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Decision-Making by Airport Ground Services by Means of Math-Economic Simulation and Fuzzy Logic

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Abstract: Decision making by the aircrafts services of the international airport which provides for intensive traffic of aircraft and their ground handling becomes a very topical issue. If earlier it was believed that the intensity is provided only by the number of runways, nowadays a large accumulation of aircraft on the airport platform-field creates equally complex difficulties in comparison with aircraft take-offs and landings. Solving such problems with the use of "Crisp methods" of queuing theory gives little. This study deals with modern "Fuzzy methods" based on simulation modeling and fuzzy logic.

Key words: Airport ground services, priority assignment, actor-network theory, simulation, fuzzy logic, math-economic models

INTRODUCTION

Currently, the task of improving operationally accepted decisions at international Airports (AP) of Russia is very relevant. In modern AP, functionally interrelated services are used, including: air traffic control service, airfield services at the aerodrome (refueling, preflight maintenance and check of aircraft), meteorological services to the aerodrome, services to ensure the registration, boarding of passengers on a plane and disembarking from an airplane, cargo loading and unloading of aircrafts and etc.

The most responsible in terms of safety is the air traffic control service which must be able to select the necessary information from a large volume of messages and also have the possibility of additional spatial simulation which allows correctly representing the air position of the ai rplanes in space and predict their position after a certain time during the flight. However, this service cannot fully perform its functions without coordinating interaction with other functional services.

Therefore, the staff is provided with Decision Support Systems (DSS) including those working in online mode as well as computer training apparatus and corresponding software (Emelyanov *et al*., 2017).

MATERIALS AND METHODS

Fuzzy logic in conclusions formation based on data of simulation experiments: Simulation modeling is applied when (Emelyanov, 2000; Law and Kelton, 2004): either statistical data for decision-making is not enough or such data can't be obtained and the "Natural" experiment is impossible.

In such cases, simulation modeling is used either as an addition to statistical methods or as an independent method. To make rational decisions using data from simulation models you can use such methods which are listed in order of increasing mathematical complexity (Emelyanov *et al*., 2015).

Linear programming if regression analysis allows you to obtain a linear response surface with linear constraints which has an acceptable level of significance and this is not always possible in practice.

Nonlinear programming is the Frank-Woolf method when it is possible to obtain a nonlinear surface with approximation near extreme values by surfaces of even (usually the second) order which is not always possible (Vishnyakova *et al*., 2005).

Gradient methods are the Gauss-Seidel method when it is not possible to obtain the response surface but it is possible to obtain partial derivatives at points. However,

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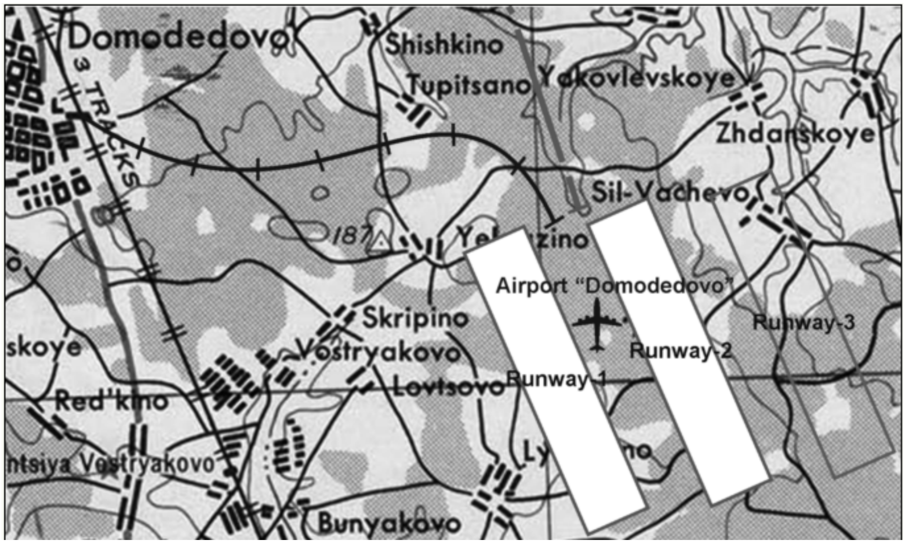

Fig. 1: Topographic fragment of the airport zone

in this case, bifurcation points occur accidentally on the trajectory of searching for extreme values (Bulygina *et al*., 2018) "Defective" changes in search directions.

