further studies examined the quantitative impact of each factor on flight delay. Analysing the characteristics of flight departure and arrival delays by plotting probability density functions, Muller [*et al*] [8] investigated several causative factors for delays such as transportation volume, aircraft type, aircraft maintenance, airline operations, weather conditions, changes in procedures during the flight, capacity limitations, customer service issues, and late arrival of an aircraft or of a crew. Another article by Shaowu Chen, Yaning Zhang and others entitled «Study of Flight Departure

Table 1

Causes and duration of delays (%) (compiled based on [10])

Cause of delay / Duration	Less than 15 minutes	0:15–0:30	0:31–1:00	1:01–2:00	More than 2:00
Not categorised delay (different causes)	32,61	5,98	2,99	2,77	2,38
Airline operational causes	2,20	4,36	4,76	4,76	2,79
Delay due to passengers and their luggage	2,97	3,46	1,68	0,81	0,55
Delay caused during maintenance of the aircraft by suppliers (loading and unloading, fuel, catering)	2,44	2,83	0,95	0,53	0,20
Delay caused by maintenance or aircraft defect	1,85	3,98	5,08	6,72	12,83
Delay caused by operational control and crew duty regulations	3,24	4,43	2,96	2,46	2,00
Delay caused by air traffic control	12,76	15,24	8,58	4,60	2,50
Delay caused by airport constraints	10,81	6,09	2,06	1,02	0,67
Delay caused by previous flight delay	31,12	53,64	70,94	76,41	76,08

Delay and Causal Factor Using Spatial Analysis» used several methodological approaches («Several approaches have been used to analyse the factors that affect flight arrival and departure delay»). The results show that the weather contributed to 69 % of delays [9].

However, it is worth noting the fact that when studying the causes of flight delays, conflicting statistics were formed among studies in the US and Europe. European research shows that the largest time delays are delays associated with late arrival of aircraft, that is, with a violation of the traffic schedule (Table 1).

In the USA, the main cause is associated with «weather conditions» that provoke the disruption of operations of already overloaded airports. In addition, the main cause for flight delays that is mentioned for the United States is poor planning of the airport operations that is without considering the actual traffic capacity (Pic. 1).

Proposals for Implementation of a Method for Managing a Disruption

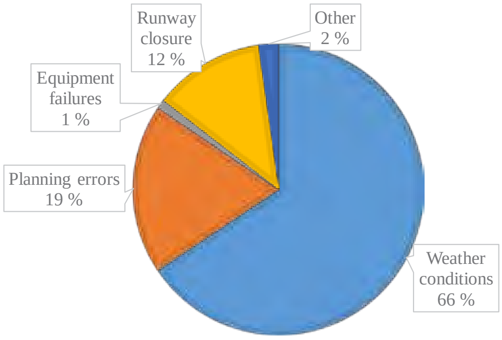
Methods for managing a disruptive situation are considered in a number of scientific and practical developments for managing resources in a disruptive situation. So, for example, in the study [12] the objective function is the total delay time, which tends to a minimum. The optimal distribution of organisational resources is the essence of solving this problem. Options for studying the components of losses and their magnitude have not been studied in the work.

In this paper, it is proposed to consider a simulation model, based on which it is possible to study the costs of an airline in case of a flight delay and the decision-making algorithm for managing a disruption associated with a massive flight delay at the airport. The simulation is based on a disruption associated with the delay of 13 flights. Under the terms of the study, the delay began at 18:00 on the first day and started to be resolved from 03:00 on the next day. The researcher will have to build a queue for departure starting at 03:00 with an interval of 30 minutes. Table 2 shows the daily flight plan for the current day and the beginning of the next day. The schedule presented in the table is hypothetical, since the described situation models a learning task for developing decision-making skills during a disruptive situation and skills to evaluate the decisions made. There may be several options for building a queue for departure. First, it can take the form of a conventional queuing system «first in – first out», that is, following the traffic schedule laid down in the daily plan. The second option is «last in – first out» to minimise the delay time for those flights that are closer to the time when the airport opens for departure. The third option is to minimise the airline's losses from the delay. The model includes losses from aircraft downtime per hour of downtime. Therefore, the larger is the aircraft, the greater is the loss from fixed costs. The next group of losses is the cost of serving delayed passengers – the cost of food after four hours of delay, of hotel accommodation after six hours of delay. Let us assume that the compensation to passengers of 0,25 minimum wage per each hour of delay is 25 rubles. The amount of the minimum wage is calculated based on the Federal Law («The calculation of payments for civil obligations established depending on the minimum wage is made from July 1, 2000 to December 31, 2000, based on the basic amount equal to 83 rubles 49

Table 2

Initial conditions for solving the problem of managing a disruption [performed by the author]

