TRANSPORTA UN SAKARU INSTITŪTS

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PĒTĪJUMS PAR ALTERNATĪVĀM VADĪBAS METODĒM SAUSZEMES TRANSPORTLĪDZEKĻU KUSTĪBAI LIDOSTĀS

PROMOCIJAS DARBS

izvirzīts inženierzinātņu doktora (Dr.sc.ing.) zinātniskā grāda iegūšanai

Zinātņu nozare „Transports un satiksme”

Apakšnozare „Telemātika un loģistika”

Zinātniskie vadītāji:

Dr.habil.sc.ing., profesors Jurijs Tolujevs

Dr.sc.ing., profesors Aleksandrs Medvedevs

RĪGA – 2018

Alomar I. **Pētījums par alternatīvām vadības metodēm virsszemes transportlīdzekļu kustībai lidostās**

Promocijas darbs. Rīga: Transporta un sakaru institūts, 2018. 115 lpp.

TRANSPORT AND TELECOMMUNICATION INSTITUTE

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AN INVESTIGATION OF ALTERNATIVE METHODS FOR CONTROLLING THE MOVEMENT OF GROUND VEHICLES IN AIRPORTS

DOCTORAL THESIS

to obtain the scientific degree Doctor of Science in Engineering (Dr.sc.ing.)

Scientific area “Transport and Communications”

Scientific subarea “Telematics and Logistics”

Scientific supervisors:

Dr.habil.sc.ing., professor Jurijs Tolujevs

Dr.sc.ing., professor Aleksandrs Medvedevs

RIGA – 2018

ANOTĀCIJA

Iyada Alomara disertācijas darbs “Pētījums par alternatīvām vadības metodēm virsszemes transportlīdzekļu kustībai lidostās”. Zinātniskie vadītāji Dr.habil.sc.ing., profesors Jurijs Tolujevs un Dr.sc.ing., profesors Aleksandrs Medvedevs.

Darba galvenais mērķis ir tādu metožu un instrumentu izstrāde, kas ļauj modelēt un novērtēt virszemes transporta sistēmu darbības īpašības lidostās ar dažādiem individuālo transportlīdzekļu satiksmes vadības veidiem.

Šajā dokumentā ir apskatīti uzdevumi uzlabot transporta procesus lidostās, kurus risina gan lielas nacionālās, gan starptautiskās programmas, kā arī atsevišķu zinātnieku un speciālistu darbības. Kā galvenā problēma ir izvirzīta problēma, kas saistīta ar gaisa kuģu aizkavēšanos, sakarā ar nepietiekoši efektīvām virszemes transportlīdzekļu darbībām, kas piedalās gaisa kuģu sagatavošanas procesā nākamajam lidojumam.

Pētījums rāda, ka galvenā transporta procesu analīzes un optimizācijas metode lidostās ir datoru simulācija. Tiek dots detalizēts simulācijas paradigmu apraksts, ko izmanto, lai izveidotu transporta procesu modeļus lidostās. Tiek ņemtas vērā divas programmatūras sistēmu klases, kuras var izmantot šādu modeļu izveidošanai, un tiek pamatots lēmums par General Purpose Simulation Software izvēli kā līdzekli virszemes transportlīdzekļu kustības vadības alternatīvu metožu analīzes problēmu risināšanai.

Darba praktiskajā daļā ir aprakstīti virszemes transportlīdzekļu kustības procesu konceptuālie un izpildāmie datoru modeļi apstākļos, kad ir iespējams atsevišķi vadīt katru virszemes transportlīdzekli, pamatojoties uz izvēlēto relatīvo vai absolūto prioritāšu sistēmu. Ir parādīts, ka izstrādātās metodes un rīki ļauj novērtēt jebkuru alternatīvu vadības metožu efektivitāti, plānojot un veicot eksperimentus ar modeļiem.

Promocijas darbs ir uzrakstīts angļu valodā, sastāv no ievada, 3 nodaļām un nobeiguma, iekļauj 116 lappuses, 51 attēlus un 16 tabulas. Izmantotās literatūras sarakstā ir 121 avoti.

ANNOTATION

The thesis of Iyad Alomar “An investigation of alternative methods for controlling the movement of ground vehicles in airports”. Scientific supervisors Dr.habil.sc.ing., prof. Jurijs Tolujevs and Dr.sc.ing., prof. Aleksandrs Medvedevs.

The main goal of the research is to develop methods and tools which will allow modeling and evaluating the characteristics of the operation of ground transportation systems at airports with different ways of managing the movement of individual ground handling vehicles.

The research contains review of objectives of developing the transport processes in the airports, within the framework of national or international projects as well as the activities and researches of individual scientists and specialists in this field. As the main problem, the aircraft flight delays was chosen, due to insufficient operations of the ground vehicles, which take a part in handling of the aircraft and preparing it to the next flight.

The research shows that the main method of analyzing and optimizing transport processes at airports is simulation. Also, it contains the details description of the simulation paradigms which were used to development the models of transport processes in the airports. Two classes of software which can be used to create such models and to the justification of the decision of selecting the General Purpose Simulation Software as a tool for solving problems of analysis of alternative methods for managing the movement of ground vehicles were considered.

The practical part of the research contains a description of the conceptual and executable computer models of the processes of movement of ground vehicles in conditions where it is possible to individually manage each vehicle based on the selected system of relative or absolute priorities. It is shown that the developed methods and tools allow evaluating the effectiveness of any alternative control methods by planning and carrying out experiments with models.

The thesis consists of the introduction, three chapters, and conclusions. It contains 116 pages, 51 figures, and 16 tables. The list of references and information sources contains 121 titles.

Gratitude

To my Mother's soul…

To all my family that inspired and supported me during my whole life…

I would like to express my sincere gratitude and appreciation to my scientific supervisor Dr.habil.sc.ing., prof. Jurijs Tolujevs for his valuable advice, recommendations, support and patience, my scientific supervisor Dr.sc.ing., prof. Aleksandrs Medvedevs, Dr.sc.ing., prof. Irina Yatskiv and Dr.habil.sc.ing. prof. Igor Kabashkin, they filled me with optimism throughout the whole process of working with the dissertation.

Acknowledgements

This work has been supported by the ALLIANCE project (http://alliance-project.eu/) and has been funded within the European Commission's H2020 Programme under con-tract number 692426. This paper expresses the opinions of the authors and not necessarily those of the European Commission. The European Commission is not liable for any use that may be made of the information contained in this paper.

CONTENT

ABBREVIATIONS

AB	Agent Based
AC	Aircraft
A-CDM	Airport Collaborative Decision Making
ANO	Air Navigation Order
ANS	Air Navigation Service
ANSI	American National Standards Institute
APU	Auxiliary Power Unit
A-SMGCS	Advanced-Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Transportation System
BPMN	Business Process Model and Notation
BV	Background Vehicles
CACI	California Analysis Center Inc.
CAST	Comprehensive Airport Simulation Tool
CAD	Computer Aided Design
CDMA	Code Division Multiple Access
CVSM	Conventional Vertical Separation Minimum
DE	Discrete Event
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FIFO	Firs In First Out
FMCG	Fast-Moving Consumer Goods
GDP	Gross Domestic Product
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPU	Ground Power Unit
GPSS	General Purpose Simulation System
GSE	Ground Support Equipment
GUI	Graphical User Interface
GV	Ground Vehicles
ICAO	International Civil Aviation Organization

IATA	International Air Transport Association
IFR	Instrument Flight Rules
ISO	International Organization for Standardization
KPI	Key Performance Indicator
MACAD	Mantea Airfield Capacity and Delay
MILP	Mixed-integer Linear Programming
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NOTAMS	Notice to Airmen
OEM	Original Equipment Manufacturer
OPAL	Optimization Platform for Airport including Landside
RIX	Riga International Airport
RPK	Revenue Per Kilometer
RTP	Real-time Transport Protocol
RVSM	Reduced Vertical Separation Minimum
SESAR	Single European Sky ATM Research
SD	System Dynamic
SIDs	Standard Instrument Departures
STARs	Standard Arrival Routes
SWIM	System Wide Information Management
TAAM	Total Airspace and Airport Modeler
TETRA	Terrestrial Trunked Radio
ULD	Unit Load Device
VBA	Visual Basic for Applications
VFR	Visual Flight Rules
VNO	Vilnius International Airport
WiMAX	Worldwide Interoperability for Microwave Access
WiFi	Wireless Fidelity

LIST OF ILLUSTRATIONS IN THE BODY OF THESIS

LIST OF TABLES IN THE BODY OF THESIS

INTRODUCTION

Relevance of the problem and motivation of the research

Air transport is the most important mean of transportation of both the passengers and cargo within individual countries as well as internationally. According to the IATA reports (The International Air Transport Association) in 2017, about 4 billion passengers were transported by air transport all over the world. IATA report 2050 announces that according to the forecasts for 2050, the number of passengers who use air transport may approach 16 billion a year.

The main element of the air transport infrastructure is airports. In many cases, namely the airports throughput is a factor limiting the passengers and goods flows passing through the geographical location to which the airport belongs. In the case of passengers' transportation, the throughput of the airport depends on three characteristics:

a) the number of aircrafts (AC) that can be landed or departed taking into consideration the capabilities of the *airspace* and *airside* zones of the airport within an hour or a working day;
b) the aircraft ground handling speed for the aircraft located in the in the *landside* zone of the airport;
c) the rate of servicing of the departing and arriving passenger's flows airport terminal building, including baggage processing.

In case of freight traffic as an item *c* the indicators of the performance of warehousing processes sorting and transportation of cargo units within the airport territory should be considered.

Up to date, the influence of factors related to the groups *a* and *c*, are well investigated, since the principles of organization of the corresponding processes are well known and the processes themselves are observed at various airports are only slightly different from each other. The greatest variety of options of processes organization belongs to a group of factors *b*. In the ground handling process of single aircraft located at the stand, more than 10 Ground handling Vehicles (GV) are involved. All these GV make a trip in the airport landside zone. Handling time of the concrete AC is function of moments of the buses arrivals for passengers transporting, trucks for transporting trolleys with luggage as well as other GV.

All these GV participate in traffic observed in transport networks, specially dedicated for the GV movement. Exactness of GV arrival to concrete AC is a function of traffic conditions in the network, which in its turn are influenced by the following factors:

a) the size and topology of the network;

b) the number of GV simultaneously participating in the movement;

c) the means of movement management of individual GV.

The relevance of the research is determined by the fact, that the identification and elimination of factors that adversely affect the accuracy of the GV movement will lead to a reduction in the number of aircraft delays during ground handling. Since each of these delays can lead to the distortion of the flight schedule of an individual airline or airport as a whole. As a result of the reduction in the number of flight delays, the level of passenger's service will be increased and simultaneously the airline's financial losses associated with changes in flight schedules will be reduced.

As referred to the title of the research, the focal point in the study of alternative methods for management of the movement of GV. Under alternative methods here be comprehended as methods that are not yet applied in practice but in the future can lead to a reduction in the number of unwanted aircraft delays during ground handling. Developing these methods, the state-of-the-art technology, is taken into account allowing remote control of each individual GV, as well as the prospects for introducing unmanned GVs.

The task of detailed modeling of the ground handling processes of an individual AC is unsettled in any of the reviewed publications. In addition, there remains an open question of choosing the type of software for solving the task of analyzing the strategies for GV traffic control at the airport. Taking into account the ultimate practical goal of the research, which is to reduce the number of undesirable aircraft delays during ground handling, and the above described state of research in this field, it was concluded to develop own methods and tools to simulate and evaluate the characteristics of ground transportation systems at airports at different ways of managing of the movement of dedicated GV.

Statment of the research task

The goal of the research is to develop methods and tools which allow modeling and evaluating the output characteristics of ground transportation systems performance at the airports at various ways of controlling the movement of individual vehicles.

To achieve this goal, the following objectives have been formulated:

- to develop a detailed description of the aircraft ground handling processes in modern airports;
- to review of the recent trends of technology development for managing AC ground handling processes;

- to identify the main tasks, methods and tools for modeling of transport processes at airports;
- to carry on a comparative analysis of two classes of software products that can be used to investigate alternative ground traffic control systems and justify the choice of software products that will be used to study specific systems;
- to develop conceptual models of the individual traffic control processes of the ground vehicles during the drive-through the intersections;
- to develop executable program models of individual traffic control processes for ground vehicles and evaluate the effectiveness of alternative management methods;
- to develop a conceptual model for the acquisition data process on the status of the all classes of mobile objects at the airport's cargo terminal;
- to develop an executable program model for the acquisition data process on the status of mobile objects and demonstrate how to use the received protocols of events and states by employees of cargo terminal.

The object of research is the transport systems of airports which used during ground handling of AC.

The subject of the research is methods of modeling and analysis of alternative approaches to the management of the of ground vehicles movement.

The methodology and methods of the research

During the development of conceptual models of the studied processes, the methods of system analysis, queuing theory and probability theory were used. Over carrying out numerical experiments with the models, the methods of the theory of experimental design were used. Over developing executable computer models, AnyLogic and Plant Simulation software packages were applied.

Thesis structure

First chapter starts with a detailed analysis of the main ground handling processes of the aircrafts, herewith the emphasis is on the problem of aircraft delays while performing these processes. Later on the current trends in the development of technical means and methods for ground handling processes managing of aircrafts are considered. As the framework conditions for the creation of new management systems, the perspective of the development of future airports is described. Chapter one will be closed with the statement of the task of the research.

Second chapter describes the types of transport processes at the airports, which nowadays are often researched using simulation. The overview of simulation paradigms is given. On the basis of these paradigms the transport processes in airports could be developed. Two competing types of software products are described: General Purpose Simulation Software and Airport Simulation Software. The chapter closes with the argumentation for choosing of the programming software type which will be used while problem- solving of this research.

Third chapter describes the conceptual model of aircraft ground handling processes which is the basis for creating the below described executable simulation models. The first model is considered as a rough model and it allows evaluating the ground handling systems throughput. Second model is a detailed model and it allows evaluating the various performances of ground handling processes according to the current situation in the transport network as well as the given alternative methods of the traffic control. The conceptual model of transport processes at the cargo terminal also is described in this chapter. On the basis of this conceptual model the executable simulation models were developed. The third chapter also describes the prospects and results of the simulation experiments with all developed models. Based on the results of the experiments, the corresponding conclusions are drawn

Conclusions contain summary of the executed work, description of most significant results obtained and directions for future researches.

1. MODERN PROBLEMS OF TRANSPORT PROCESSES MANAGEMENT AT AIRPORTS

The worldwide economic growth during last decades led to necessity of huge increase in worldwide transport systems including air transportation system. The airport capacity growth still does not fulfil with market requirements and this leads to massive delays and congestion at the airports airfield.

Taking the above stated into consideration and after analyzing the current state of art, it is important to summarize the most important challenges to the air transportation system:

- the improvement of the air traffic punctuality and the reduction of the number of the delays;
- safety of operation on the ground as well as in the air;
- reducing of the CO emission into atmosphere;
- improvement of flight schedule to satisfy passengers and customer's needs;
- innovation of airport design and operation procedures.

1.1. Current trends in the development of airport ground processes control techniques

The key questions of organization of air transportation and airport development are solved within the framework of national or international projects in which hundreds of specialists form dissimilar profile are involved.

A revolutionary modernization of the NAS (National Airspace System) system has been planned in USA during the period from 2007 until 2025 by implementing the project NextGen (Next Generation Air Transportation System). The NextGen aims to move America's air traffic control system from the current ground based system to a satellite based system with features of GPS technologies ~~feature~~. They assume that when dealing with airport operations, some points override others; they grouped these points in the following way:

a. A-CDM (Airport Collaborative Decision Making);
b. unambiguous communications;
c. runway entrance control;
d. no confusing lights; less stop and go;
e. continuous taxi speed; improved controller efficiency;
f. optimizing the use of available infrastructure;
g. A-SMGCS (Advance-Surface Movement Guidance and Control System).

In 2004, a similar European project SESAR (Single European Sky ATM Research), where the ATM abbreviation mean Air Traffic Management, started in parallel to the NextGen. It is expected that the implementation of the SESAR project up to 2025 will allows to triple the throughput of Europe's airspace and increase the flight safety in ten times. The SESAR project is composed of three separate phases:

- Phase 1: a definition phase (2004–2008), to deliver an ATM master plan defining the content, the development and deployment plans of the next generation of ATM systems. This definition phase is launched by Eurocontrol, and co-funded by the European Commission under the Trans-European Transport Networks programme and executed by a large consortium of all air transport stakeholders.
- Phase 2: a development phase (2008–2013), to produce the required new generation of technological systems and components as defined in the definition phase. This phase is managed by the SESAR Joint Undertaking.
- Phase 3: a deployment phase (2014–2020), for a large-scale production and implementation of the new air traffic management infrastructure, composed of fully harmonized and interoperable components which guarantee high performance air transport activities in Europe.

SESAR's target concept relies on a number of new key features:

a. the network operation plan, a dynamic rolling plan for continuous operations that ensures a common view of the network situation;
b. full integration of airport operations as part of ATM and the planning process;
c. trajectory management, reducing the constraints of airspace organization to a minimum;
d. new aircraft separation modes, allowing increased safety, capacity and efficiency;
e. information management (SWIM), securely connecting all the ATM stakeholders which will share the same data;
f. humans as the central decision-makers: controllers and pilots will be assisted by new automated functions to ease their workload and handle complex decision-making processes.