"A very bad case" when you can get only some of the acceptable solutions, the choice of which can affect the dynamics of the process or system. In this case, dynamic programming is used (Emelyanov, 2013).

And if there is no certainty that the above methods "Work" then there are means of fuzzy logic (Kruglov *et al*., 2001) including using fuzzy pyramidal networks (Bulygina *et al*., 2018) and fuzzy inference algorithms (Borisov *et al*., 2014) such as Sugeno, Tsukamoto, Mamdani and Larsen. These tools are included in the simulation model of the controlled process in the form of a fuzzy controller that performs intelligent computations. The corresponding complex model is considered.

DSS and simulation model of airport services: Let's consider the actual initial data on the example of the Moscow Airport "Domodedovo" enterprise where there are two runways (Runway-1 and 2) and these bands have different exploitative characteristics which should be taken into account in the model. These runways are located in parallel at a safe distance (Fig. 1). Such features allow them to be used simultaneously. In addition to these runways, the new runway-3 is being built and the construction of which continues currently.

The main characteristics of the airport "Domodedovo" the researchers received from the official sites of the airport and the FA "Rosavia":

- Occupation time of runway-1 depends on the type of aircraft: 0.5÷1.0 min
- Occupation time of runway-2 is also determined by the type of aircraft: 0.5÷1.5 min
- Average interval of air planes arrival depends on the weather conditions: 7 min
- Time of aircraft maintenance in the parking lot and at the platform for ground handling (without taking into account the aircraft of airlines which are based at AP because they may be there for weeks): up to 720 min
- Average time of aircraft refueling depends on the type of aircraft: 12 min
- Maximum allowable number of waiting arriving airplanes in the AP zone depends on weather conditions: 4 (bad)÷12 (good)
- Maximum number of refuellers simultaneously serving the aircraft: 12
- Maximum number of aircraft to be prepared simultaneously for takeoff: 45
- Total number of entries in all sectors (A-D and F): 56
- Proportion of charter and transit flights in the general AP-traffic can be varied
- Aircraft ground handling disciplines: either "Natural queue" or with assignment of priorities

Consider the simulation model in terms of the "Actor Pilgrim" simulation system (Emelianov *et al*., 2014) which uses elements of fuzzy inference which takes into account that the runway capacity of the runway is different.

Figure 2 shows the structural block diagram of the simulation model, depicted in graphical terms of