Delayed flights						
No of flight	Destination	Departure time scheduled		Aircraft type	Number of passengers	Expenses per aircraft type
		Hours	Minutes			
711	Kozelsk	18	0	AN24	32	980
712	Moscow-DME	18	30	A319	104	31387
713	Yekaterinburg	19	0	A320	80	36729
714	Chelyabinsk	20	0	B735	85	33390
715	Murmansk	20	30	ERJ-170	50	18200
716	Khabarovsk	21	0	B757	110	49418
717	Voronezh	22	0	B738	80	38000
718	Samara	22	30	ERJ-170	45	18200
719	Krasnoyarsk	23	0	B739	150	39000
720	Novosibirsk	23	30	B767	105	48000
721	Tyumen	0	30	B735	90	33390
722	Kaliningrad	1	30	A320	120	36729
723	Volgograd	2	30	F50	40	13356
Scheduled flights						
772	Moscow-VKO	6	30	B735	100	33390
773	Yakutsk	7	0	B757	90	49418
774	Ufa	7	30	B738	110	38000
775	Krasnodar	8	0	A320	90	36729
776	Sochi	8	30	B738	104	38000
777	Anapa	9	0	ERJ-170	68	18200



Pic. 1. Flight delays causes [11].

kopecks, from January 1, 2001 based on basic amount equal to 100 rubles»[9]).

The model is made in the form of a e-spreadsheet, in which each decision is calculated and estimated by the amount of losses, which allows checking the cost of decisions made, comparing the results, and choosing a possible variant of the order of departure of flights.

Table 2 shows that in the morning of the next day, regular flights depart from 06:30, but not all delayed flights of the previous day have departed during these hours. The researcher has yet to solve the problem of what to do with the departure of these flights. If they are delayed, there will be new losses already from the delay of these flights. But on the other hand, the release of scheduled flights will increase the delay of flights of the previous day. The researcher can get a result in the form of an estimate of losses in cases of departure of flights of the current day according to the schedule, their delay and departure of flights of the previous day or alternation of flight departure – a flight of the current day, a flight of the past day.

The total amount of losses is determined by the formula:

$$L = DAC_{(t)} + CF_{(t)} + CH_{(t)} + CPD_{(t)}, \quad (1)$$

where L – the amount of losses regarding the delayed flight;

DAC – losses from aircraft downtime;

CF – the cost of food for passengers;

CH – the cost of accommodation of passengers in a hotel;

CPD – compensation to passengers for a flight delay.

As can be seen from formula 1, all components of losses depend on time.

In this case $T_{(DAC)} = Td$; $T_{(CF)} = Td - 4$; $T_{(CH)} = Td - 6$; $T_{(CPD)} = Td$, where Td – delay time (in hours) and then

$$Td = Ta - Ts, \quad (2)$$

where Ta – actual departure time of the aircraft;

Ts – scheduled departure time of the aircraft.

[9] Federal Law No. 82-FZ of June 19, 2000 (as amended on December 19, 2022) «On the minimum wage». Article 5. [Electronic resource]: http://www.consultant.ru/document/cons_doc_LAW_27572/5bdc78bf7e3015a0ea0c0ea5bef708a6c79e2f0a/#dst100019. Last accessed 13.01.2023.

Daily plan												
Destination	Scheduled departure time		Actual departure time		Delay time		Number of passengers	Expenses per passengers			Expenses per aircraft	Penalties
	Hours	Minutes	Hours	Minutes	Hours	Minutes		food	accommodation	compensation		
Kozelsk	18	0	3	0	9	0	32	7040	64000	7200	8820	0
Moscow-DME	18	30	3	30	9	0	104	22880	208000	23400	282483	0
Yekaterinburg	19	0	4	0	9	0	80	17600	160000	18000	330561	0
Chelyabinsk	20	0	4	30	8	30	85	18700	170000	18062,5	283815	0
Murmansk	20	30	5	0	8	30	50	11000	100000	10625	154700	0
Khabarovsk	21	0	5	30	8	30	110	24200	220000	23375	420053	0
Voronezh	22	0	6	0	8	0	80	17600	160000	16000	304000	0
Samara	22	30	9	30	11	0	45	9900	90000	12375	200200	0
Krasnoyarsk	23	0	10	0	11	0	150	33000	300000	41250	429000	0
Novosibirsk	23	30	10	30	11	0	105	23100	210000	28875	528000	0
Tyumen	0	30	11	0	10	30	90	19800	180000	23625	350595	0
Kaliningrad	1	30	11	30	10	0	120	26400	240000	30000	367290	0
Volgograd	2	30	12	0	9	30	40	8800	80000	9500	126882	0
Moscow-VKO	6	30	6	30	0	0	100	0	0	0	0	0
Yakutsk	7	0	7	0	0	0	90	0	0	0	0	0
Ufa	7	30	7	30	0	0	110	0	0	0	0	0
Krasnodar	8	0	8	0	0	0	90	0	0	0	0	0
Sochi	8	30	8	30	0	0	104	0	0	0	0	0
Anapa	9	0	9	0	0	0	68	0	0	0	0	0
								240020	2182000	262287,5	3786399	0

Total expenses 6 470 707 rubles.

