A MODEL FOR GROUND TRANSPORTATION SYSTEMS SIMULATION AT AIRPORTS UNDER CENTRALIZED CONTROL

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ABSTRACT

This paper formulates requirements for a simulation model designed to study the movement of all types of vehicles in the ground space of the aerodrome on condition that a centralized control system provides continuous automatic control of their movement and sends commands of control to prevent dangerous situations. Examples of object movement models in 2D space are considered. The advantages of using a grid-based space for analyzing the interaction of objects are shown. It is concluded that commercial packages of processes modeling with discrete events or packages of transport flows modeling do not provide the conditions for implementing all the formulated requirements to the model. There are formulated principles of building models that can be implemented using universal programming languages. An example of developing a test model using the VBA language in MS Excel is described.

INTRODUCTION

All the main functions of organizing and controlling vehicles movement at the airport are currently performed by a person working as an air traffic controller. His main task is to ensure safety by preventing aircraft collision with each other, ground transport or other objects. Also, the vehicles themselves (aircraft, various types of cars, buses, tow trucks, etc.) are controlled today by people who perform the functions of pilots or drivers. Very often, the coordination of participants' actions in the transport process is made only by voice information exchange through the radio communication. It is obvious that the ideal level of safety of transport processes at airports cannot be achieved while maintaining a large share of human participation in the planning and implementation of the individual vehicle's movement. The main way to solve this problem is to increase the level of automation of traffic control processes in the ground space of the airport.

The document entitled "Vision 2050", published by International Air Transport Association (IATA 2011), notes that in the future, traffic control in the airfield zone will be transferred to automated systems, as a result of which air and ground traffic controllers will primarily perform the role of operators and monitor the functioning of such systems. Polish specialists (Augustyn and Znojek 2015) describe the airport process functioning of the future, accompanying the path of a particular aircraft from the moment of its landing to the parking stand and from the parking stand to lining up position before takeoff. Centralized objects control on the territory of the airfield starts with obtaining accurate data about each object location in real time. The control system issues commands that set the speed and direction of movement of all moving objects, and this takes into account not only the values of physical parameters of objects (location, geometric dimensions, speed and movement direction), but also data such as the type of object, the final destination of the route, the function and the priority level.

An implementation of automatic centralized control, of course, does not cancel the use of decentralized (local) vehicle control methods. These methods include both conventional manual control, which is provided by drivers or pilots, and the most modern technologies for automatic control of unmanned vehicles. Decentralized control methods are based on the construction of the space dynamic model, which directly surrounds a specific vehicle. Both data from various types of sensors located onboard the vehicle, and data obtained during communication with other participants of transportation process, are used as source data for such a model. A lot of publications are devoted to the research of decentralized control methods (see, for example, (Le-Anh and de Koster 2006) and (Craighead et al. 2007)), but they are not a matter of consideration in this article.

In (Augustyn and Znojek 2015), the concept of dividing the airfield area by zones, the occupancy state of which should be taken into account by the automatic dispatcher, is briefly mentioned. In turn, the zones where vehicles are moving can be divided into cells that are sequentially occupied or vacated during the movement of a particular object. The idea of allocating controlled zones is described in detail (Tabares and Mora-Camino 2017). Fig. 1 shows the GSE (Ground Support Equipment) zones and directions in the vicinity of the aircraft parking area.

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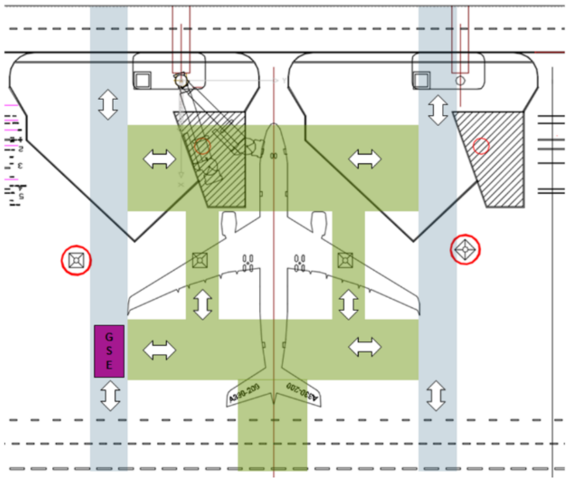

Figure 1: Proposed zoning and directions for GSE automated solution (Tabares and Mora-Camino 2017)

It is known that simulation is the most efficient method of studying transport processes at airports (Alomar et al. 2017). In order to study the process of mobile object control, a model that includes the following components must be developed:

- a model of objects movement on the selected paths and the model of the free movement on the grounds;
- a model for determining the location coordinates, speed, and direction of objects movement;
- a model of an automatic dispatcher that generates commands to control the movement of objects.