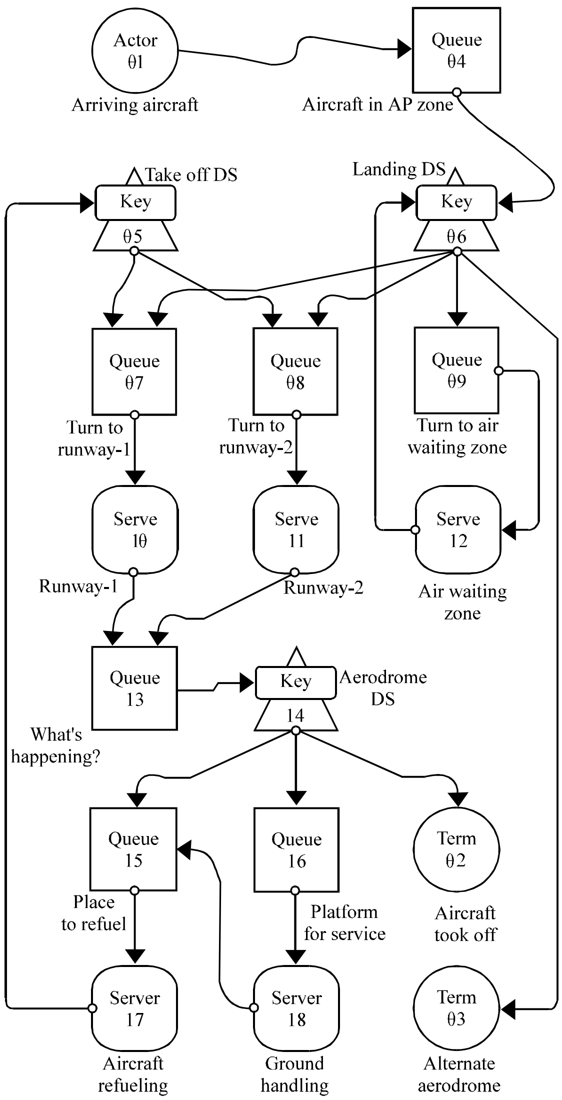

Fig. 2: Structural diagram of the model in graphical terms "Actor pilgrim"

simulation system which reproduces the basic processes performed by airport services, including takeoffs and landings of aircrafts as well as the functioning of ground services. Consider support nodes (05), (06), (14):

- (05) "Take-off DS" dispatching the airplanes to take-off (occupation of lanes, taxiing)
- (06) "Landing DS" for dispatching the sides in the AP zone (entrance, queuing in the circle in waiting zone, runway occupation, landing and taxiing or leaving from air zone to the alternate aerodrome)
- (14) "Aerodrome DS" dispatching of airfield services for refueling aircrafts with fuel, preparing them at airdrome platform to flight and others

The model is designed to solve some problems, including the following.

Problem 1: Optimization of the operation of aerodrome services those on which traffic and AP using depend: both in relation of arrival and departure of aircraft and cargo and passenger traffic through sectors A-D and F.

The answer to the problem 1. If there is a large accumulation of vessels on the airfield when the aircraft of the aircraft must "Fly" rather than "Stand", the methods of works and engineering in aviation transport need to be improved.

Problem 2: Receiving the answer to the question: "Is the third runway-3 (indicated by the developers of the model in Fig. 1) needed, since, the construction is in the future"?

The answer to the Problem 2. With the heaviest traffic when the average interval for receiving and dispatching ships is 2.5 min, we have the use of two runways:

- Using of runway-1 is 28.6%
- Using of runway-2 is 5.8%

All attempts to reduce the average interval of takeoffs-landings and make <2.5 min were unsuccessful. Such traffic leads the aerodrome services into a "Stupor" as the management of their work remained at the level of the 1960's and it was they and not the absence of the runway-3 that cause the delays. Therefore, the terms of the Queuing Systems (QS) are used (Saaty, 2010).

The main reasons for the decrease in the effectiveness of service "Aerodrome DS" when aircrafts ground handling at airdrome platform or in hangar is the use the discipline of "Natural queue" to dispatching (in the worst case) or priorities assignment (in the best case) taking into account only the administrative significance of the planned flight.

Usually the "Crisp" order of assigning priorities is as follows. First of all, serviced aircrafts that have only arrived and they just need to fly again. Aircrafts which for a while stood in the parking lot of the airfield but must fly in the near future should be serviced secondly.

And the newly arrived planes which in the near future will not fly and are towed to the parking lot are serviced last.

Fuzzy adaptive controller for priorities assignment in real time: However, apart from the administrative importance of the flight there are other reasons that must be taken into account when assigning priorities.

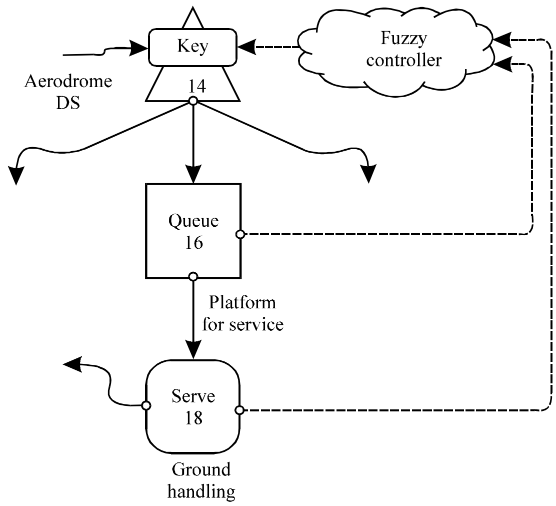

Fig. 3: Priorities fuzzy controller in adaptive complex model

For example, the normalized times spent on preparing the Yak 42 and Boeing 777 aircraft are fundamentally different. And the downtime of aircraft of different types is estimated in monetary terms in different ways. In accordant to these reasons, the decision support system must be "Strengthened" by the introduction into model of special software a priorities fuzzy controller (Dao and Chen, 2012; Datta, 2015) which allows to adapt the dispatching process in real time to the airport events. The structural scheme for including such a controller in the model is shown in Fig. 3.