Pic. 2. Departure queue according to the algorithm «first in – first out» [performed by the author].

Daily plan											
Destination	Scheduled departure time		Actual departure time		Delay time		Number of passengers	Expenses per passengers			Expenses per aircraft
	Hours	Minutes	Hours	Minutes	Hours	Minutes		food	accommodation	compensation	
Volgograd	2	30	3	0	0	30	40	0	0	500	6678
Kaliningrad	1	30	3	30	2	0	120	0	0	6000	73458
Tyumen	0	30	4	0	3	30	90	0	0	7875	116865
Novosibirsk	23	30	4	30	5	0	105	23100	0	13125	240000
Krasnoyarsk	23	0	5	0	6	0	150	33000	0	22500	234000
Samara	22	30	5	30	7	0	45	9900	90000	7875	127400
Voronezh	22	0	6	0	8	0	80	17600	160000	16000	304000
Khabarovsk	21	0	9	30	12	30	110	24200	220000	34375	617725
Murmansk	20	30	10	0	13	30	50	11000	100000	16875	245700
Chelyabinsk	20	0	10	30	14	30	85	18700	170000	30812,5	484155
Yekaterinburg	19	0	11	0	16	0	80	17600	160000	32000	587664
Moscow-DME	18	30	11	30	17	0	104	22880	208000	44200	533579
Kozelsk	18	0	12	0	18	0	32	7040	64000	14400	17640
Moscow-VKO	6	30	6	30	0	0	100	0	0	0	0
Yakutsk	7	0	7	0	0	0	90	0	0	0	0
Ufa	7	30	7	30	0	0	110	0	0	0	0
Krasnodar	8	0	8	0	0	0	90	0	0	0	0
Sochi	8	30	8	30	0	0	104	0	0	0	0
Anapa	9	0	9	0	0	0	68	0	0	0	0
								185020	1172000	246537,5	3588864

Total expenses 5 192 422 rubles.

Pic. 3. Departure queue according to the algorithm «last in – first out» [performed by the author].

Daily plan											
Destination	Scheduled departure time		Actual departure time		Delay time		Number of passengers	Expenses per passengers			Expenses per aircraft
	Hours	Minutes	Hours	Minutes	Hours	Minutes		food	accommodation	compensation	
Khabarovsk	21	0	3	0	6	0	110	24200	0	16500	296508
Novosibirsk	23	30	3	30	4	0	105	0	0	10500	192000
Krasnoyarsk	23	0	4	0	5	0	150	33000	0	18750	195000
Kaliningrad	1	30	4	30	3	0	120	0	0	9000	110187
Moscow-DME	18	30	5	0	10	30	104	22880	208000	27300	329563,5
Voronezh	22	0	5	30	7	30	80	17600	160000	15000	285000
Tyumen	0	30	6	0	5	30	90	19800	0	12375	183645
Yekaterinburg	19	0	9	30	14	30	80	17600	160000	29000	532570,5
Chelyabinsk	20	0	10	0	14	0	85	18700	170000	29750	467460
Murmansk	20	30	10	30	14	0	50	11000	100000	17500	254800
Samara	22	30	11	0	12	30	45	9900	90000	14062,5	227500
Volgograd	2	30	11	30	9	0	40	8800	80000	9000	120204
Kozelsk	18	0	12	0	18	0	32	7040	64000	14400	17640
Moscow-VKO	6	30	6	30	0	0	100	0	0	0	0
Yakutsk	7	0	7	0	0	0	90	0	0	0	0
Ufa	7	30	7	30	0	0	110	0	0	0	0
Krasnodar	8	0	8	0	0	0	90	0	0	0	0
Sochi	8	30	8	30	0	0	104	0	0	0	0
Anapa	9	0	9	0	0	0	68	0	0	0	0
								190520	1032000	223137,5	3212078

Total expenses 4 657 736 rubles.

Pic. 4. Departure queue minimizing delay losses [performed by the author].

Next, we consider the results of building a queue for departure according to the condition «last in – first out» and a variant in which the queue for departure will be built with the condition of minimizing losses from delay.

Options for building a queue for departure in Pics. 2 and 3 do not establish an additional condition L = F(t) → min. The queue option in Pic. 4 sets this condition. The task of the researcher is to offer several options for arranging flights and choose the least unprofitable among them.

CONCLUSIONS

The given examples show that the use of the model allows simulating the process of managing a disruptive situation. In addition to the solutions given as an example, it is possible to build other variants of queues for departure of aircraft. The model allows changing the parameters that form the composition and magnitude of delay losses. Examples of queuing show that it is possible to queuing departure flights with the least delay losses. The purpose of the model is to show the possibilities of simulation modelling for solving operation problems associated with making managerial decisions. The model can be used for training air transport system specialists and as the basis for a corporate information system module.

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