ICAO and EUROCONTROL defined the "Advanced-Surface Movement Guidance and Control System" (A-SMGCS) to ensure the safety and the efficiency of surface traffic at the airport movement areas (runways, taxiways and apron area). A-SMGCS is specially designed to manage the movement processes of aircraft and GV at the airport. Nowadays EUROCONTROL has validated only the first two levels of the system and the work continues on the implementation of the remaining two levels.

It is particularly important, for reasons of passenger security and safety, that all aspects are considered for effective air operations and also for effective ground handling. Many researches were performed in order to meet the growing passenger flows. Philippe Bonnefoy and others, issued a research which known as “Evolution and Development of Multi-Airport Systems” where the core of this research was creating Multi-Airport Systems. A multi-airport system is defined as a set of two or more significant airports, that serve commercial traffic within a metropolitan region. But with this solution they defined that the congestion problem at the three major airports in New York could also drive the emergence of a new secondary airport. However, the development of multi-airport system possesses several challenges in terms of planning and development (Bonnefoy et al., 2011).

Richard de Neufville, Professor of Engineering Systems and Civil and Environmental Engineering Massachusetts Institute of Technology, also issued a research in this area in his article “Airports of the Future: The Development of Airport Systems”. Worldwide development presented as some emerging trends towards focused specialization in airport operations, and their major types of airport are defined (De Neufville, 2003):

- 24/7 intercontinental airports serving the global international passenger traffic;
- cheap fare, short haul airports that strive to be inexpensive to match the demands of their clients; and
- cargo airports dedicated to serving integrated freight operators.

Rebecca Price and Alexander Dreiling issued an article “Design led innovation: Shifting from smart follower to digital strategy leader in the Australian airport sector”. They said that the proposed future aerotropolis airport model argues that airports act as cities, home to people, businesses, industries, and a pivot point for economic growth. A cultural and organizational transformation within the airport sector supported by business model innovations will be required to accompany such a monumental shift toward the future operations of (Price et al., 2013).

The smart follower or innovation-adopting organization selects and absorbs the success of innovation generators and leaders within and outside of their industry, reducing the risk of market failure. However, this approach toward innovation also cements risk and innovation adverse cultural dynamics within stakeholders which can yield low organizational creativity and deficiencies in problem solving.

Some of these researches take a form of analysis and they are legislative acts only, and others are NOTAMs (Notice(s) to Airmen) and instructions to all operators.

As stated in the law and regulation of aerodromes (Abeyratne, 2014), here are five main factors which play major roles in improving airport capacity:

a. Integration of GNSS use;
b. Integration of arrival/departure/surface management;
c. Optimization management;
d. Improvement of surface surveillance;
e. Airport collaborative decision making.

It is impossible to improve items number (b) and (d) without good management and optimization of ground vehicles movement and operation. On the other hand, the accidents and incidents which take place at aerodromes involving ground vehicle operations and impact on aircraft by these vehicles, are rapidly increasing.

The most extensive researches were provided by a Portuguese team of scientists, (Casaca, 2008). They explain that the present level of technological development in the information and communication Technologies allows the definition of a low-cost platform for the vehicle navigation component of A-SMGCS, and present good ideas regarding how to use and integrate all the known communication network systems like WiFi, TETRA, CDMA and WiMAX, to optimize ground vehicle movements within the local area network.

Gonzalez and a group of researchers issued a publication in 2013 (Gonzalez et al., 2013), where they stated that the optimization of future ground operations for aircraft cannot be understood without the study of the main platform, the Sky. For said purpose these two projects stand out; NextGen and SECAR. Evertse and others (Evertse and Visser, 2015) also carried out research in real-time airport surface movement planning and minimizing aircraft emissions and fuel burn. They used mixed-integer linear programming (MILP). The MILP model, as implemented, permits the tool to refresh the total taxi planning every 15 seconds, allowing response to unforeseen disturbances in the traffic flow. However, they took into consideration only the real-time taxi movement planning and optimization of taxing time. Again they ignored all other inputs that could affect this process.

A group of polish scientists (Augustyn and Znojek, 2015) started to study the problem of optimization and management of ground handling processes and proposed that the ATC operator takes a supervisory role only. Ground-based processors will send all the necessary information to the aircraft. They believe that this technology, which uses digital data link and real-time planning, can automatically and independently recognize and preplan. The function of ATC is then only to monitor the current operations and would intervene and rectify problems as required, in the event that they occur.

Zepra Enterprise Solutions (Airport Visualizer, 2017) produced new soft 'Airport Visualizer'. This soft already works at Ataturk International Airport, Istanbul. This program from our point of view is more effective as far as it is works not only with aircrafts, but it also takes into consideration ground vehicles movement.

The prerequisite of this software program is the transparency and visibility of all vital processes. The Airport Map, fully and seamlessly integrated to all of the airports' resource management and planning systems, provides this vital information tool, not only for the ground handlers' motorized GSE, e.g. tractors, loaders, GPUs etc., but also for all motorized vehicles used in ground operations – plus all non-motorized equipment and assets such as dollies, ULDs or palettes. The user of this fleet management solution will be able to monitor and control the operational effectiveness of all mobile assets on a single screen and benefit from real-time data and mission critical reporting.

Almost about 90% of airports' infrastructures involved in ground handling system thus, good managing of this, can appear in good aviation project management. That is why the airports design should give a realistic overview of typical service provider involved in airlines, airports as well as high quality and safety manufacturing operations. Also, it is obvious that airports design should create the interdependence between safety of aircraft operations and the satisfaction of passengers in economic aspects. The most important of airports value is time, safety, security and the amount of money spent, so the passengers are interested in technological advanced projects. All costumers look for their high comfort and satisfaction. However, all those things cannot be provided without proper dealing management and good organization of grand holding. Of course, the cost value should be the most important in quality handling of service, because total quality service is the single and the most important issue in providing passengers service successfully. That is why the innovation of the airports design should take into consideration by the following aspects:

1. First the future project should be dealing in parallel with two areas:
   - air navigation system;
   - airports' infrastructure.
2. The usage of new technology in ground handling for almost two decades centered on ground transport inters change.

3. Reduce of human errors in all aspects in the aviation market. Obviously, the high service quality leads to customer's retention, which has shown to be cheaper in the long terms with high levels of the customer turnover.

The Airports design includes a crucial role in the aviation safety chain, linking safety of airlines with their security of passengers and freight customers. There are centers of economic activity attract business parks and serve as multi-modal transfer points. It's a complex of new design airport buildings and security infrastructure systems that serve from time to time the needs of a variety of interests. Most of these interests are concerned in the new construction terminal building (Airlines Park with their aircraft for unloading and loading, passenger's baggage and their move between ground transport and aircraft). Airlines, the airport operator, and businesses look for to serve all the time and assist passengers and airport visitors, and the terminal building supports these activities. Future concepts of modern airports address three basic elements:

a. More comfortable handling of passengers;
b. Capacity and quality increase with the high level of air operations;
c. Reduction the environmental impact on nature by clean energy projects.

Larger airports have grown, and this has provided the knowledge on how to predict and solve the major problems such as optimal use of the airport capacity, insufficient runway capacity etc.

Nowadays terminal buildings are renovated, upgraded, modified. In addition, entertainment places were built to accommodate growth in air travel. In the future most of the existing airports will be renovated taking into account the comfortable facilities where terminal building must be rebuilt within the constraints of existing property runway, boundaries and highway systems during safety continuing airline operations. The future terminal buildings are improbably to be radically different in basic concept, but surely, they will be larger and busier than any airports that currently exist.

The traditional structure of aviation project management is characterized by routine work process and planning, organizing, controlling and coordination process, within the confirmation of the line organization. One of the ways to achieve success in designing of airport is the qualification of the suitable method in aviation project management. The survey of the new areas of investigative co-operation in different scientific disciplines is required. Necessary strategies of using the modern technologies for safety and security are one of the most important research areas. Integrating technical, safety of natural environmental, psychological and economical sciences with creates the chances of increase result of airport design.

Moreover, airports design should be based not only on supervision of procedures, the power of aviation project management and formal security rules to obey orders but also on passenger's rights. Despite this, project's tools for airport design are well known available e.g. risk analyses, planning, organizing, doing, controlling and budgeting, the aviation projects could fail due to lack of methods and techniques but there is sometimes poor correlation between innovation power of doing aviation projects and human resource management doing with natural environment protection. Moreover, the relation between awareness employees (team) and environment protection can be increasing the level of quality of airport project management. This concept gives the updates in leading of aviation project in order to decrease cost level and improve aircraft safety level with natural environment protection.

1.2. The perspective of airport design

The body of this paragraph published in (Medvedev et al., 2017).

The perspective of airport design presents a new way of approaching to the culture, structure and the communication procedures of the team workers (Figure 1.1). The methodology should fulfill with the following aspects:

1. Defining the problem or challenge and mission of the airport project.
2. Logical structuring the airport project regard to interim results and specific activities.
3. Decision-making process in creating the airport project in correlation with natural environment protection.
4. Planning and controlling line of time, money, quality, information and communication in organization of airport project.
5. That is why the good face of airport design perspective gives a systematic way of working together. The innovation of airport design could be created on minimum two or more pillars. The two pillars give strength in airport project leading related to:
   - finding and making optimum use of the power of imagination, the power of co-operation and the power to shape structure;
   - synergy in working from a leadership as personal development perspective to provide the good working result of project team and the success from aviation product perspectives.

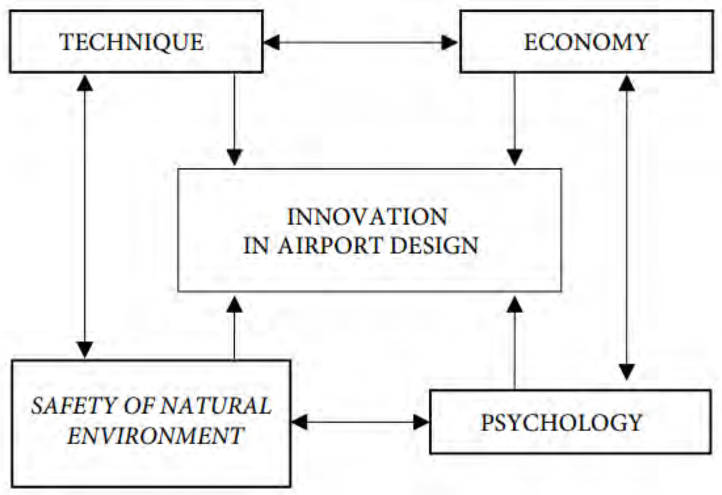


Figure 1.1. Integration of different scientific disciplines for innovation of airport design (Medvedev et al., 2017)

Additionally, the innovation of airport design should correlate in three perspectives and three powers for enterprise:

1. The personal development perspective is supported by the power of Imagination.
2. The project's team perspective and the power of Co-operation, target at team synergy, mutual trust and good management of relationships in and around the aviation project.
3. The project perspective, supported by the power to Shape, ensures the management of time, money, quality and other control factors.

The new approach to innovation of airport design shows the wide and new vision of work organization with consideration of natural environment protection that encompasses:

1. the innovative technology with new project process in order to lead aviation project;
2. the improvement of acknowledge working teams in airport project;
3. the new way solution of essential problems for success achieving in the airport structure;
4. the education improvement of the aviation project team.

The aviation projects are very often successful when the investor, project team and line managers choose to face the challenge all together. This gives involvement, positive energy, satisfaction and good desired result. As well as the new project managers should develop a creative structuring approach instead of strictly logical one talking into consideration the control factors such as money, timeline, quality, communication and well organization Figure 1.2.

New technologies give us a wide selection for choices of data collection units, it can be:

a. Positioning system sensors, like GPS sensors and tracking system.

b. Video information. Using special intelligent programs, which transfer video images into the event log. For example, from a video image the program can set a protocol about trolley No. 20 reach point x at time 21h34m12s. This program may be kind of Real-time Transport Protocol (RTP) (Schulzrinne, 2003).
c. Information interpretation from various elements of the system that uses various sensors installed at the system elements.
d. Human who involved in inserting information about the state of each system element via communication devices.

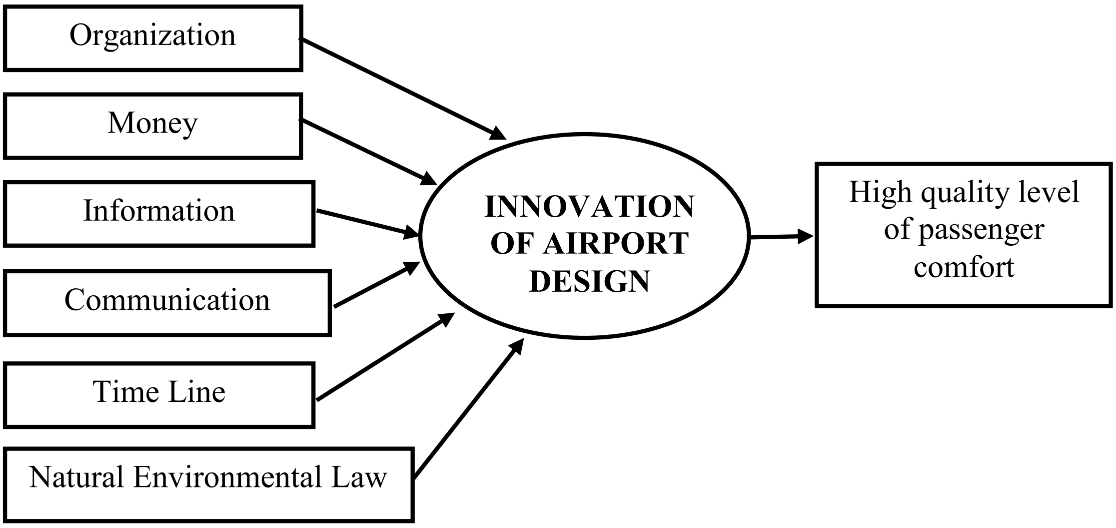


Figure 1.2. The transformation process in aviation project management (Medvedev et al., 2017)

All these 5 methods can provide new information data streams required for simulation and modelling of the whole process including the movement of the aircraft itself.

It is important to mention that the fact, that for the current research, not only the coordinates (x, y, z) of each separate system elements are important, but also the state of these elements have a very high degree of importance.

The above described system can be useful in aviation world because it can:

a. Increase vehicles safe movement at the aerodrome, owing to all process will be automated and under real-time control.
b. Increasing the productivity of the system (logistics index), due to minimizing of time losing during aircraft servicing. Also this system can be linked to ATC system, and in case of any delay or change in aircraft schedule all system on the ground will react in time and reset itself in order to match new slot time.

c. Decrease of the carbon emissions in the atmosphere, as all vehicles can be controlled from the control center, and the control center can choose the short way and from which starting point the vehicles will start moving, depending on aircraft stand.

Currently the innovations in airport design are created for the provision of services in aviation. The service providers in aircraft operations usually focus not only on the quality of the service, but also on the efficiency. The innovation in airport design involves complex predictions and involves a high degree of competition and aviation equipment development, with new methods, tools and materials, with sustainable technologies and well organized airport infrastructure. It is particularly important, for reasons of passenger security and safety, that all aspects are considered for effective air operations and also for effective ground handling

1.3. Problems arising during ground vehicles movement on the aerodrome

The critical airport operation schedule and operations conditions are one of reasons lead to delay in aircraft arrival/departure schedule. To reduce delays time on the ground as well as in the flight (Alomar et al., 2017b), it is quite important to improve the critical airport operation. Key factor in this improvement is management of arrival and departure time of the aircraft (runway sequencing and scheduling) (Alomar et al., 2017c), (Jason et a., 2010), 32 (Bianco et al., 2006), on time gate arrival and correct gate assignment (Bohme et al., 2007), and ground vehicles movement.

The ground vehicles movement at the aerodrome problem related to that fact that a lot of routes those used by ground vehicles have intersection with aircraft taxi ways. Usually the priority goes to aircrafts going to/from their destinations to either reduce the overall travel time and/or to meet some target time windows. At small airports to avoid conflicts between ground vehicles at the aerodrome, it is quite enough to apply to the shortest path algorithm (Bianco et al., 2007). For hub airports this method is not effective and in such airports it isrequired to search other solutions using modelling and simulations (Alomar et al., 2017b).

Human factors play a major role in this field as far as the management of the whole process still under control of the operator(s) those in their terms subject to a lot of disease, fatigue, tired and most important here that human nature has tendency to make mistakes. (Dorndorf et al., 2007) (Cormen et al., 2001) (ISAGO, 2016) (Balk and Bossenbroek, 2010). Optimistic researchers looking to the future airports those controlling totally not by human but by machine.

Another impact of the problem of ground vehicles movement at aerodrome is the dynamic nature of the problem. The dynamic nature leads to reduction the accuracy of the positions for certain vehicles or certain aircraft. This fact requires permanent updating of the location of all ground vehicles moving at the aerodrome including aircrafts themselves. To deal with this issue a simple modelling and simulation approach, can help (ACI World, 2010)

Next problem is environmental impact. emission have different sources:

a. Aircraft in taxiing;
b. Gases coming out from the ground handling vehicles;
c. Auxiliary power units used at the aerodrome.