This work is devoted to the analysis of alternative methods for developing simulation models, for which the above-mentioned properties are an attribute. The result of an analysis that has been done, is the decision to develop special methods of conceptual and computer modeling that allow to solve set tasks of researching transport processes at airports in a centralized control environment.

A PROCESS MODELING PARADIGM CHOOSING

The main feature of the object movement model is the need to take into account their relative positions in 2D space. In this regard the real shape and size of each object should be taken into account, since one of the main tasks of the air traffic controller is to prevent collisions between both moving objects with each other and moving objects with obstacles. A straightforward way to solve this problem is to represent the shape of a moving or stationary object in the form of a polygon (Fig. 2). Then it becomes necessary to check the intersection condition of all polygons that display moving objects with their neighboring objects or obstacles nearby. The above-mentioned check in the model has to be carried out with a time interval of about 0.1 seconds, since during this time at a speed of 30-40 km/h the object can travel a distance of about 1 meter. The problem of checking the intersection condition of two polygons can be solved using geometric modeling methods, but this problem will have to be solved 600 times per each minute of the model time, which with dozens of interacting objects will lead to a noticeable slowdown of the simulation program.

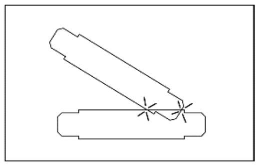

Figure 2: Objects collision detection represented by polygons

The second feature of the object movement model is the necessity to take into account accelerations and related changes in the objects speed movement. It is clear that the processes of acceleration and deceleration of aircraft will differ from those observed in ground vehicles. It is important to note that such processes can occur both at the initiative of drivers and in response to the commands of the automatic dispatcher. Fig. 3 shows the results of speed measuring of 10 aircraft on one particular taxiway during for 180 seconds (Mazur and Schreckenberg 2018). It is seen that the speeds vary over a wide range, for example, from 6 to 10 m/s.

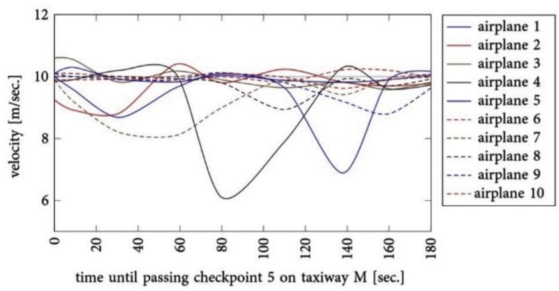

Figure 3: Speed-time plot of 10 airplanes taxiing on taxiway (Mazur and Schreckenberg 2018)

The two features of the object movement model that have already been mentioned above make it impossible to use the discrete event simulation paradigm. The necessity of application the time step "delta T" into a model is also related to the fact that a real automatic dispatcher also has to receive information about the current state of all traffic participants several times per second. The "delta T" method is used in commercial traffic flow simulation software packages, such as Vissim (PTV Vision). But in such models, the movement of objects is carried out mainly along the dedicated lanes, i.e. in mathematical terms, the models are one-dimensional, since they only take into account the distance between the cars following by each other. Models based on cellular automata are also one-dimensional (Mazur and Schreckenberg 2018). In traffic flow models, the principles of local control are applied, when a new speed value is determined for each car in the "delta T" step, depending on the speed of the car in front and the distance to it. In such models there is no aim to collect data about individual objects and centralized control of these objects. Since standard methods of transport flow modeling do not allow to solve the set task of modeling in 2D space, there appears a necessity to consider other areas of modeling application for studying the interaction of controlled moving objects.

EXAMPLES OF MOVING OBJECTS MODELING IN 2D SPACE

Since the beginning of the 90s, transport systems based on Automated Guided Vehicles (AGVs) have been used in production and logistics. Most often, such systems are modeled under the assumption that individual vehicles move along fixed sections of the route that collectively make up the transport network. The Central control system usually sets only a driving route to each vehicle and then does not control its position during the trip. Conflict situations that may occur between vehicles are resolved by means of local control systems that are installed on the vehicles themselves. A typical example of a model created using the Plant Simulation package based on the Discrete Event Simulation paradigm can be found in (Selmair et al. 2019).
This work is interested in simulations of the systems with multiple free navigating AGVs. A serious research is the master thesis (de Groot 1997), in which moving objects and obstacles are described using polygons, and the "delta T" principle is used to display the dynamics of the process. To predict a collision of objects the geometric model mentioned above is used (see Fig. 2). The simulation model is implemented using the Python programming language. An example of a scenario simulation involving 10 AGVs is shown in Fig. 4.