The fuzzy controller is created in the form of a software-mathematical procedure using the modeling package "Actor Pilgrim". For this (in brief): The corresponding linguistic variables are introduced:

- NA the number of request or applications from the group in question in the queue
- RP the receipt probability of a request from the group
- ST the time of group servicing in QS channels
- CG cost of group maintenance
- TL time or penalty losses due to delay in the queue

Then their logical values are set, usually the typical L-Low; A-Average; H-High but it is possible and with the detailing of the type "Very". Next, the membership functions •$_L$, •$_A$, •$_H$ are selected. For example, it may by symmetric functions of the Gaussian type (Fig. 4) if the risks are insignificant or of lognormal type in other case (Emelyanov, 2000).

Another example is when the method of time series analysis using scenarios (Borisov *et al*., 2016) is used to create such functions. The result of defuzzification is the assignment of priorities.

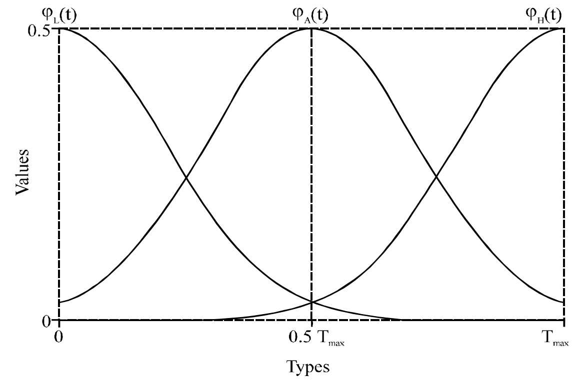

Fig. 4: Symmetric membership functions of the Gaussian type

RESULTS AND DISCUSSION

First, consider queuing system with dynamic priorities, assigned by "Crisp" algorithms (Bulygina *et al*., 2017). Hereinafter, we assume that time is measured discretely, for example by whole minutes and we consider a multi-channel system where each incoming application or request is assigned the "Urgency priority" according to the rule: either equal to the time of arrival in the simplest case or from more complex rules or distribution laws.

Let's consider an example: in the simplest case, the newly received request (or application) takes precedence over the pending bid if and only if the difference between the priority number of the urgency of this request and the priority number of the priority of the previous request is no less than the time during which it expects the previous demand.

This case is an example of how, at peak of intensive utilization, it is possible to "push" those applications that have been waiting for performance for a long time. However, in this example, the algorithm for prioritizing maintenance is not entirely unambiguous and has the features of fuzzy logic and timing. The general block diagram of the adaptive fuzzy priority assignment controller is shown in Fig. 5.

"Actor pilgrim" undemanding to resources and allowing models to work with virtually any region or water area of Russia with topographic basis of medium and large scales (except the North polar hat). The own electronic topographic subsystem is implemented. Some experience in the creation, debugging and practical application of such complex models is given by Bulygina *et al*. (2017).

Models are performed in a multi-process mode which increases their speed. At the same time, it is possible to