Emission from item (a) can be reduced by means of making taxing with lowest required engines for that purposes, as an example A320 and B737 can perform taxiing with one engine only, but this solution also has some restrictions as far as it is impossible to shut down any engine before certain cooling g cycle after thrust reverser deploying. (Advisory Circular and FAA, 2015) (Pesic et al., 2001) (Cros and Frings, 2008) (ICAO Databank, 2007)

Emission from (b and c) are related to each other's. it is possible to reduce emission from APU by forcing all aircraft to shut down the APU's while aircraft at the gate, but to do that other sourses of power must be connecteed to the aircraft likes air condition, GPU, etc. those in their turn exhaust emission to the atmosphere. This problem could be solved by using of electrical operated machine instead of fuel operation machine. (Herndon et al., 2004)

Reducing the amount of emission from (b) can be obtained by optimization of ground handling process including optimization of ground handling vehicles movement. (Koeners and Rademker, 2011), (Austin Airport Electrification, 2011). To check different way of optimization and the result of the proposed solution, modeling and simulation can help.

Another problem is flight scheduling, as far as any schedule interruption will cause inconvenience to all related parties and as a result, flight schedules may become infeasible and have to be updated timely (GSE ZRH, 2014) and on other hand will cause huge economical loose for an airliner. Usually airports develop the schedule in accordance with local needs of operations (Štimac et al., 2013) (Stojkovic et al., 2002) (Mou and Wanlin, 2013). Currently new kind of operational multi-crew scheduling problem which consists in simultaneously modifying, as necessary, the existing flight departure times and planned individual work days (Teodorovic and Stojkovic, 1995).

Taking into consideration all stated above, it can be stated that it is possible to reduce aircraft downtime on the ground and consequently reduce emissions and airlines cost, by good organization and optimization of ground handling processes. The analysis of all above given data led to the conclusion that the most critical area in ground handling optimization is optimization of ground handling vehicles movement at the aerodrome, and the best method for studding this subject is simulation and modelling.

1.4. The influence of aircraft ground handling on the airports and airlines indicators

The body of this paragraph published in (Alomar et al., 2017c).

Fast increasing volume in the air transport industry directly affects airport enterprises and initialized significant changes in airports' ownership and management. Airlines and airports, operating in a stressed and competitive environment (Fu et al., 2011). This stress has close relationship to operational efficiency which in it turns is one of the major profit increment sources, so efficiency estimation and enhancement became a subject of major interest of airport's stockholders (Tea et al., 2006). Airport efficiency estimation can serve different purposes (Tea, 2011) and has important relevanc to stakeholders in charge. Here in after a list of interested parties which includes (Scotti, 1992):

- airline management staff interested in identifying efficient airports for their operational activities;
- airport management staff who require efficiency comparison between airports to improve airport operations and enhance its standing in a competitive environment;
- policy makers who are needed for benchmarking results for airport improvement programs and optimal decisions about subsidies and resource allocation; and
- municipalities, which require efficient airports for attracting businesses and tourists into their regions.

In order to allow airport to perform all planed takeoff and landing on schedule, airport managers and stakeholders have to understand the level of responsibility that lies on each sector of airport, especially management of ground vehicles movement at the aerodrome. Good management lead to increase throughput functionality.

Management of aircraft and ground handling vehicles at the aerodrome considered as a complex task that required high level of responsibility and controllability.

The main function of any airport department is to operate safely and effective as well as on-time operation. EASA master plan 2025 stated that all stakeholders have to be ready for increasing in passenger's flow in next 10 years by 5 times.

As stated in white papers (White paper, 2011), transport is fundamental to our economy and society. Mobility is vital for the internal market and for the quality of life of citizens as they enjoy their freedom to travel. Transport enables economic growth and job creation. It must be sustainable in the light of the new challenges nowadays, as well as new technologies for vehicles and traffic management will be the key to lower transport emissions in the EU as in the rest of the world. Transport is global, so effective action requires strong international cooperation. Starting from 2001 White Paper on Transport, issued many recommendations in this field as far as additional market opening has taken place in aviation, meanwhile the Single European Sky has been successfully launched (White paper, 2001). The EU transport industry reaches about 10 million employees and about 5% of EU GDP (European Commission, 2016). The globalism of aviation sectors requires the continuation of the improvement of the efficiency of aircraft and traffic management operations. Airport capacity needs to be optimized and where necessary, increased to fulfil growing demand for more than doubling of EU air transport activities by 2050.

The future prosperity of our continent will depend on the ability of all of its regions to remain fully and competitively integrated in the world economy. Efficient transport is vital in making this happen. On one hand, the EU has called for and the international community has agreed, on the need for thoroughly reduced world greenhouse gas emissions, with the goal of limiting climate change below 2ºC. Overall, the EU needs to reduce emissions by 80-95% below 1990 levels by 2050. On the other hand, there is a huge demand for increasing airport capacity, caused by the increasing number of passengers and goods flow. Air travel has become accessible to billions of more travelers in recent years. In 2012, 2.8 billion passengers expected to use air travel (Porter, 2011). According to the IATA 2050 report, it is expected that 16 billion passengers and 400 million tons of cargo will be transported by aircraft in 2050. A good example of this is that China plans to build new 1600 airports up to 2030 to increase the airport quantity from 399 to 2000. For that China will invest $45 billion. With this increase, the human will be the weakest point in this chain. As far as human cannot follow and organize all that flow increasing softly without founding new instruments which could help him, and ICAO report 2050 proposed the conception of airport without ground and ATC human controllers. This conception requires more effective infrastructures and newest technological design.

Following this huge increment, stockholders have to pay attention to the eco-efficiency and sustainability that is often used as a synonym for eco-efficiency or environmental efficiency and mitigation in the sense of reducing environmental impact per unit of business performance, for instance, per revenue per kilometer (RPK) or aircraft movement. The aim is to “do more with less”. The pursuit of eco-efficiency does not imply a constraint on growth in the scale of an activity (Knudsen, 2004).

Sustainable development requires balancing local and global efforts to meet basic human needs without destroying or degrading the natural environment (Statement at the World Summit on Sustainable Development) (United Nations, 2002). The question then becomes how to represent the relationship between those needs and the environment. Figure 1.3 demonstrate breakdown of airlines' total operations cost.

The director of St. Joseph's College, Darjeeling, India, Milindo Chakrabarti stated that one of the major parts of the cost incurred to airlines is that of the ground handling services. In order to reduce waiting time and downtime of the aircraft on the ground, it is necessary to optimize the use of the resources and personnel involved in the ground handling process. From another point of view, it is important to maintain aviation transportation at a high level of sustainability, as far as sustainability is subject to a wide range of general and specific interpretations, in the general political debate but specifically within the aviation sector and among its stakeholders (Report, 2000).

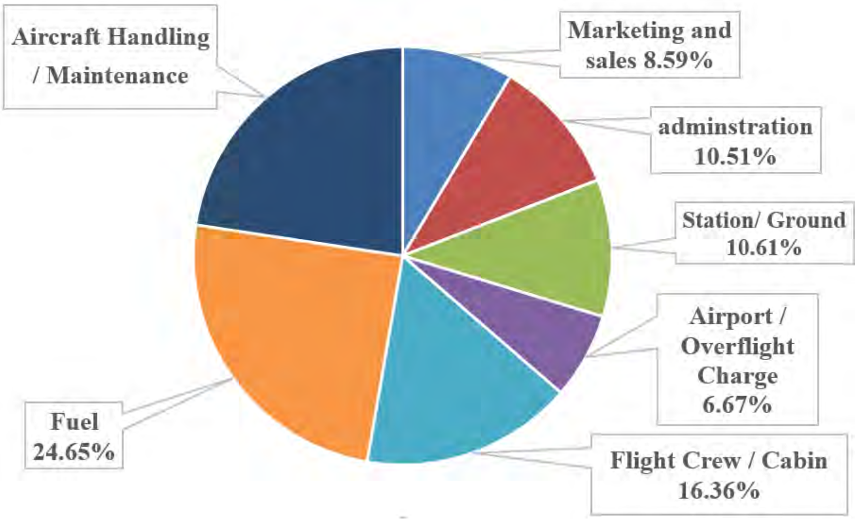


Figure 1.3. Major parts of the airlines cost

Bad optimization can not only affect sustainability, but it will affect external costs, which is a third concept generally defined as the costs that are not reflected in the price paid by the user/traveler and are therefore not factors attended to in the market (INFRAS, 2002). Individuals using a given form of transportation are not generally aware of the external costs involved and it is possible that many of these costs may have never been defined. Broadly, the external costs can be defined as costs due to:

- accidents;
- air pollution;
- climate change;
- noise;
- congestion.

A big part of ground handling cost goes to extension of aircraft turnaround time for handling processes, from another point this additional time lead to additional CO premises. Figure 1.4 illustrates the average number of departures out of the ten airports as a function of the day of the week as well as the average percentage of aircraft delayed by more than 15 minutes.

The distribution of delays between all flight time is demonstrated in Figure 1.5.

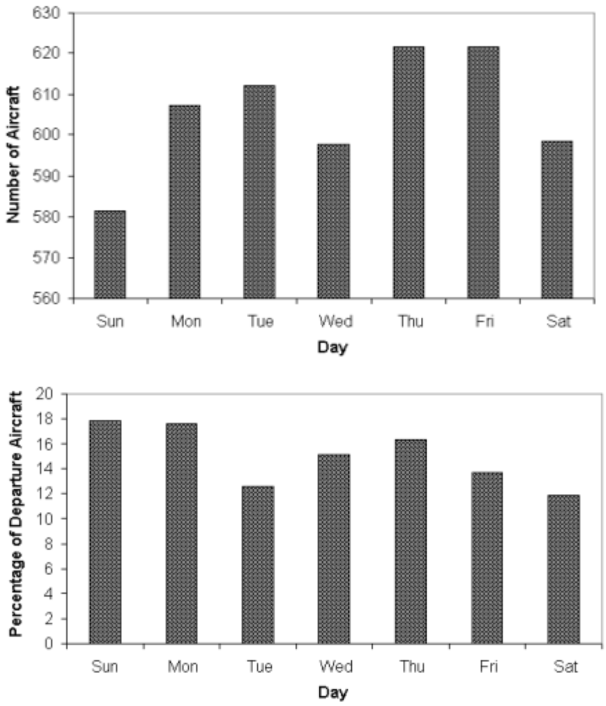


Figure 1.4. Average number of departures and percentage of departures delayed by more than 15 minutes as a function of day of week (Mueller, 2002)

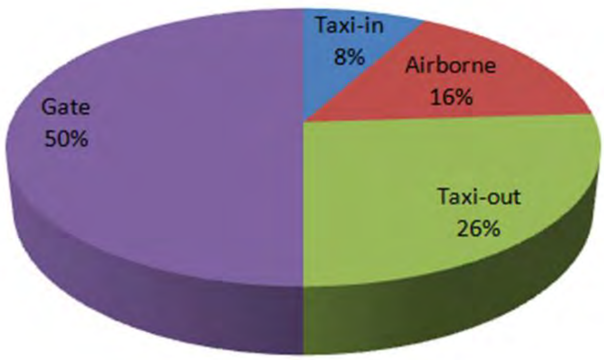


Figure 1.5. Distribution of delays by phase of flight (LLC Simio, 2016)

Airports are systems that are part of today's society and an integral part of society's demand for mobility (Knudsen, 2004). As mentioned above that airports create impacts on the environment, it is also acknowledged that they contribute to regional economic benefits and that they affect society by enabling growth. This "airport system" is realized by using products or services and environmental goods like resources. As shown in Figure 1.6 it produces products or services and environmental impacts. These operations are part of the economy – whether local or regional – and they interact with the surrounding society. It is the goal of the airport to keep these aspects in a balance and secure future operations.

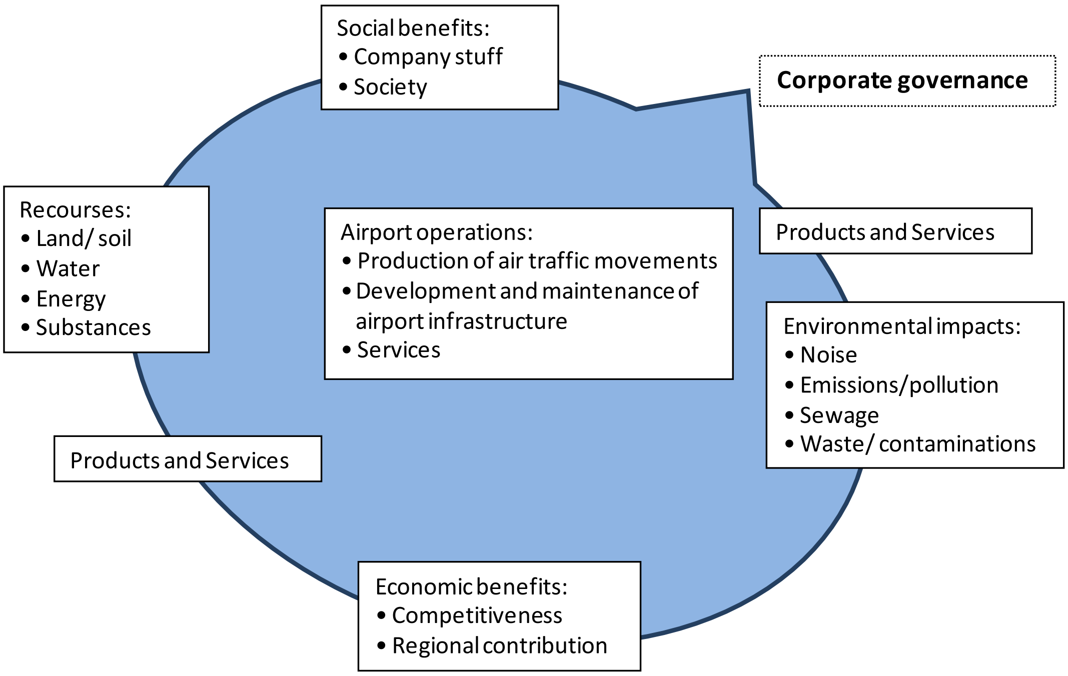


Figure 1.6. Sustainable Operation of an Airport (Knudsen, 2004)

New technologies for vehicles and traffic management will be the key to lower transport emissions in the EU, as in the rest of the world. Looking 40 years ahead, it is clear that transport cannot develop along the path that it currently is on as far as the transport industry in itself represents an important part of the economy.

The increase in delays in the National Airspace System (NAS) has been the subject of several studies in recent years. Historical delay data for these airports are summarized and the various causal factors related to aircraft, airline operations, change of procedures and traffic volumes are also discussed (Mueller and Chatterji, 2002).

1.5. Detailed analysis of the main ground handling processes

1.5.1. Definition and types of the ground handling processes

This subparagraph contains general information about ground handling processes, these processes were subject of many studies. In depth was described in the dissertation work (Trabelsi, 2013).

Ground handling addresses the many services required by a transportation aircraft while it is on the ground, parked at a terminal gate or a remote position in an airport, either at arrival from a last flight or at departure for a new flight.

Aircraft ground handling is composed of a set of operations applied to an aircraft to make it ready for a new commercial flight or to finalize an arriving commercial flight.

This includes the processing of boarding/de-boarding (disembarking) passengers, baggage and freight, as well as the aircraft itself (fueling, cleaning, sanitation, etc.). A typical ground handling process is composed of the following steps: De-boarding (disembarking) passengers, unloading baggage, fueling, catering, cleaning, sanitation, potable water supply, boarding passengers, loading baggage, de-icing and pushing back the aircraft.

Here the most current ground handling activities encountered at commercial airports are introduced and analyzed by considering the corresponding equipment and fleets as well as the constraints applied to them. Figure 1.7 illustrates the taxonomy of aircraft handling.