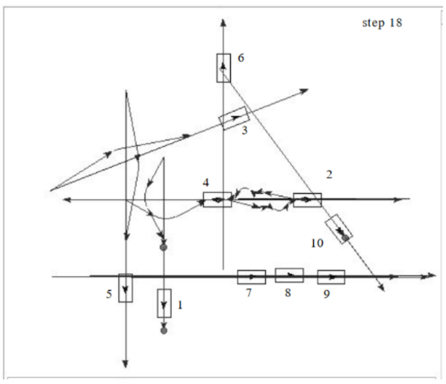

Figure 4: A simulation test with 10 AGVs (de Groot 1997)

A simulation model of the system with free navigating AGVs can also be found in the paper (Berman et al. 2003). It mainly focuses on local management of distinct AGVs in order to prevent AGVs from colliding with each other as well as with obstacles (Fig. 5). The simulation model is implemented using the Visual C++ programming language.

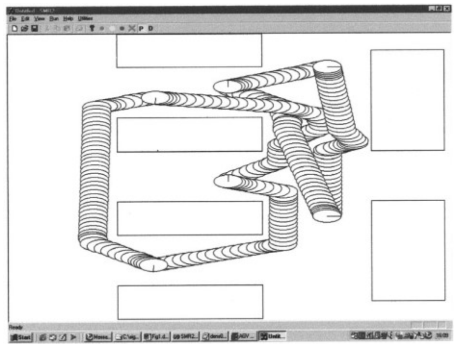

Figure 5: A simulation test with 6 AGVs (Berman et al. 2003)

APPLICATION OF 2D GRID SPACE

All the models described above used a continuous 2D space, in which the position of each point is described by a pair of coordinates (x, y). It is in such space, in particular, a rather difficult task of identifying the intersection of graphic images of objects, described in polygons, was solved. This space additionally can be further divided into cells with coordinates [j, i], where *i* and *j* are the row and column numbers, respectively. If dimensions for a cell are assigned for example, 2x2 meters, so the following coordinates conversion is trivial: (10.7; 15.3) → [6; 8]. Since for each point with coordinates (x, y), the coordinates of the cell in which it is located are known, many tasks of controlling the objects movement can be reduced for checking whether the object points belong to the corresponding cells or not. For example, two polygons are not in the intersection state if they do not have any sharing single cells. The accuracy of calculating the real distances between the points depends on the size of cell d. in Fig. 6 it is shown that two points p_1 and p_2 will be located in different cells both in the case of $\{p_1^1, p_2^1\}$, and in the case of $\{p_1^2, p_2^2\}$. Since the distance between the centers of the cells is $d\sqrt{2}$, the error in interpreting the position of the points in both cases will be equal to this value. For example, if $d = 2$ meters, the maximum error will be 2.83 meters.

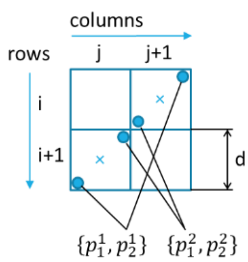

Figure 6: The limits in points location of neighboring cells

Since the accuracy of technical systems for determining the location of moving objects rarely exceeds this value, such accuracy can be considered sufficient, for example, when modeling the movement of vehicles on the airfield

area. In case of higher accuracy of determining the coordinates of objects, the value of d could be reduced, for example, to 1 meter.
The article (Szlapcynski 2006) describes the application of 2D grid space, which the author calls the term “raster grids”. The model shows the process of maneuvering ships in the water port area, where there is a risk of collision between each other or with port facilities. It should be noted that the concept of grid-based space is widely implemented in modeling processes that occur in certain geographical areas. Most often, these processes belong to class of a very slow ones, for example, the processes of urban areas development. There are models that were created to research also relatively fast processes, such as floods or fires. The article (Mazzoleni et al. 2006) reports on the development of a universal software package with which ecological models such as animal distribution, fire propagation, seed dispersal, and different models for simulation of vegetation dynamics have been created. The main part of the package has been implemented in Visual Basic (VB6) using ActiveX and COM components. The article (Taillandier et al. 2016) discusses how to improve the accuracy of raster models by adding objects represented by vector models to them.