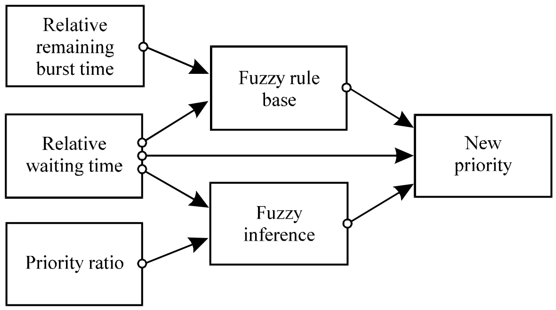

Fig. 5: Block diagram of fuzzy inference real-time controller

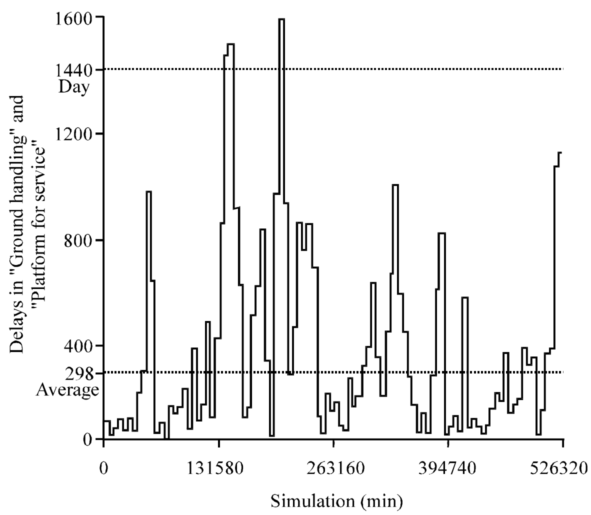

Fig. 6: Times or penalty money losses due to delay in the queue

use the model separately from modeling environment of the "Actor pilgrim" simulation system as a single exe-file.

The fuzzy controller is created using the tools "Actor Pilgrim". This new software procedure for the implementation of fuzzy algorithms is developed with using C/C++ and then are included in the system "Actor pilgrim".

The fuzzy controller made it possible to identify the conditions under which the "Extraordinary operations" of the airport services arose: both at short intervals of time and throughout the year.

An example of a hypothetical situation is shown in Fig. 6: if the airport operates in the "Heavy traffic" mode (Sani and Daman, 2014) then it incurs significant losses. Such abnormal work occurs at the airport in the existing conditions, if the average interval between take-offs and landings is reduced from 3.5-2.5 min.

The bottleneck is ground handling in such case but not runways (2 and 3). And this interesting circumstance was discovered with the help of a simulation model.

Some words about instrumental software using by authors: The model is developed by means of "Actor pilgrim". This simulation system is intended for constructing of simulation models discrete and discrete-continuous types. Such models are designed for the joint study of system dynamics which can be of different nature and to be functional in conditions of uncertainty and risk:

- Systems dynamics of events in time
- Spatial dynamics of processes and objects, for example, on the earth's surface with their exact binding to topographic measurements
- Financial dynamics associated with the movement of money and financial instruments
- These three types of system dynamics can be modeled when there is a possibility of risk occurrence

This simulation system was created using the Actor Networks Theory (ANT) used in technologies, engineering, economics and even in sociology (Latour, 2007).

The "Actor" (actant or network agent) is an object or entity that performs an action or is exposed to an impact. It can be any personage in the life cycle of constructing and developing a model network (microbe, theorem, organization, animal or human, computer, car or simple messengers, etc.,).

An actor network is the actors or agents collecting a network of people and things that interact in a single space and whose activities are directed toward the solution of a common task.

The process is an actions in the network that can influence the community of actors their number, composition, internal attributes and this action is associated with the dynamics and changes in time, spatial and even monetary dimensions.

A "Living" actor is always involved in some particular process. Of course, the actor cannot be regarded as "Homo sapience", since, it is a virtual character and it does not have a central nervous system. Compact actors (agent programs) are internal dynamic intelligent "Atoms" of some computer simulation model (Emelyanov, 2013).

However, actor can be provided by some simulated intellectual abilities in the model. Thanks to such abilities it is possible to create model-transformers and even simulated "Communities of actors".

CONCLUSION

Modeling shows that if feedbacks are implemented in the simulation model and the fuzzy adaptive controller is programmed that the dynamic assignment of priorities using the fuzzy inference procedure gives a greater effect in terms of money at peak of intensive utilization of the node 18 than a "Crisp"-algorithm (Emelyanov *et al.*, 2017).

An adaptive neuro-fuzzy procedure, for example, the adaptive network fuzzy inference procedure (Bulygina *et al.*, 2018) or the fuzzy pyramidal network which is to be investigated, can also have a significant effect.

In addition, analogous complex models created in "Actor pilgrim" were tested and applied in real conditions when studying emergencies in the affected regions of some countries.

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