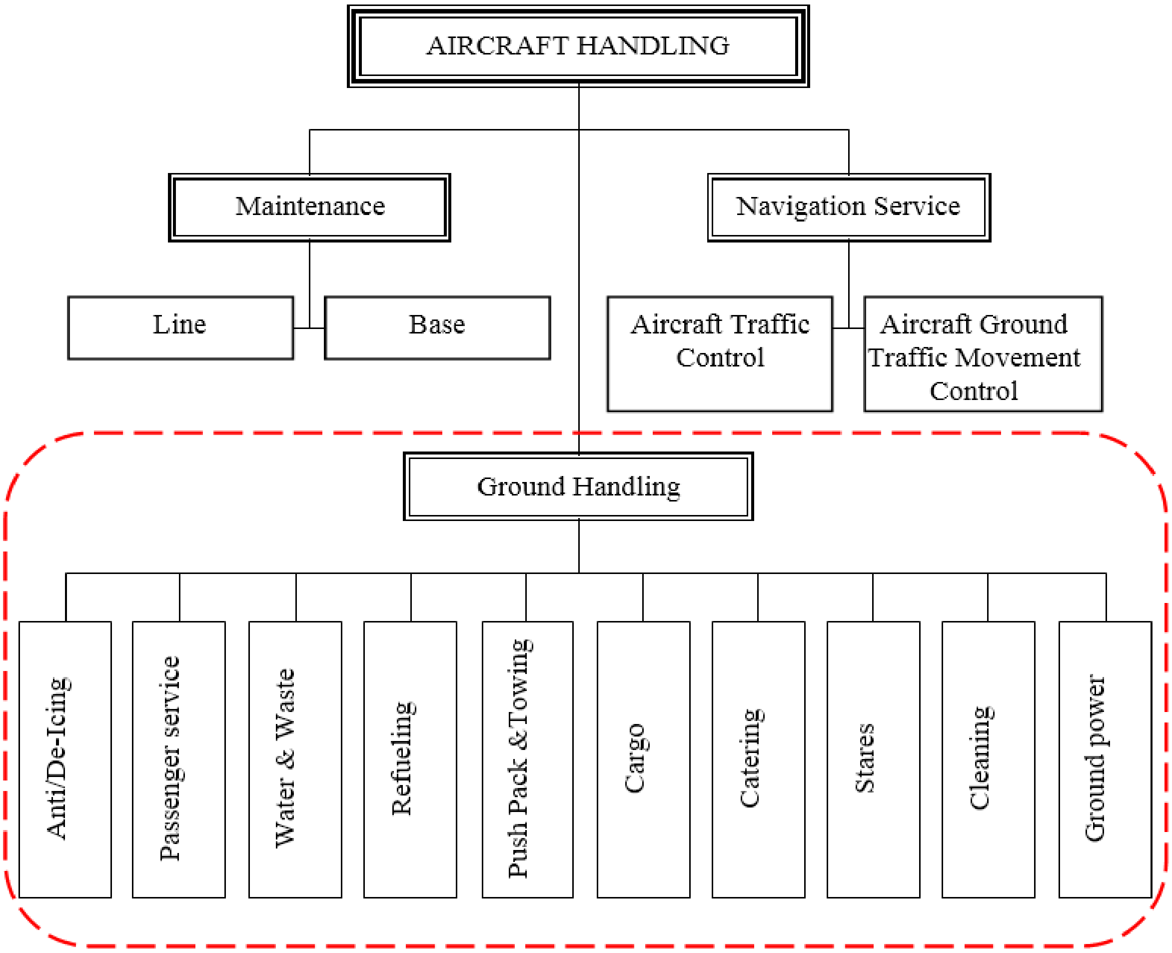


Figure 1.7. Taxonomy of Aircraft Handling

Pushback and towing process (ISO 9667, 2017), (ISO 8267-1:2015)

Pushback means the movement of the aircraft from the nose-in parking stand by means of the power of a specialized ground vehicle (tractor) connected to the nose landing gear. Towing means the movement of the aircraft from one parking area to another using specialized ground vehicle (tractor). Occasionally, the towing or pushback procedures performed after certain kinds of aircraft technical maintenance. Subject to aircraft maintenance manual, usually three-line service technicians are required when towing or pushing back the airplane into or out of a hangar. Communication between the wing-walkers and the tug operator is extremely important. Unless the movement of the aircraft is taking place outside the movement area controlled by ATC, a Specialized radio telephotography clearance required to run the process. Usually but not always, this will be obtained by the aircraft commander or other person in charge in the flight deck. The prescribed radio telephotography phraseology for pushback is contained in ICAO PANS-ATM. At some stands, aircraft can start taxiing by its own since the engine can be started up at the stand. The push-back process marks a transition from ground handling operator-airline interaction to ATC-airline interaction.

The passenger embarking/disembarking processes (ISO 7718-1, 2016) (ISO 7718-2, 2016)

At commercial airports, boarding is the term to describe the entry of passengers into an aircraft. It starts with allowing the entrance of passengers into the aircraft and ends with the conclusion of the seating of all the passengers and closure of the doors. In contrast, for the disembarking process operations are performed in the reverse order. Nevertheless, for these processes, air stairs or air bridges are used. The embarking/disembarking processes depend on the policy of the airlines (e.g. Low-Cost Airlines, Flag Carrier Airlines) and resources available at a specific airport (principal or remote terminals). By using air bridges, either the front left door of the aircraft or 2 left hand doors depending on the model is used while by means of stairs (mobile stairs or integrated stairs), a second stair for the rear left door of the aircraft can be used in order to speed-up the process. Hence, the operation with air stairs is faster than the process with air bridges. However, this latter statement is true only when no buses are needed to move passengers between the aircraft stand and the passenger terminal building. Otherwise air bridges are more effective and faster. These operations are supervised by ground personnel and cabin crew. Moreover, embarking/disembarking can be performed simultaneously with luggage loading and unloading since these services do not need the same area around the aircraft (in general the left side is devoted to passengers while the right side is devoted to luggage).

Luggage loading/offloading processes

Checked-in luggage can be stowed in the aircraft in two different ways. Either the bags are stowed in bulks or in pre-packed containers. As the containers can be packed before the aircraft arrives to the airport, the ground handling process time for loading luggage will be shorter with container loading than with bulks if the number of bags is large. The checked-in luggage on a flight has to be sorted, unless it is a charter flight (or other point-to-point flight) where all the bags have the same priority and destination. Otherwise, they might be divided into transferring bags, high-prioritized bags or odd size bags and so on.

Catering process (ISO 27470:2011)

The catering involves the withdrawal of the leftover food and drinks from the previous flight and the supply of the aircraft with fresh food and drinks for the next flight. This process can start when all passengers have left the aircraft.

The catering companies use high-loaders to get the catering cabinets on and off the aircraft. High-loaders do not fit all aircraft types, so planning of the assignment of high-loaders to flights is required. This process takes between five and seventy-five minutes depending on how much food is needed and the way it is packaged.

The catering teams need to go back to the depot between serving two aircrafts in order to empty the garbage and get new food. The catering coordinator makes rough estimates of the necessary manpower to perform catering over weeks and the detailed planning, of who is serving each aircraft, are realized every day.

Refueling processes (ISO 45, 1999)

Fueling can be performed in two different ways. At some stands there are hydrant systems with fuel pipes in the ground that the dispenser trucks can connect to, in order to fill up the aircraft. At aircraft stands where the hydrant system is not available, fueling is performed by tankers. There are different types of dispenser trucks: the larger types can serve all kinds of aircraft while the smaller types can only serve small aircrafts. However, the small dispensers may be preferred when the area around the aircraft is tightly limited. Also, the tanks vary in size. In general, their capacity varies from eight to forty cubic meters of fuel. Fueling cannot be performed simultaneously with loading and unloading luggage since these services need the same area beside the aircraft. Before the fuel company starts to fill up, they always check the water content in the fuel. The area around the aircraft has to be planned so that the dispenser truck or tanker has a free way for evacuation. There are also some airlines with specific rules about fueling while passengers are on-board. Most airlines allow it, but only under certain conditions (e.g. there must be fire extinguisher ready in the immediate surroundings of the aircraft or there must be two ways of communications between the apron and the aircraft). The time it takes to fill up an aircraft depends on the capacity of the pipes in the aircraft and, of course, on the amount of fuel needed. The pilot decides how much fuel is needed and must report that to the refueling company before they can start to fill up the aircraft. Today, there is no pre-planned schedule for each truck. Not until a fueling request arrives from the pilot, the refueling company coordinator assigns a refueling team to it. This is to say that once a refueling service is requested, the refueling team will be assigned to the request and perform the refueling.

Cleaning processes

The airlines can request different types of aircraft cleaning services. During daytime the cleaning can take from five minutes (take garbage away) up to forty minutes (garbage evacuation, seat-pockets cleaning, belts placement, vacuum cleaning, etc.). The latter is only performed on aircraft with longer turnaround times. Longer and more careful cleaning is performed during night-time when the aircraft is on the ground and stay for a longer time. On most aircrafts, cleaning and catering can be performed at the same time, but for some small aircraft there is not enough space for both of them at the same time. In the latter case, it does not matter if cleaning or catering is performed first. The cleaning teams can proceed directly from an aircraft to the next one, but at breaks and when they need additional materials (pillows and blankets), they have to go back to the base. There is no significant difference between the cleaning activities at different aircraft types so all cleaning teams can be assigned to any aircraft type.

Anti/De-icing processes (ISO 11076, 2012)

Since very thin layers of frost and ice on the aircraft have a negative effect on the lifting force and the control of an aircraft, de-icing is needed, if any part of the aircraft is covered with snow or frost, or if there is a precipitation that could cause this to happen. The de-icing process is divided into two steps: during the first step, frost and ice are removed from the aircraft, usually by a warm, buoyant glycol mix (type 1 fluid). The next step is called anti-icing and it is performed to prevent new frost and ice from appearing on the aircraft before take-off by a thicker fluid (Type 2 fluid). The time from anti-icing to take-off (called hold-over time) is limited, as the effect of the Type 2 fluid vanishes after a while. This means that it is not useful to de-ice an aircraft a long time before take-off. How long the hold-over time is dependent on the type of fluid, temperatures and type of precipitation. Therefore, it is important to find a de-icing truck that can serve the aircraft at the right time. If the aircraft is served too late, the stopover time will increase with a possible late departure as a result. If the de-icing is performed too early, the procedure might have to be repeated. This result in a rather difficult planning problem, even if the right time windows were known in advance. Today, the de-icing coordinator plans in general on a tactical basis considering the current weather conditions and the flight schedule, and operationally (when a truck is dispatched) based on a request from the pilot. When the coordinator gets this request, he decides which truck should be assigned to the involved aircraft. In general, no pre-planned schedule is built and the truck-drivers do not know in advance which aircraft they are going to de-ice during the day. The request from the pilot usually arrives at the beginning of the stopover process, assuming that all activities will be performed on time. The de-icing truck will arrive at the aircraft some minutes (depending on the quantity of ice/snow/frost) before the scheduled departure time.

Potable/waste water service. (ISO 17775, 2006)

The aircraft has to be released from wasted water and re-supplied with fresh water for the next flight. This is performed by two different vehicles which most often operate at the aircraft opposite side of the luggage handling and feeling side. This means that water and sanitation can be carried out simultaneously with luggage de-boarding/boarding and feeling, but they must not be performed simultaneously for safety and space constraints.

1.5.2. Ground handling fleet management

Ground handling services usually performed by many service providers. While providing the services, a different type of ground handling vehicles are used, each of these vehicles are specific for certain type of handling. These fleets of ground handling vehicles should be coordinated in order to run the turnaround process in assigned time period. The duration of turnaround processes could be variable as function of volume of passengers and luggage to be served, in addition to other conditions not related to ground handling process which can affect the turnaround process (as an example strikes, weather, etc.).

The airline representative keep communication with the ground handling fleet manager(s) in order to manage and monitor the ground handling activities upon arrival and before departure of the aircraft. The function of ground handling fleet manager is to reduce as much as possible the turnaround time by reducing the waiting time for passengers and luggage processing and to make sure that the passengers and luggage are on board before schedule departing time.

After the ground handling completion, the ground handling fleet manager inform the airline representative about the completion the turnaround process. At this point it is important to note that at the big airports many fleet managers could work in parallel, all of them finally linked to the fleet manager supervisor, who in his turn monitor the processes in general. Figure 1.8 illustrates the location of the ground handling fleet management in the aircraft handling circuit.

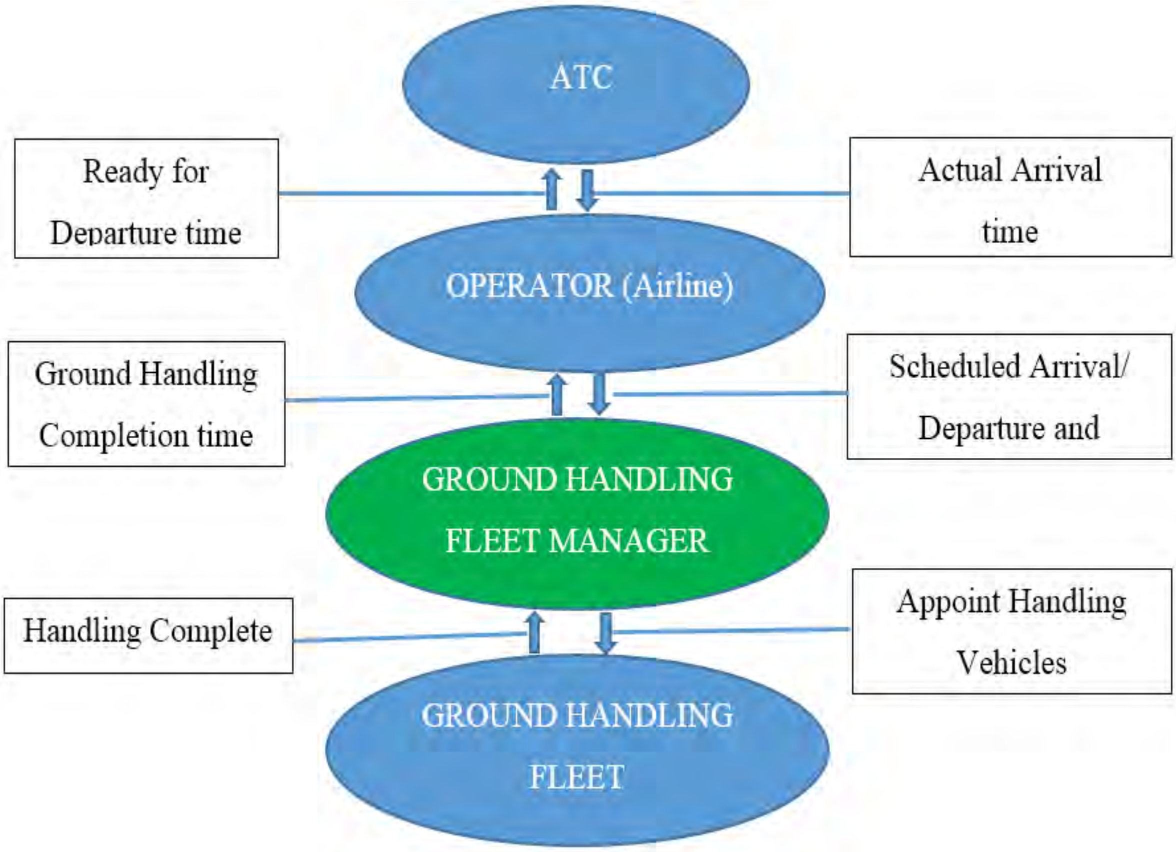


Figure 1.8. Ground handling fleet manager position and functions

Main duties of ground handling fleet manager

- coordination of plan and interaction with operational services of the airline;
- finding the solutions of the conflict situation arising in case of aircraft technical malfunction, flight delays etc.;
- tracking the aircraft's location at the current time to give the on-time command for ground handling fleet to start the movement;
- tracking and monitoring the ground handling fleet to make sure that the services are done as per schedule;
- tracking the transfer passengers.

All ground handling fleet vehicles drivers should be trained and pass the related examination and they must hold the licenses to operate the vehicles they drive to ensure traffic safety at the aerodrome in accordance with the requirements of ICAO DOC 9476. Hereinafter some of these rules

- unless other order given via VHF communication, drivers of ground handling vehicles and in all cases must give the way (hold on position) to taxiing or towing aircraft;

- special vehicles towing the aircraft (tractor) should give the way to the taxiing aircraft;
- aircrafts taxiing in into the parking area or taxiing out from it, have the priority over all other ground handling vehicles and all of them have to maintain the traffic safety rules;
- in case the aircraft is taxiing in parallel to the traffic routes of vehicles adjacent to the aircraft's parking areas, the ground handling vehicles are not allowed to undertake the aircraft, since the aircrafts are not equipped with turn signals and the driver should expect the aircrafts to turn into a parking lot at any time.

1.5.3. Ground handling as a complex process

From the above stated description, it is clearly seen that each of the activities that include ground handling process makes use of specialized equipment which must be made available at the aircraft parking area at the right time to avoid delays. Some of the ground handling activities must be performed as soon as possible after the arrival of the aircraft at their parking stand and others must be performed only some time before departure from their parking stand (ISO 10847, 2017). Depending on aircraft operation, these two subsets of activities can be performed in immediate sequence or are separated by an idle period of variable duration according to arrival and departure schedules of a given aircraft. Figure 1.9 displays a standard situation for an aircraft undergoing a turnaround process where space is a rather limited resource and some tasks cannot be performed simultaneously mainly for safety reasons. It appears that the efficient operation of such complex process which repeats with each aircraft arrival or departure is very difficult to be achieved while it is a critical issue for airport operations performance. Then advanced management tools may be useful to cope in a satisfactory way with this problem.