SELECTED METHOD OF MODEL IMPLEMENTATION

The simulation examples discussed above, which have at least some properties that are similar to the properties of the set task of modeling transport processes on the airfield, indicate that such problems can be solved only with the help of universal programming languages. Commercial process simulation packages with Discrete Event Simulation packages or traffic flow simulation packages do not provide the conditions for implementing all the stated requirements for the model. The principled decision related to object movement processes modeling with an orientation on the application of universal programming languages are described below.
1. Moving objects and obstacles are located in a 2D space in which it uses both continuous coordinates (x, y) and cell coordinates [i, j].
2. Each moving or stationary object is described with the usage of a convex polygon, the points of which can be located in several cells of a discrete space.
3. One of the points of a moving object is declared as a reference point. The current position of the object is determined by the coordinates of the reference point (x_{ref}, y_{ref}) and the angle of rotation α relative to the northbound angle.
4. It is agreed that there are eight discrete directions of moving objects orientations, i. e.
$\alpha \in \{N, NE, E, SE, S, SW, W, NW\}$.
5. For each class of moving objects, eight graphical models are created that display the location of the occupied cells by the specified coordinates (x_{ref}, y_{ref}) and the rotation angle α (Fig. 7).

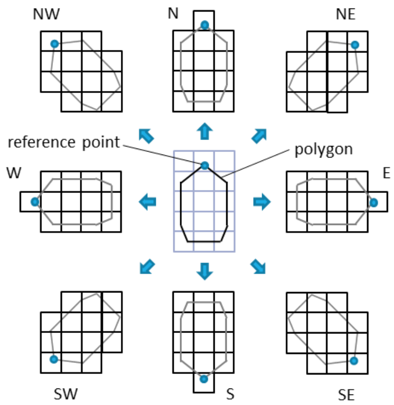

Figure 7: Eight graphic models of a moving object

6. The actual trajectory of the R_{real} object is replaced by a sequence of cells according to Bresenham's line algorithm. The simulated R_{sim} path passes through the center points of the cells that make up this path (Fig. 8). At any given time, the p_{ref} reference point can be located at any point in the R_{sim} path, depending on the distance passed.

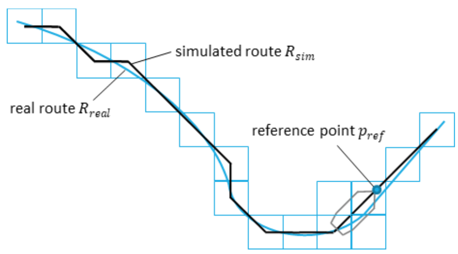

Figure 8: The replacement of real route with a sequence of cells

The first experiments, where the principles described above have been implemented, were conducted in MS Excel using macros written in the VBA programming language. The dimensions of the Excel table cells that display the airfield plan are selected so that they form a grid-based space with the cell size $d = 2$ meters. Fixed routes for aircraft and ground vehicles, as well as work areas and obstacles, are coded by assigning a color to the corresponding cells. Graphic models of moving objects are created in the form of ShapeRange. The objects positions on the screen are set using the Left, Top, and Rotation properties of these objects. Continuous animation is provided by interrupting the execution of a VBA program using the DoEvents function. In Fig. 9 there is a fragment of the simulation model, which shows the paths of ground vehicles and aircraft.