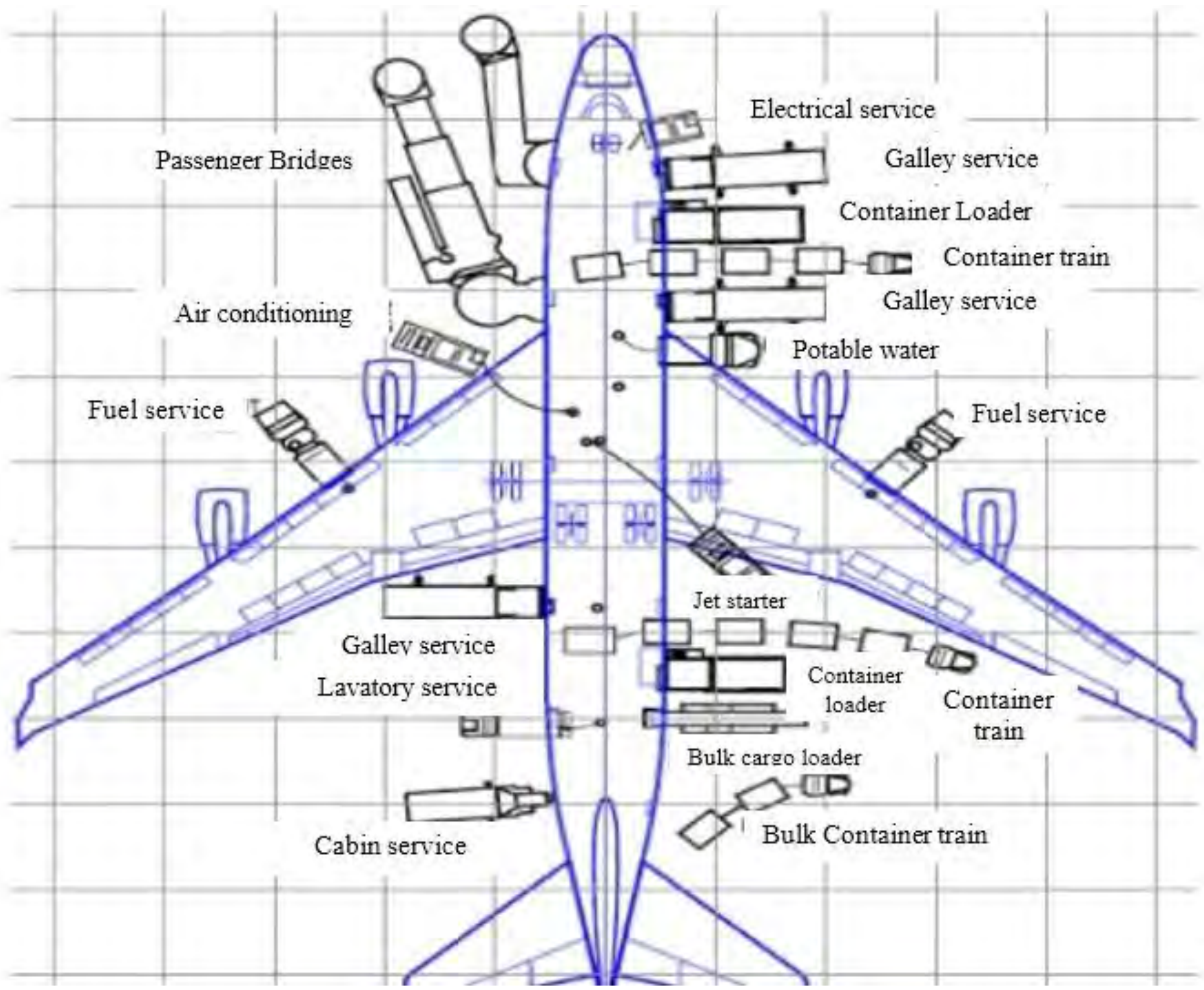


Figure 1.9. Aircraft servicing equipment's - Typical B747 handling operation (Aircraft ground handling, URL 2018)

1.6. Analysis of Riga international airport flight delays

The body of this paragraph published in (Alomar et al., 2018).

In recent years, the increase number of aircraft flight delays in the National Airspace System (NAS) has been the subject of several studies (EUROCONTROL, 2013). Flight delays became a fact of each air travel system user and sometimes it has dramatic consequences when the passengers have connection flight. Flight delays have negative consequences on airlines, airports and passengers. On-time operation of the airports and airlines schedules are the target of all airports and airlines stockholders in order to fulfil with passengers and customer requirements as well as getting more new customers (Sternberg et al., 2017). As far as delays are considered as one of the most sensitive remembered performance indicators of any transportation system, it is quite important to give definition of this terminology. In aviation sector delays are understood as the period of time by which a flight is late or postponed in other words a delay is the difference between the scheduled and the real time of departure or arrival of flight (Wieland, 1997). In other words, delays are defined as “the time lapse which occurs when a planned event does not happen at the planned time” (Guest, 2017). Taking into consideration airports all over the world, the tendency of approximately 20% of all flights have delays by several reasons as well as near to 4% flights are cancelled (see Figure 1.10 and Table 1.1).

In last decades, the expansion in aviation transport has not been smooth. It has expanded in spurts, where periods of growth and increased service were followed by industry recessions and cost cutting (U.S. URL, 2017). However, this expansion has seriously strained the air travel industry on the ground, where the infrastructures such airport gates, runways, and air traffic control systems, have begun to cause massive delays (Smith, 2000). Delays have thus become a standard element of air travel.

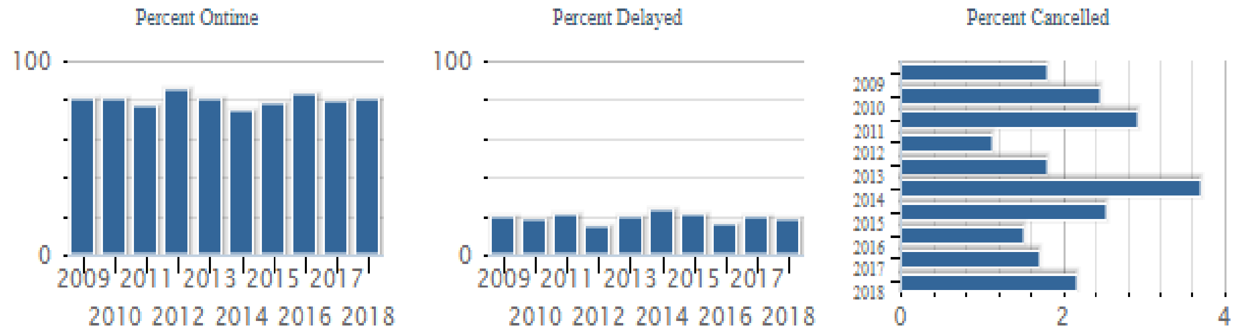


Figure 1.10. Worldwide flight delay (Bureau of Transportation statistics, URL, 2018)

When the airports commence the organization of their schedules, they must commit their resources to satisfying their customers’, this require all service providers involved in ground handling processes to ensure high efficiency of handling activities and avoiding delays (Mueller and Chatterji, 2002). To explain the level of complexity of flight delays, it is important to understand the network entirely starting from passengers’ registration at origin airport and ending by baggage delivery at the destination airport.

There is a known relationship between levels of delays and fares, aircraft sizes, flight frequency and complains about airline service (Bhadra, 2009), (Pai, 2010), (Zou, 2014).

From scheduling point of view, which is often built up months before the day of operation, the predictability of operation has a major impact to which extent the use of available resources (aircraft, crew, etc.) can be maximized (Jetzki, 2009). The analysis at the European airport delays shows that 80% of delays on flight arrival could be forecast from the delay on departure.

The airline which flight destination has been studied allows a very small margin between the scheduled and the real flight and taxiing times, which does not allow absorption of any part of departure delays.

Table 1.1. Worldwide flight delay (Bureau of Transportation statistics URL, 2018)

Year	Ontime Arrivals	Ontime (%)	Arrival Delays	Delayed (%)	Flights Cancelled	Cancelled (%)	Diverted	Flight Operations
2009	1,676,021	79.21%	396,832	18.75%	38,178	1.80%	4,933	2,115,964
2010	1,662,187	79.77%	365,667	17.55%	51,001	2.45%	4,816	2,083,671
2011	1,516,915	76.47%	403,857	20.36%	58,147	2.93%	4,708	1,983,627
2012	1,672,130	84.54%	280,010	14.16%	22,136	1.12%	3,529	1,977,805
2013	1,641,905	79.40%	384,824	18.61%	37,282	1.80%	3,959	2,067,970
2014	1,399,748	74.07%	415,537	21.99%	69,981	3.70%	4,542	1,889,808
2015	1,467,236	77.69%	368,829	19.53%	48,021	2.54%	4,536	1,888,622
2016	1,497,645	82.72%	281,738	15.56%	27,330	1.51%	3,755	1,810,468
2017	1,439,256	79.19%	342,744	18.86%	31,123	1.71%	4,337	1,817,460
2018	1,846,689	80.33%	397,600	17.30%	49,681	2.16%	4,913	2,298,883

70% of delays on departure, could be forecast from the departure plane load factor, when the plane is not significantly delayed on arrival.

There is some evidence that the scheduled stop time plays an important role in absorbing the arrival delays. For instance, a 45-minute scheduled stop time does not allow a delay recovery, if the departure plane is 80% loaded.

From economic point of view, the direct costs originated by flight delays amounted in Europe to 1,250 million euros during 2010 according to the European airline delay cost reference values report from the Westminster University (Cook and Tanner, 2011).

Reviewing the air transport passenger flow for Baltic states, it is easy to note that in recent years the demand for air transport has been rising as demonstrated below. Figure 1.x) illustrates the increasing in passenger's flow.

Aviation sector in Baltic states

Based on the data presented on Figure 1.11 a confirmation of that in each of the Baltic States, Latvia, Lithuania, Estonia there is a significant increase in demand for passenger transport. In Lithuania it was 13%, in Latvia it was 4,6% and in Estonia 2,5%. Figure 1.12 demonstrates the growth in certain Baltic state airports in all three countries separately. Figure 1.11 illustrates the distribution of passengers at airports in the Baltic States in 2016.

Figure 1.11. Growth of the passenger flow at Baltic states airports (Vilnius airport URL, 2017)

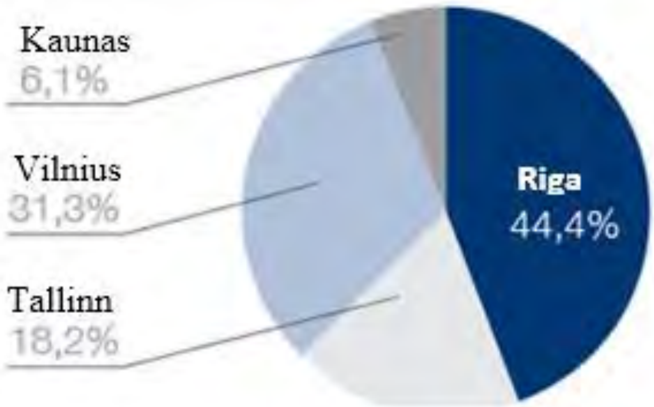


Figure 1.12. Distribution of passengers at airports in the Baltic States in 2016 (Riga International airport URL, 2017a)

Related to passenger flow in Latvia, the tendency of stable growth, not only for last 2 years, but for the period from 2004-2016 it was noted, including the period of worldwide economic crises at 2008. Figure 1.13 demonstrates the growth of passenger flow for Riga International Airport.

In Latvia, the aviation sector provides 0,7% GDP, at the same level as the light industry, at the same time the number of specialist involved in aviation sector for the year 2015 in Latvia increased by 100% comparing to year 2005 (see Figure 1.14).

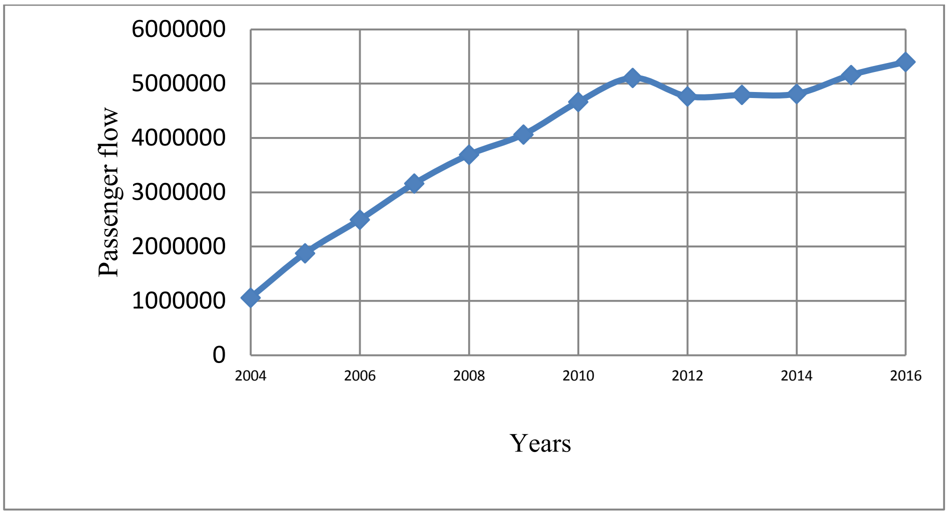


Figure 1.13. Passenger flow growth in Latvia (Riga International airport URL, 2017b)

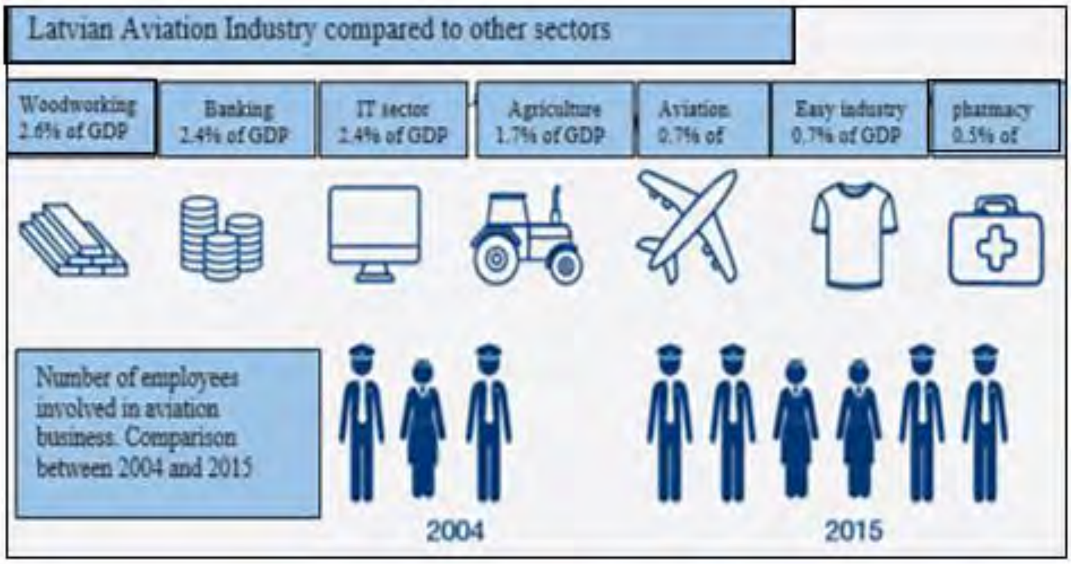


Figure 1.14. Latvian Aviation Industry compared to other sectors (Riga International airport, URL, 2017b)

Further, a statistical analysis of Riga International Airport flight delays will be performed and then in future link and use the results of the analysis in our research.

Analysis of Aircraft Flight delays at Riga International Airport

Using the data collected by the Riga International Airport statistical bureau, it is clearly seen that more than 9000 (9251) flight delays were registered at Riga international airport in 2016. All flight delays were categorized by delays codes. Approximately 70 reasons of flight delays were registered. The total time of all flight delays in 2016 was 3200 hours. For illustration, flight delays were grouped to months (see Figure 1.15), from this figure, the impact of seasons on flight delays can be noted. The delays number increase by approximately 30% during high seasons.

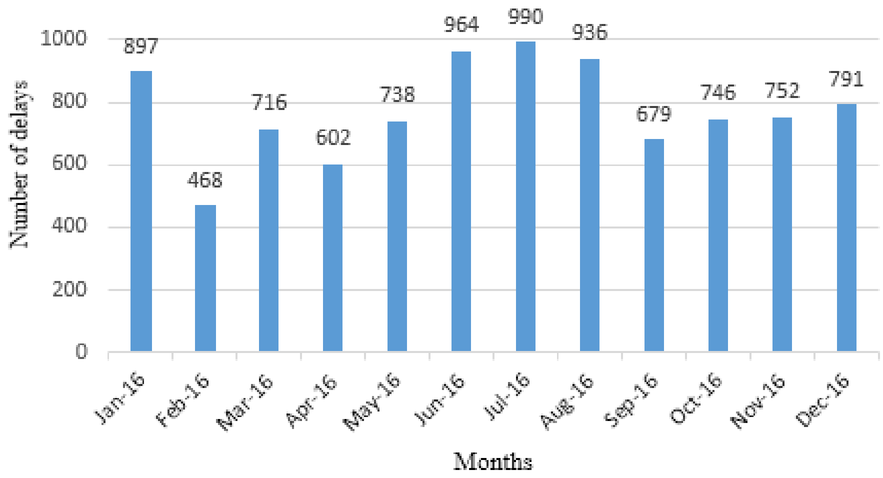


Figure 1.15. Seasonality characteristic of flight delays.

Major part of delays was caused by reasons related to Figure 1.16 (Group A):

- Availability of aircrafts at Riga International Airport.
- Restrictions at airport of destination or departure – airport and/or runway closed due to obstructions, etc., awaiting load from another flight, late arrival of aircraft from another flight or previous sector. Total delays time for this category was more than 1500 hours. Average flight delay time was 19 minutes.
- Technical maintenance of aircrafts including scheduled and non-scheduled maintenance and flight diverting due to maintenance reasons. Total delays due to this reason was more than 600 hours. Average flight delay time was 54 minutes.
- Delays due to discrepancy with ATC data (Air Traffic Control). Total delays time for this category was more than 300 hours. Average flight delay time was 19 minutes.
- Delays due to ground handling process. Total delays time for this category was more than 2500 hours. Average flight delay time was 15 minutes.

For further and more detailed analysis, the flight delays by reasons not related to airport operation procedures (Air Traffic Control, weather, crew, etc.) were grouped separately from other flight delays reasons. This analysis mainly will deal with reasons related to airport operations procedures (group A of Table 2). The reasons in group B will be not discussed during this research as far as our research focuses on optimization of ground handling vehicles movement at the aerodrome. There are a lot of researches dealing with other reasons of flight delays such as (Vane, 2016) which deals with weather impact on flight delays and (Ivanov et al., 2017) which deals mainly with air traffic flow management.

Table 2. Characteristic of main flight delays groups

No	Problems group	Numbers of delay	Time of delay total (h)	Time of delay total (min)	Average of delay(min)
Group A: characteristic of main flight delays related to airport procedure					
1	Ground handling	1188	251,72	16510	15
2	Plan maintenance	676	602,92	36175	54
3	Automated equipment failure	209	50,92	3055	15
4	Crew problems	472	91,42	5485	12
5	Other	140	23,73	1424	10
Total of the group A		2685	1020.70	62649	23
Group B: characteristic of main flight delays related to other procedures					
6	Weather	468	131,43	7886	17
7	Air traffic flow management	975	311,20	18672	19
8	Aircraft problems	4851	1550,35	93021	19
9	Airline problems	272	186,37	11182	41
Total of the group B		6566	2179.35	130761	20
Total of groups A+B		**9251**	**3200,05**	**193410**	**21**

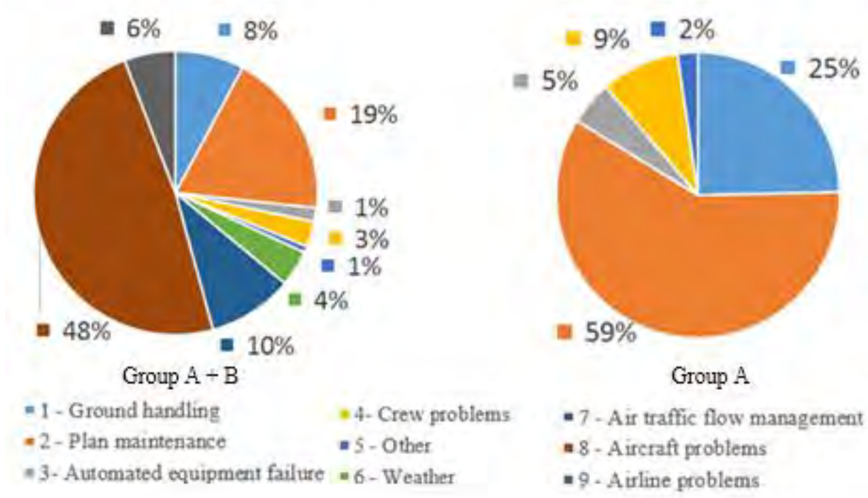


Figure 1.16. Distribution of the flight delay times (h) for selected groups in accordance with Table 2

Taking into account above mentioned correction, the flight delays related to ground handling services at Riga International Airport will be more than 25% of total delays time (see Figure 1.16, Group B).

From Figure 1.16 and Table 2 it is seen that main cause of flight delays is technical maintenance of aircraft, the second by importance is ground handling services 25% of total delays. As far as ground handling process is quite wide, and there are a lot of reasons hidden behind, and not all of them related to ground handling vehicles movement at the aerodrome. Description of ground handling causes are illustrated in Table 3 and Figure 1.17. At the meantime Table 3 illustrates that more than 600 flight delays or 49% of total delays related to ground handling causes, directly related to ground handling vehicles movement at the aerodrome (group B, D-I), as well as 44% from total delays were related to passenger's registration and errors in baggage registrations.

Table 3. Characteristic of flight delays related to ground handling services

No	Problems group	Numbers of delay	Time of delay total (h)	Time of delay total (min)	Average of delay (min)
A	Check-in error	676	133,78	8027	12
B	Baggage processing	2	0,23	14	7
C	Cargo	83	21,15	1269	25
D	Loading/unloading	507	129,27	7756	15
E	Servicing equipment	36	4,83	290	8
F	Aircraft cleaning	18	2,62	157	9
G	Fuelling/defueling	17	4,17	250	15
H	Catering	13	2,15	129	10
I	Operation requirements	74	8,25	495	7
TOTAL		**1426**	**306,45**	**18387**	**13**

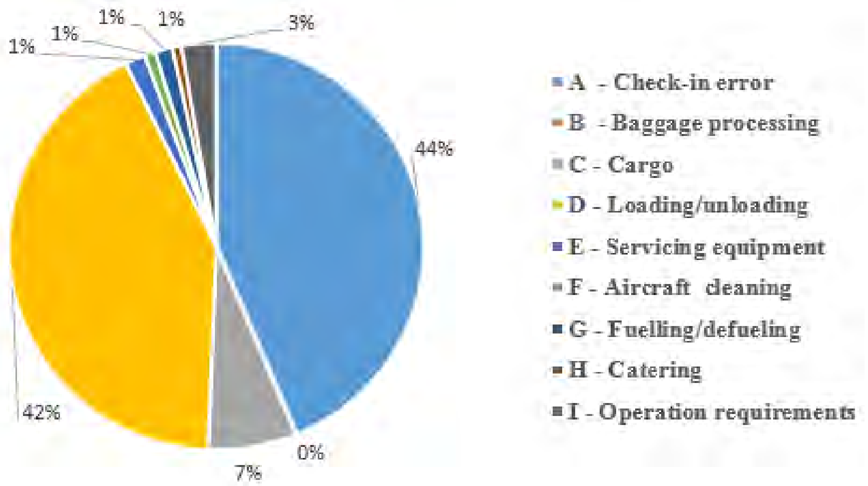


Figure 1.17. Distribution of the flight delays times (h) due to ground handling services for selected groups in accordance with Table 3

The performance of the analysis of flight delays related to the use of ground handling vehicles movement at the aerodrome, demonstrates that the main cause of the delays in this group is tightly related to aircraft loading/offloading procedure (group D, Table 3 and Figure 1.17), more than 500 aircraft flight delay.

Maximum duration of flight delays is 15 minutes, total duration of flight delays by this reason is 130 hours or 85% of delays in this certain group. Next causes are presented here in after (see Figure 1.18).

From above presented data, the conclusion that one of the main factors that play a major role in increasing the efficiency of airport operations is reducing the downtime of the aircrafts on the ground by reasons related to ground handling services. The most important way to improve airport efficiency is control and optimization of ground handling vehicles movement at the aerodrome.

In order to deal with the delays related to ground handling movement at the aerodrome at Riga International Airport, a simulation model will be developed for fragment of Riga International Airport, where the testing and simulation of the operation of above mentioned airport will be run.

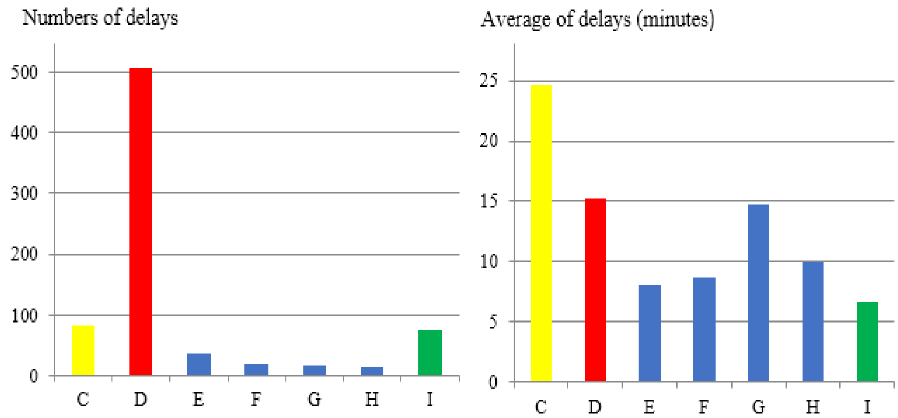


Figure 1.18. Characteristic of flight delays by cause of ground handling movement at the aerodrome.

The authors of this research currently are working on the optimization of ground handling vehicles movement issues by using simulation modelling (Alomar et al., 2018). The researched methods of increasing of the effectiveness of ground handling vehicles movement are based on the implementation of prioritization rules of vehicles movement and changes in the geometry of sections of the road on which traffic congestion may occur. Data on flight delays at Riga International Airport are used by the authors to validate the simulation model of ground handling vehicles movement, as it becomes possible to compare the results of statistical modelling with real data. The models tested in this way can be used to optimize the ground handling vehicles movement in large airports with intensive traffic.

1.7. Statement of the research task

Reducing the number of unwanted aircraft delays in ground handling is an important task for any airport worldwide. In case of resources sufficiency that are required for handling of the AC, particularly the improvement of transport process could positively affect the maintaining of preplanned handling time. In its turn, under the specified configuration of transport network, the establishment of new management principles which are based on constant monitoring of the location and state of each vehicle were used as a method to influence the transport process.

The goal of the research is to develop methods and tools which allow modeling and evaluating the output characteristics of ground transportation systems performance at the airports at various ways of controlling the movement of individual vehicles.

To achieve this goal, the following objectives have been formulated:

- to develop a detailed description of the aircraft ground handling processes in modern airports;
- to review of the recent trends of technology development for managing AC ground handling processes;
- to identify the main tasks, methods and tools for modeling of transport processes at airports;
- to carry on a comparative analysis of two classes of software products that can be used to investigate alternative ground traffic control systems and justify the choice of software products that will be used to study specific systems;
- to develop conceptual models of the individual traffic control processes of the ground vehicles during the drive-through the intersections;
- to develop executable program models of individual traffic control processes for ground vehicles and evaluate the effectiveness of alternative management methods;
- to develop a conceptual model for the acquisition data process on the status of the all classes of mobile objects at the airport's cargo terminal;
- to develop an executable program model for the acquisition data process on the status of mobile objects and demonstrate how to use the received protocols of events and states by employees of cargo terminal.

2. METHODS AND TOOLS FOR SIMULATION OF TRANSPORT PROCESSES AT AIRPORTS

The key objective of the following review of modern methods and means for solving the transport analysis problems at airports is to make a well-grounded choice of the tools that are intended to be applied to conduct the analysis of transport traffic's impact on the duration of the turnaround process of aircraft. Firstly, the whole set of transport analysis problems at airports solvable using simulation is clarified. Right after that the modern paradigms of transport process modelling are studied in detail. Additionally, several general-purpose simulation and airport simulation software products are described.

2.1. Types of transport processes at airports that may be studied using simulation

The main transport processes at the airport, which serve the flows of passengers, include the following:

- Aircraft Traffic: the movement of aircraft in the airspace of the airfield and on the runway;
- Airside and Apron Traffic: onground moving and towing of aircraft as well as movement of vehicles that participate in aircraft maintenance;
- Passenger Flow: traffic and maintenance flows of departing and arriving passengers at the airport facilities;
- Baggage Handling: processes related to baggage flows of departing and arriving passengers.

Up to date, the world has accumulated lots of experience and knowledge concerning simulation of all the above processes. In this work, three aspects are described for each type of process, namely: (a) relevant scientific publications, (b) an example of a state-of-the-art 3D model, and (c) typical problems for which simulation is utilized. It should be emphasized that scientific publications will be presented only in the form of individual examples, since the selection procedure does not aim to conduct a full review. The purpose of this literature is to show that simulation has been used for more than 30 years to study the mentioned processes at airports and it still remains the most effective means for testing both new technological solutions and new management principles.

2.1.1. Aircraft Traffic Simulation

The monograph (Bianco et al., 1997) consists of 9 independent articles devoted to the application of mathematical and computer modelling for the analysis of air traffic management (ATM) systems. In particular, new operational concepts for automated ATM, ground-holding algorithms and ATC simulation facilities are described in detail. Although the book represents the results obtained in early 1997, the content of this book was so zeitgeisty that in 2011 Springer has issues a softcover reprint of the original 1st edition of 1997.

The paper by Stelmach (2006) describes a simulation that takes into account both the processes of aircraft maintenance during the flight in the airport zone and the passenger service processes that affect the parking time of the aircraft. The model provides the user with the ability to analyse the results of various disturbances types, for instance, deviations from the expected characteristics of both processes. Based on the simulation results, analytical models were also constructed in order to evaluate the characteristics of aircraft traffic at the airport taking into account real disturbances.

The paper by Alam (2009) parses an air traffic simulation system that allows to test new ATM concepts experimentally. Particular attention is paid to the modelling of possible conflict situations and algorithms to recognize such situations. The author also applies several data mining techniques to assess the algorithm's vulnerability, which should ultimately lead to a decrease in the overall vulnerability of the ATM system.

Figure 2.1 shows an example of 3D animation of the aircraft movement in the airport zone produced using the Airport Simulation Software CAST by the Airport Research Center (ARC URL, 2018).

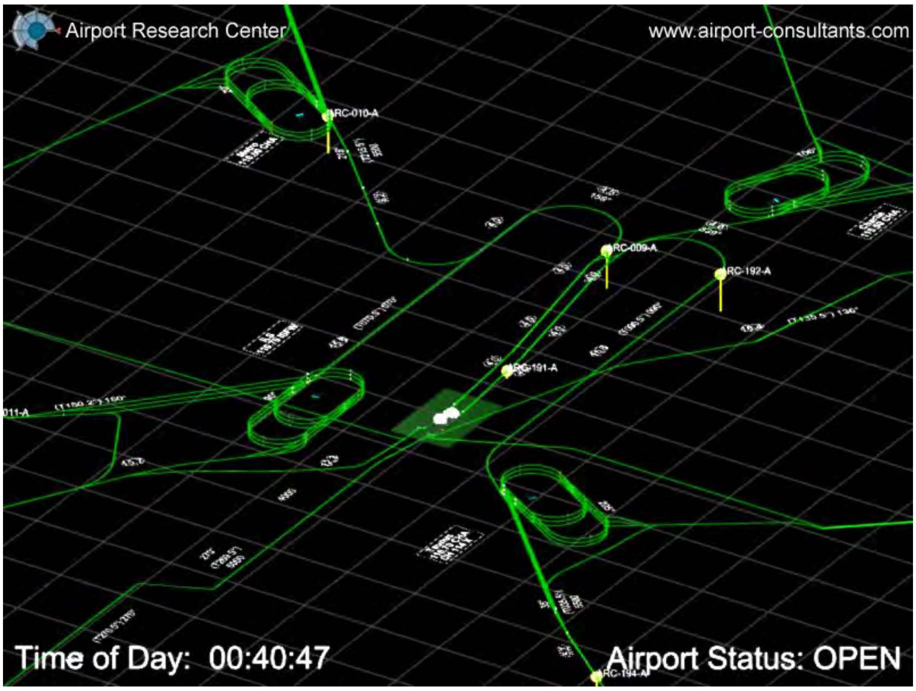


Figure 2.1. An ensemble for Aircraft Traffic Simulation (ARC URL, 2018)

The typical issues that are conventionally solved by simulation are the following (ARC URL, 2018):

- Which layout alternatives reduce delay?
- What is the demand for aircraft in x years?
- How does the optimal stand allocation concept for the next season look like?
- What is the capacity effect of an additional runway exit?
- What is the optimal position of a new runway exit?
- Which taxi routing concept leads to a maximum in punctuality?
- When are additional taxiways required?
- What is the most efficient taxi routing during construction?
- Are there bottlenecks due to future traffic growth?
- At which point of time is an extension of the infrastructure needed (stands, taxi ways, runway)?
- What benefits it is possible to gain in case of investment?
- What is the most environmentally friendly operational concept?
- What is the most efficient de-icing strategy?

2.1.2. Airside and Apron Traffic Simulation

The simulation model described by Cheng (1998) allows a user to analyse rigorously the delays of an aircraft during the way along apron taxiways. Using such a model, it becomes possible to find a solution for preventing conflicts and minimizing delays by choosing the optimal stand or gates.

In the study by Confessore et al. (2005), the simulation solves the optimization problem of aircraft movements in apron taxiways. The result of the work does not imply their use for operational control of on-flight and taxiway processes, however is aimed to support specialists engaged in the development of projects related to improve existing processes on the sites of a specific aerodrome apron. The key goal of process improvement is the reduction of aircraft delays with regard to the safety requirements related to surface movement of aircraft.

The paper by Couluris et al. (2008) describes the functionality of the modelling system designed for the study of aircraft movement on the airport surface developed by NASA. The model displays the dynamics of each aircraft's movement and records the events of each flight. It recognizes and solves conflicts arising from the movement of aircraft in airside and apron taxiways. In order to estimate the simulated processes, the throughput and traffic delay data are utilized.

The recent article (Wellens and Mota, 2017) contains a description of the simulation model applied to evaluate the efficiency of the ground delay program. Such programs are activated at airports where a decrease in capacity is expected for a long time, for instance, due to poor weather conditions.

Figure 2.2 demonstrates an example of a 2D animation of the aircraft's motion in the Airside and Apron airspace of an airfield made using the Airport Simulation Software CAST by the Airport Research Center (ARC URL, 2018).

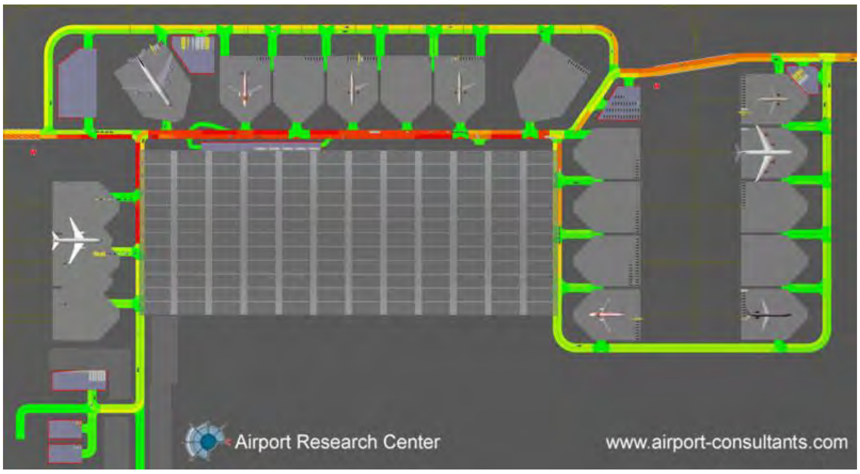


Figure 2.2. Airside and Apron Traffic Simulation in an airport (ARC URL, 2018)

The typical issues that are conventionally solved by simulation are the following (ARC URL, 2018):

– Does the infrastructure provide enough capacity?
– Are there bottlenecks (highly stressed routes, intersections)?
– Is there enough parking space available?
– What are the best locations for parking and preparation?
– How will construction measures influence on operations?
– How should an optimal traffic guidance concept look like?
– What driving times are expected?
– How many resources (staff, equipment) are required?
– Which vehicle allocation strategies are beneficial? (trade-off between punctuality and resource requirements)
– How does the optimal operational concept look like?
– Is the layout of the infrastructure stable, i.e. insusceptible against failures and changes?