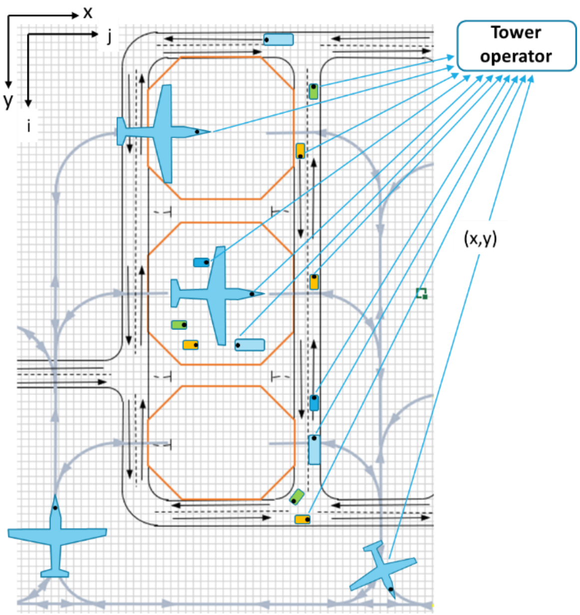

Figure 9: A simulation model fragment using grid-based space

The model generates a data stream from moving objects, which is recorded in the form of a protocol (see Fig. 10). This protocol displays events that can occur at any time. The main task of each event is to transmit the moving object actual position by the radio channel of local coordinates (x, y). In this way, the data flow from the supposed real equipment for determining the location of moving objects is simulated. Based on this data, the speeds, accelerations, and directions of movement of objects are calculated.

Event protocol			
Real-time stamp	Object ID	X-coordinate	Y-coordinate
10:45:12.84	ob_2	323.5	156.5
10:45:12.91	ob_1	247.2	140.7
10:45:13.03	ob_2	323.5	147.2
10:45:13.12	ob_3	323.5	170.6
10:45:13.84	ob_1	256.4	140.7

State protocol								
	ob_1				ob_2			
Discrete time	X-coord.	Y-coord.	i-cell	j-cell	X-coord.	Y-coord.	i-cell	j-cell
10:45:12.8	246.2	140.7	71	124	323.5	156.5	79	162
10:45:13.0	248.2	140.7	71	125	323.5	154.5	78	162
10:45:13.2	250.2	140.7	71	126	323.5	152.5	77	162
10:45:13.4	252.2	140.7	71	127	323.5	150.5	76	162
10:45:13.6	254.2	140.7	71	128	323.5	148.5	75	162
10:45:13.8	256.2	140.7	71	129	323.5	146.5	74	162

Figure 10: A creation of a state protocol based on event protocol data

By processing the event protocol data, a secondary protocol is created with the name "State protocol". This Protocol uses a discrete time with a "delta T" step, which is selected taking into account the speed of automatic system of situation analysis in the transport system of the aerodrome. In Fig. 10 an example where the time was equal to 0.2s is shown. The state protocol, along with the coordinates (x, y), at the same time contains the coordinates (i, j) that show the position of the object reference point in grid-based space.

HOW TO USE THE GTSS PROGRAM

The program developed by the authors was named GTSS (Ground Traffic Scenario Simulation). This program is not intended for statistical modeling of aircraft and ground vehicles mass flows, but for modeling specific, precisely described scenarios in order to test the feasibility of centralized control algorithms. The GTSS program is a universal tool for solving the tasks described above, since it can be applied to research the transport process at any airport. To prepare the program for researching a new object it is necessary to do the following:

- on the "Aerodrome" Excel sheet, create a network of square cells by setting, for example, the following parameter values: ColumnWidth=0.5, RowHeigth=5;
- set the display scale of the airfield plan, for example, when the side of the cell is 1 or 2 meters;
- display the airfield plan graphically, for example, as shown in Fig. 9;
- for each fixed path of object moving, mark all cells, which are a part of the path, with a color and number (see Fig. 8);
- create classes of movable objects as Shape objects and create eight "cell" models for each class, as shown in Fig. 7.

The rest of the model source data is set by filling in specially prepared tables. The tables of the "Scenario" type, which describe the processes of specific mobile objects appearing at specified points in the transport network of the airfield, are of particular importance.

CONCLUSIONS AND FUTURE WORK

The chosen method of modeling, which uses discretization both space and time, makes it possible to significantly simplify the solution of problems of analyzing the relative positions of objects in 2D space. The developed model of object movement in 2D space is the basis for implementing the model of an automatic dispatcher that generates commands for controlling the movement of objects. The data in the state protocol is an information base for various algorithms of analyzing the current situation and predicting the development of this situation for the next minutes and seconds. In particular, as a result of this analysis, the situations that require the intervention of the dispatcher should be identified. Examples of operational solutions for an automatic system or dispatcher are the following:

- to stop the movement of one or more objects if they are in danger of colliding with each other or with an obstacle;
- to prohibit all vehicles other than one or more precisely defined moving through a specific

intersection in order to provide their arriving at destination as soon as possible;

- to report new routes to distinct vehicles if congestions occur at specific nodes in the transport network.

This study is particularly at the stage of developing models of automatic decision-making for operational control of the ground vehicles and aircraft movement on the airfield.

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