2.1.3. Passenger Flow Simulation

The study by Takakuwa and Oyama (2003) describes the simulated model of passenger flows observed in the airport facilities. This model is based on a special source data generator, which assists to analyse the passenger flows by create various conditions for loading rooms in the airport. In particular, the model reviled the effect of using the check-in counters for servicing passengers of an economic class, which were previously used only for passengers of the first and business class.

The paper by Guizzi et al. (2009) presents a simulation model that displays the flows of departing passengers from the moment they appear in the airport to the boarding gate. The model is focused on controlling the flow of passengers in the check-in zone. The developed model has many tuning parameters, which allows to use it for the passenger flow simulation at various airports.

The pivotal purpose of applying the simulation model described by Chiang and Taaffe (2014) is to study the behaviour of passenger flows in the concourse of the terminal. The paper shows the effect of the congestion of passengers at the facility on the service level As an example, the paper studies the service of passengers that are sent for boarding to 12 gates and use four sets of moving walkways.

The paper by Fonseca et al. (2014) emphasizes the fact that the simulation model should display passenger flows not only at the airport facility, but also at the multimodal station and other sites in the vicinity of the airport. The authors argue that only such a comprehensive simulation makes it possible to evaluate the characteristics of all real passenger flows related to the airport area.

Figure 2.3 demonstrates an example of 3D animation of passenger flows in an airport facility created using the Airport Simulation Software CAST by the Airport Research Center (ARC URL, 2018).

During the passenger flow simulation, maintenance operations are taken into account at the following standard terminal facilities:

- Ticket Counter,
- Check-in Counter,
- Boarding Pass Control,
- Security Control,
- Passport Control,
- Gate Control,
- Immigration Control,

– Customs Control (Red, Blue, Green),
– Seat Unit.

Figure 2.3. Passenger flow simulation in an airport (ARC URL, 2018)

The most important evaluation options are:

– Utilization of stopover-, movement- and queuing areas,
– Journey duration of passengers in the terminal,
– Passenger waiting times and queue lengths,
– Service times of passenger service facilities.

2.1.4. Baggage Handling System Simulation

Even in early 1969, Robinson wrote a paper (1969), in which simulation was used to analyse the configuration options for the baggage handling system. The experiments were carried out for relatively large aircraft under different baggage-per-passenger conditions. The simulation model was created using the GPSS III programming language. The pivotal simulation results were the statistical descriptions of the passenger's delays who were waiting for their luggage after arriving at the airport.

In the study by Savrasovs et al. (2009), a simulation model of the baggage handling system at the Riga airport is described. The model was created using the ExtendSim simulation package supported by 3D animation. The initial data for the model were obtained by observing the operation of a real system. The simulation experiments allowed to show that bottlenecks in the baggage handling system would arise at those points where operations are performed manually by airport personnel.

In 2017 Cavada et al. describe a simulated baggage handling system at the Santiago International Airport in Chile. The model displays all stages of handling baggage for departing passengers, from the moment of baggage check-in to the boarding into the airplane.

In the company BNP employees are engaged in simulation of baggage handling equipment at airports since 1995 (BNP, 2018). Complex models contain up to 20,000 individual conveyor sections. In order to create such models, the AutoMod and Quest packages are used. The parameters of the models are adjusted so precisely that the characteristics of the movement of the units of luggage in the model do not differ at all from those of the real system.

Figure 2.4 shows an example of a 3D animation of a luggage handling system created with Quest's BNP software package (BNP URL, 2018).

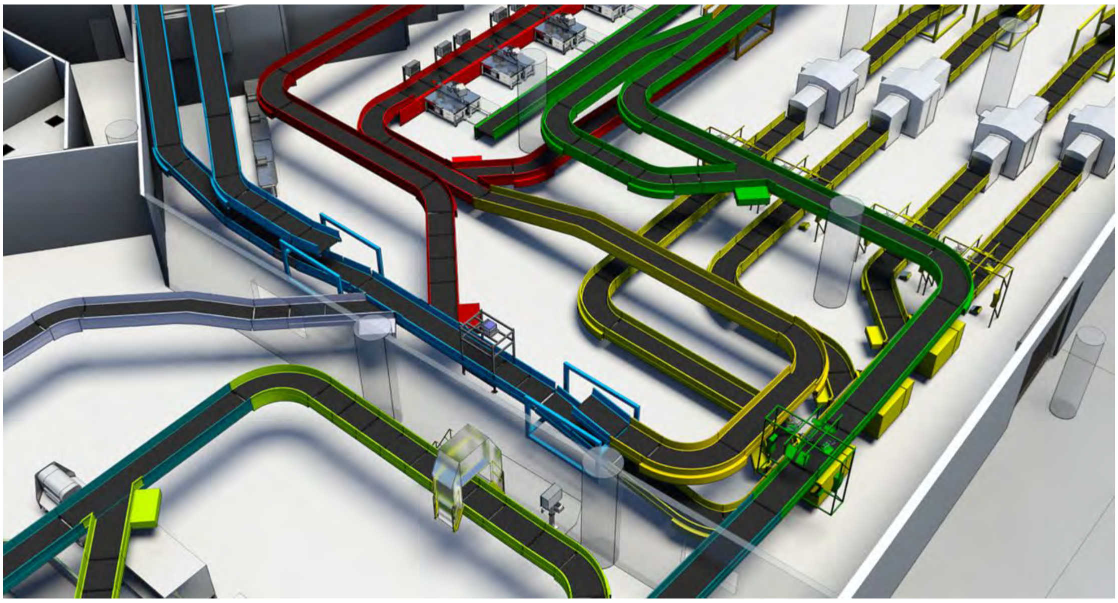


Figure 2.4. 3D model of a baggage handling system (BNP URL, 2018)

The key objectives of simulation for baggage handling systems at airports are related to determining the capacity of each individual subsystem, as well as the search for bottlenecks and system vulnerabilities that determine the upper limits of capacity. The most important are the results of simulation experiments that allow to check the alternative versions of the luggage flow organization in case of the failure of certain pieces of equipment.

2.2. Modeling and simulation methods that currently exist

The term "simulation" in the modern language of science and technology always means the application of computers to work with models. However, it is necessary to distinguish between two types of models, depending on what the role that computers play in the design and utilization of the model. The first type includes the set of mathematical models, which are encoded in form of programs from the scientific literature, textbooks, reference books and other technical documentation since the 50s of the last century in order to be run on computers. For such models, the computer is only a new approach of using them, but not a tool to create them. Working with models of such a type is called "simulation". It is meant carrying out numerous design experiments for different values of the input parameters of mathematical models. The second type of computer models includes such models, which are originally designed using a computer and exist only in the form of computer programs. In the future statements the term "simulation" will be only applied to mention this type of model.

The content and objectives of this work correspond only to one particular class of simulation models, which can be called dynamic models of processes. The term "process" indicates in this case the fact that the key point in such models is not simply to display a certain set of objects of the modelled system, but, on contrary, to display the process of interaction of objects among themselves, which occurs within a given time and space framework. The concept of "dynamic" means that in such models all the changes that occur can be associated to points on the time axis.

Exactly with respect to the models of processes the notion of modelling paradigm is widely used today (Borshchev, 2013). This concept means a set of principles of designing a conceptual model in the form of equations, diagrams and sketches, illustrated simply on a paper, as well a complete simulation model in the form of an executable computer program. In the following text, a description of the examples of applying the three main paradigms of processes modelling to the problems of studying transport processes at airports will be written.

2.2.1. The application of “continuous” paradigm

The continuous paradigm may be applied to model any processes described using set of differential equations, but in the field of production and transport processes simulation it is most often used in the form System Dynamics. This method of models’ design was developed by a professor of Massachusetts Institute of Technology Jay Forrester in the late 50s of the last century (Forrester, 1972). The first software package to support this modelling approach was DYNAMO that appeared on the market in 1959. Besides that, today models of system dynamics are designed to solve strategic problems of planning and forecasting in industry, manufacturing enterprises and entire branches of the economy (Sterman, 2000). In the models of system dynamics, individual discrete objects, for example, planes or passengers, are not displayed, but only the number of such objects is calculated at different points of the model at each step of the modelling time "delta t".

Figure 2.5 shows the structure of a passenger terminal model developed using the System Dynamics method (Biesslich et al., 2014). Wide arrows are used to define the flow of passengers, and thin arrows stand for the interdependence of variables calculated at each step of the modelling time “delta t”. The *CurrentPAXAtTerminal* node is located in the middle of the structure, which is a variable of the “stock” type. This variable shows the change in the number of passengers in the terminal facility during one day or longer span of time. The *ArrivalDepPAX* input stream displays passengers arriving at the airport by different modes of transport. The *ArrTransferPAX* stream indicates the transit passengers who arrive on the plane and then take off also by plane. The *ArrPAX* stream refers to arriving passengers who are going to leave the airport using conventional modes of transport. *DepPAX*, *DepTransferPAX* and *DepartureArrPAX* streams show passengers leaving the terminal facility and depart in the corresponding directions.

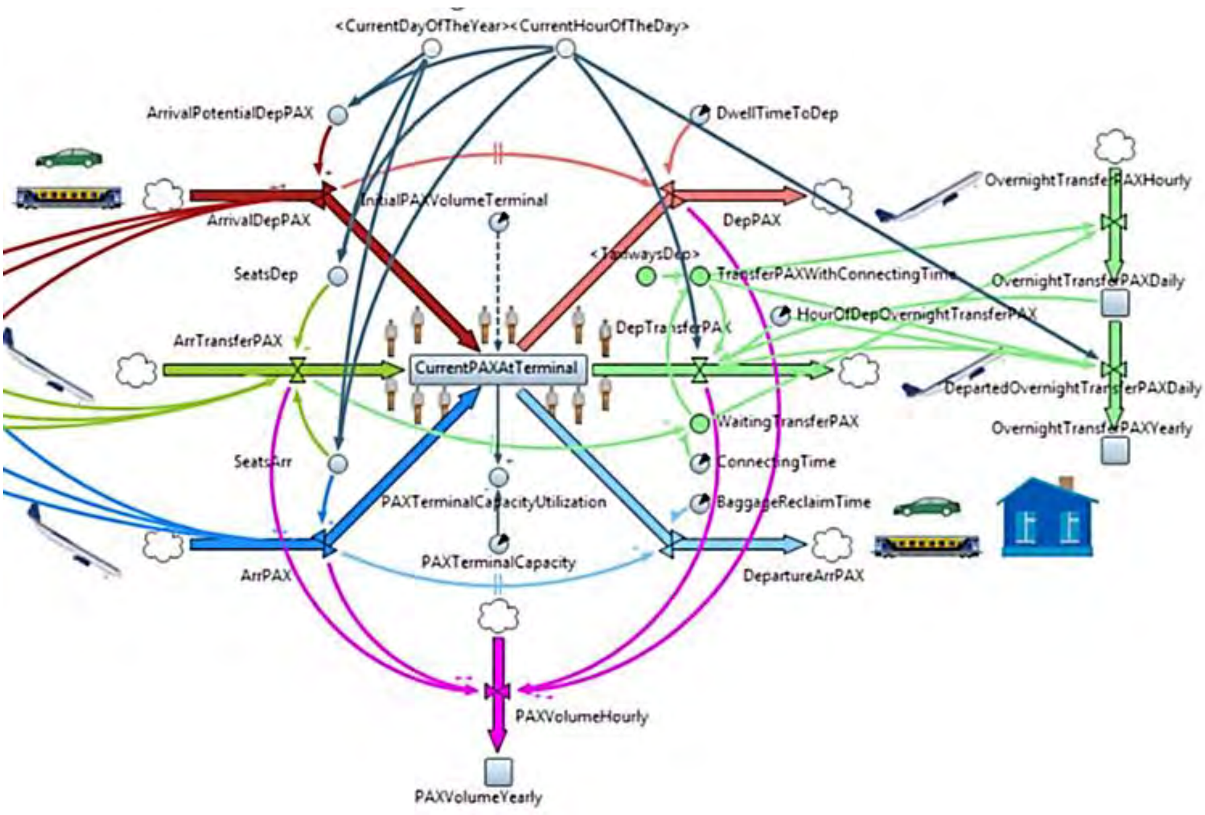


Figure 2.5. System Dynamics model of a passenger terminal (Biesslich et al., 2014)

In the study by Biesslich et al. (2014) other processes at the airport are described, for such processes models were also developed applying the System Dynamics method. The list includes Aircraft Movements and Handling, Cargo Terminal, Aviation and Non-Aviation Cash Flows. For some processes, experiments were carried out with a simulation horizon of 20 years.

In the model described by Manataki and Zografos (2010), only the passengers flow in the airport facilities are taken into account. The model is useful due to the fact of the possibility to check the options for arranging the passenger flow simultaneously changing the internal structure of the airport.

A model that analyses the passengers flow at a macroscopic level in several airports was presented in the thesis by Mühlhausen in 1999. As a coordinated interaction between the airports located in a particular region, the model analyses the ability for partial switching of passenger flows to local and long-distance railway transport.

2.2.2. The application of "discrete event" and "agent based" paradigms

The discrete event paradigm is most often used to simulate processes at the logistic level, when aircrafts, vehicles, cargo units and individual passengers are displayed as separated movable objects in models. All changes in the model occur at specific moment of time drawn form an arbitrary sequence of events spanned on the time axis of the model.

The first programming tool for this type of model was the GPSS language, developed by IBM Geoffrey Gordon in 1961. This modelling language is also used today mainly as a tool for teaching simulation modelling (O'Donovan, 1980).

The agent-based paradigm has been used since about 2000 to solve applied problems in which movable or simply mobile elements of the model have properties of a subject with personal goals and individual abilities to interact with other elements (Borshchev, 2013). For example, each individual departing passenger represented in the model as an agent and may behave in full accordance with the behaviour of a real passenger who knows exactly the number of his flight. He can go faster if he feels that he is late and, vice versa, to take advantage on a time reserve for visiting the coffee-shop. According to the principles of the computer program, models like agent based do not differ significantly from models of the discrete event type, since they use the same mechanism of timing and event scheduling.

In the research by Brandau and Tolujevs (2013) the classical model of logistic processes designed based on a discrete event paradigm is presented. The model shows the processing of cargo flows in a large aviation hub, where the "cross-docking" principle is utilized to receive and distribute cargo flows between several geographical locations. Each single night, approximately

50 cargo planes with cargo containers are located (so-called ULDs). Cargo is sorted and new ULDs are filled loading the respective aircraft. Figure 2.6 illustrates the types of discrete objects forming the corresponding streams during the movement, namely, aircraft, ULDs, Dolly carts for transportation of ULDs and tractors of the Tug type, which pull trains made up of several Dollys. The key aim of the simulation was to estimate the time for performing all cargo transhipment operations and to verify the possibility to send all the loaded aircraft according to the available schedule.

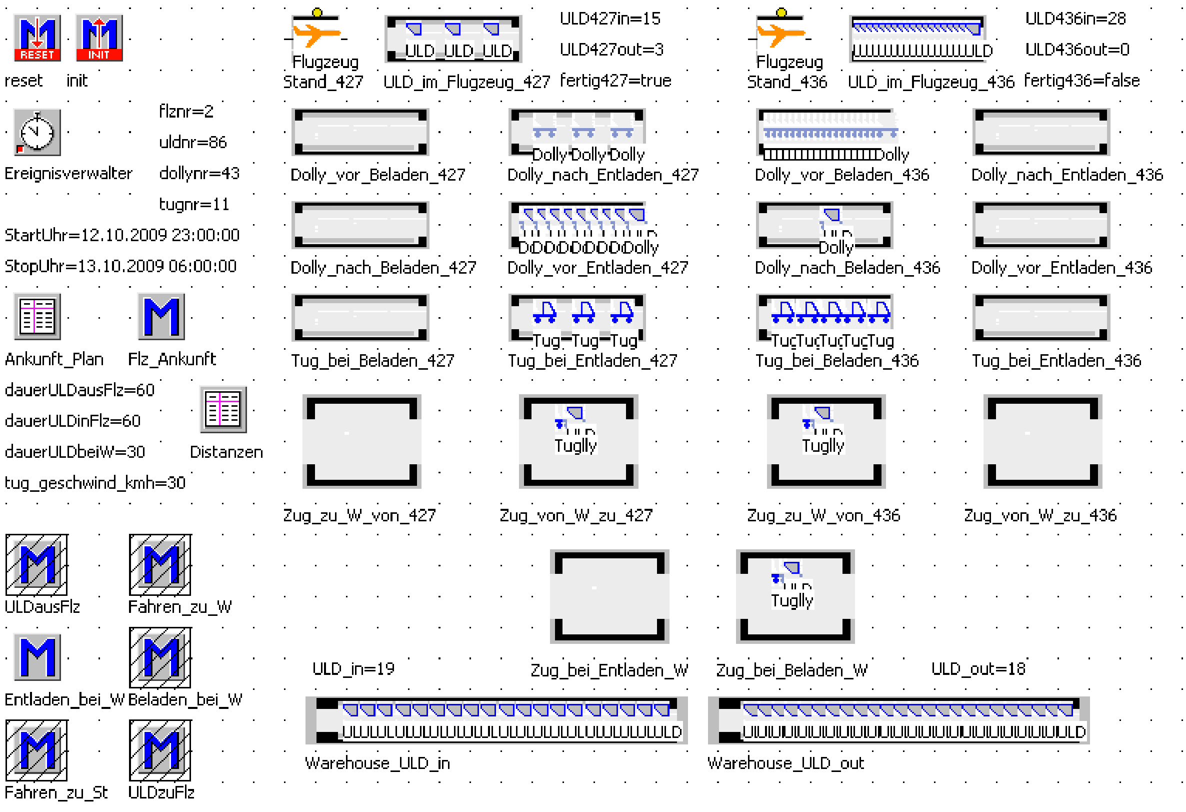


Figure 2.6. Discrete-event simulation model of a cargo terminal (Brandau and Tolujevs, 2013)

The paper by Andersson et al. (2000) describes in detail two discrete event-based simulations. The first simulation shows the capture of the taxi-out process. The second model displays the reverse process, i.e. departure of the aircraft from the parking place and taxi-in process. Both models are relatively simple queuing systems. The pivotal aim of such a research was to study and optimize the aircraft maintenance strategies, besides that to forecast possible situations with unacceptably high loading of airport resources.

The study conducted by Mas et al. (2013) focuses on an imitation model of passenger traffic along a telescopic ladder to board a plane. In particular, the model takes into account the delay of passengers due to waiting for the completion of fuelling and cabin-cleaning.

One of the chapters of the Norin’s thesis (2008) is called “A simulation model of the turnaround process”. The model displays all operations for ground handling of the turnaround process from the moment of its landing to taxiing out to the runway. Unfortunately, despite the validation of the model was performed, it was not applied to solve real problems.

The research by Dzikus and Gollnick (2010) contains a solution for determination of the optimal trajectories of aircraft and landing vehicles with regard to transport networks being mainly focused on the aircraft movement along taxiways. Applying the simulation model an estimation of the probability distribution of the real taxi times was conducted. The simulation model is hybrid, since the continuous paradigm with a fixed step of modelling time “delta t” is utilized to model the movement of aircraft, and the discrete-event paradigm is applied to model the communication process.

2.3. General purpose simulation software

Simulation packages of general purpose are defined as software products that are not oriented to model systems of one particular type, for instance, airports, hospitals, warehouse systems, etc., however such packages may be used to model almost any real-world system in case if the model developer is able to describe processes using the modelling paradigm supported by the selected package. Packages of general purpose are discussed in this work because most of the models related to processes at airports and those mentioned in the above papers have been created using such packages. The pivotal reason for the dominance of general-purpose packages is the fact that special packages designed to model processes at airports are usually 10 or even 100 times more expensive.

Since each completed simulation model is a program that the computer runs, it is worth noting that the features of simulation software which make it distinguishable from such universal programming languages as Basic, C++, Java or Python.

2.3.1. Key properties of simulation software

During the development and application of simulation models, three pivotal stages may be defined:

- to develop a conceptual model that includes a description, formalization and algorithmization of the system processes;
- to implement the conceptual model in the form of an executable computer program;
- to plan and conduct experiments with the model.

In the following section the features of simulation software, which play an important role in the implementation of the abovementioned individual steps will be discussed.

Conceptual model development

The vast majority of the simulation software's features considered here refer to packages that allow user to design discrete models using the discrete event and agent-based paradigms. All modern packages use libraries with object classes displayed as blocks on the screen and forming the model layout together. Although in "discrete" packages these libraries have very different contents, System Dynamics-based models may be built in almost any package using elements of several kinds (see Figure 2.5):

– rectangle for a stock;
– wide arrow for flow with control valve;
– node for a computed variable or constant;
– thin arrow for a logical relationship between variables.

The most primitive library for constructing discrete models consists of the following blocks:

– I = Input;
– O = Output;
– D = Distribution;
– P = Processing;
– W = Waiting.

A notable example of discrete model structure comprised of such blocks is shown in Figure 2.7. Usually models of the "discrete event" type at the conceptual level may be represented as queuing networks. The essence of the modelling processes of such systems is all about the flows of movable objects are passed through a fixed structure of the model. Each change in the position or state of the mobile object is a particular event. The model automatically records data on all the events that have occurred. This information is utilized later in order to calculate simulation results using statistical methods.

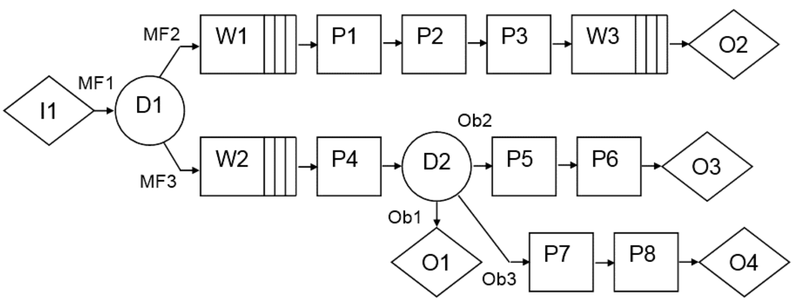


Figure 2.7. Layout of a discrete-event model

Even at the development stage, the programmer focuses on the content of the libraries in the selected modelling package in order to build the conceptual model. Access to the library blocks and their allocation on the screen is done using the graphical user interface (GUI) that is available in each modelling package. If the library contains dozens of in-built blocks that are intended to display various resources types and operations, the programmer must solve the task of selecting the appropriate blocks for all resources or operations that should be displayed in the model. If the library contains relatively few "abstract" blocks, as it is shown in Figure 2.7, then the programmer should be ready to to encode all the necessary functional properties manually.

Thus, the most important characteristic of the modelling package is the size of the library (or several libraries), which contain blocks designed to build the structure of the model. Modelling a complex system, it is often useful to divide such a system into separate interrelated subsystems "in the horizontal direction", and also applying a hierarchical principle for exaggerating the system "in the vertical direction". Almost all modern modelling packages allow creating separate local models which may be then connected to each other by horizontal and vertical connections within the framework of the final model.

Since the vast majority of discrete models are stochastic, the simulation package always offers a set of tools for describing theoretical or empirical distribution functions that are related to the corresponding random input parameters of the model. The programmer usually has the opportunity to select statistical methods for processing and interpretation of the simulation results. Some simulation results are calculated and provided to the model user in automatic mode. If they do not contain results that are interesting for a user, then during the stage of conceptual modelling, an accurate description of the indicators must be developed. Such indicators are usually calculated using another program.

Additionally, during the conceptual modelling stage, the question of the necessity of data exchange between the model and spreadsheets or databases must be solved. The vast majority of the modern modelling packages provide the tools for such data interchange.

An important mapping processes that occur during the run of the model is a computer animation. All modelling packages provide opportunities for creating 2D or 3D animation. Surely, the programmer must take into account such possibilities right at the stage of conceptual modelling.

Computer program development

At the stage of running program development in order to describe the logic of the operation with blocks and input the corresponding initial data, the developer utilizes two pivotal methods: (a) a dialogue is carried out with windows that can be opened for any block of the model, (b) custom programs are written using the internal programming language provided within the modelling package. Sometimes one of the general-purpose programming languages, for example, C++ or Java, is used as such a language, however, usually it is suggested to use an internal language of the package.

The simulation packages contain debugging tools that differ from those used for common programming languages. Along with checking the syntax of the developed program, the package's tools control the semantics of the simulated process, namely, fix logical errors that occur during program execution. For instance, an error message will appear in the situation in case of some mobile object attempts to release a resource that it did not occupy.

Debugging a program in a step-by-step mode, it becomes feasible to observe not only the values of the monitored variables, but also the ongoing situation in the model shown by the animation tools.

An important feature provided by simulation packages is the mandatory presence of the time variable. A variable that stands for the current value of modelling time. In each package, there are mechanisms to count the modelling time automatically. In packages for discrete modelling, there are also mechanisms for planning and scheduling events, the principles of which must be well-known to the programmer.

Planning and conducting an experiment with the model

For each simulation experiment the user of the model determines the set (a vector) of variable input parameters $\bar{X}$ and the set (a vector) of output indicators $\bar{Y}$ that will be utilized to analyse the results of each simulation run (see Figure 2.8). The fact that the values of the $\bar{Y}$ vector components depend on the values of the input parameters $\bar{X}$ is represented in the form of $\bar{Y}(\bar{X})$. In order to evaluate the quality of the run results further, one or more special functions $F_i(i = 1, \dots, s)$ may be derived. Values of such functions are calculated based on the vector components $\bar{Y}$. Eventually they also depend on the values of the input parameters $\bar{X}$. Such values are set by the user during the modelling experiments planning. Values of $\bar{Y}$ are such the values that are included in the composition of the simulation results. One part of these quantities can be calculated automatically by in-built tools of the modelling package, but for the other part the developer must write his own programs, which at certain points in time will calculate the required components of the vector $\bar{Y}$. Functions F_i are often represented by formulas that must also be encoded manually.

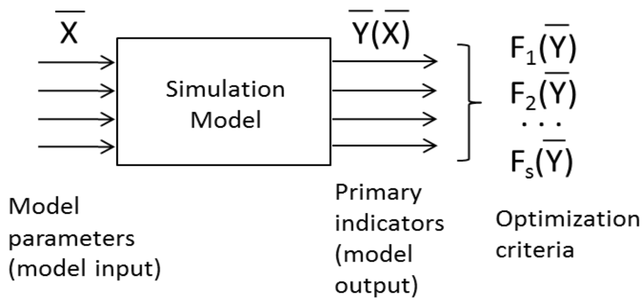


Figure 2.8. A simulation as a $\bar{Y}(\bar{X})$ dependency estimation approach

In order to plan the experiment and accumulate the results tables are often used. The general form of such tables is shown in Figure 2.9. The dimensionality of the experiment is determined by four quantities:

– *p*: the number of variable parameters, that is, number of vector components $\bar{X}$;
– *m*: the number of examined parameter sets; the number of simulation runs without taking into account parallel runs (replicas);
– *q*: the number of analysed output parameters of the model, that is, the number of vector components $\bar{Y}$;
– *n*: the number of parallel simulation runs that is performed with a fixed set of input parameters, but with different random numbers used to simulate a stochastic phenomenon.

Primary indicators (Replication no. n)			
1	2	. . .	q
y (1,1,n)	y (1,2,n)		y (1,q,n)
			y (2,q,n)
			y (m,q,n)

Primary indicators (Replication no. 2)			
1	2	. . .	q
y (1,1,2)	y (1,2,2)		y (1,q,2)
y (2,1,2)	y (2,2,2)		y (2,q,2)
			y (m,q,2)

Parameter set no.	Model parameters				Primary indicators (Replication no. 1)			
	1	2	. . .	p	1	2	. . .	q
1	x (1,1)	x (1,2)		x (1,p)	y (1,1,1)	y (1,2,1)		y (1,q,1)
2	x (2,1)	x (2,2)		x (2,p)	y (2,1,1)	y (2,2,1)		y (2,q,1)
. . .								
m	x (m,1)	x (m,2)		x (m,p)	y (m,1,1)	y (m,2,1)		y (m,q,1)

Figure 2.9. General view of a simulation experiment

The vast majority of modern modelling packages allow a user to compose and automatically execute experiment plans structured in similar way to that presented in Figure 2.9. Moreover, as part of all modern packages there are “optimizer” like modules, with which a user can organize the whole procedure for automatic optimization of the model. The essence of this procedure is that after each run of the model (or series of parallel runs), the “optimizer” module analyses the value of one or more functions F_i and calculates the new values of the vector components $\bar{X}$ after that. This cyclic process continues until the stop conditions are met, which are formulated by the model designer during the “optimizer” module configuration.

Almost all simulation packages allow a user to accumulate and display simulation results in the form of tables and diagrams, similarly to those used in spreadsheets. Quite often for these purposes, the spreadsheets themselves are also used by exporting data from the simulation results from the model to the table.

The most common forms of graphical representation of modelling results include the following:

- regular charts like “business graphics” for displaying static results, for instance, such indicators, which are not functions of time;
- plot diagrams to show dynamic results, namely such indicators, which are functions of time;
- polygons and histograms for displaying empirical distributions of indicators that are considered to be discrete or continuous random variables.

Some simulation results are computed automatically in the model, however due to their large volume in the modelling package, there are always tools to select them such that the developer can accurately compose the data that will get shown on the display screen or recorded as a file.

As it already mentioned above, almost all the modelling packages provide opportunities for designing 2D or 3D animation. In practice, 2D models are more often used, since in many simulation packages such models may be generated completely automatically, or they can be created with minimal expenses of the developer's work. Furthermore, 2D models are often quite informative in terms of the ability to analyse and unveil the transport and production processes that the basic models reproduce. The decision to create a 3D animation is adopted in the case when it is practically impossible to observe the simulated process without taking into account the third-dimensionality. Another application of 3D models is the development of photorealistic animated films intended for the public presentation of modelling results, for example, in order to prove the adequacy of the model and justify the costs already incurred or anticipated within a project related to the object under consideration.

2.3.2. Several products review

Annually in October, an organization “The Institute for Operations Research and the Management Sciences” publishes the list of software products that belong to the group “General purpose simulation software” (OR / MS Today, 2017). Packages are listed in the form of a table, the fragment of which is shown in Table 2.1. All the packages listed in this table support the “discrete event” paradigm. AnyLogic and ExtendSim packages also support the “continuous” paradigm in the form of System Dynamics. The “agent based” paradigm is fully supported only by the AnyLogic package. A more full list of general-purpose packages that are frequently used for modelling transport, production and logistics systems looks the following way: AnyLogic, Arena, AutoMod, Delmia Quest, Enterprise Dynamics, ExtendSim, Flexsim, GPSS, Plant Simulation, ProModel, Simio, Simul8 and Witness.

In order to create models based on the System Dynamics paradigm, the AnyLogic, Dynamo, iThink/Stella, PowerSim and Vensim packages are usually applied, and the most popular package for implementing the agent-based modelling concept is the AnyLogic software package.

Table 2.1. General purpose simulation software (OR/MS Today, 2017)

Software	Typical Applications of the software	Primary Markets for which the software is applied
AnyLogic	Multimethod general-purpose simulation tool. Discrete Event, Agent-Based, and System Dynamics modeling.	Supply Chains, Logistics, Manufacturing, Healthcare, Pedestrian Flows, Traffic, Mining, Defense, Social Processes, Marketing.
Enterprise Dynamics	Manufacturing, Logistics, and Material Handling Simulation.	Warehouses/Distribution Centers, Airport, Harbors, Healthcare, Pharmaceuticals, FMCG.
ExtendSim Pro	Professional level tool for modeling & analyzing complex discrete event, discrete rate, continuous, agent-based, and hybrid systems.	Consumer Products, Healthcare, Energy, Petro Chemistry, Pulp/Paper, Transportation, Pharma, Semiconductors, Military & Government, Mining.
FlexSim	Simulation and modeling of any process, with the purpose of analyzing, understanding, and optimizing that process.	Manufacturing, packaging, warehousing, material handling, supply chain, logistics, healthcare, factory, aerospace, mining.
Simio Personal Edition	Ideal product for professional modelers and researchers. Powerful object-oriented modeling and integrated 3D animation for rapid model.	Academic, Aerospace & Defense, Airports, Healthcare, Manufacturing, Mining, Military, Oil & Gas, Supply Chain, Transportation.
SIMUL8 Professional	Assembly Line, Line Balancing Strategic planning, Operations,	Manufacturing, Healthcare, Education, Engineering, Supply Chain, Logistics,

	Healthcare Systems, BPMN, Lean, Shared Services, Capacity Plan.	Government, BPMN, Lean, Automotive, Call Centers.
Tecnomatix Plant Simulation	Discrete-event simulation, visualization, analysis and optimization of production throughput, material flow, and logistics.	Automotive OEM & Supplier, Aerospace & Defense, Consumer Products, Logistics, Electronics, Machinery, Healthcare, Consulting.
WITNESS	Fast, productive predictive simulation desktop software for professional modelling and application development.	Business Planning, Process Optimization and Decision Making.
FMCG = Fast-Moving Consumer Goods BPMN = Business Process Model and Notation OEM = Original Equipment Manufacturer		

Table 2.2 represents examples of the application of general purpose simulation software in the publications discussed above. Unfortunately, in such publications, the authors do not always indicate the utilized software tool. Sometimes models are also created using general-purpose programming languages. For example, Mas et al. (2013) describe a model that was created using Visual Basic for Applications (VBA) within MS Excel. Some of the models discussed above were created using special simulation packages, which will be discussed in the next section.

Table 2.2. General purpose simulation software used for airport modelling

Reference	**Simulated processes at Airport**	**Simulation paradigm**	**Simulation software**
Confessore et al., 2005	Aircraft movement optimization in apron taxiways.	Discrete Event	Arena
Wellens and Mota, 2017	Turnaround processes.	Discrete Event	SIMIO
Guizzi et al., 2009	The flows of departing passengers from building entrance to boarding.	Discrete Event	Arena
Robinson, 1969	The analysis of options to configure the luggage handling.	Discrete Event	GPSS III
Savrasovs et al., 2009	The search for bottlenecks in luggage handling system.	Discrete Event	ExtendSim
Bießlich et al., 2014	The complex model of passanger terminal.	System Dynamics	AnyLogic
Manataki and Zografos, 2010	Passenger flow at the airport facilities.	System Dynamics	iThink/Stella
Mühlhausen, 1999	Passenger flows at the region between several airports using the railway.	System Dynamics	Powersim
Brandau and Tolujevs, 2013	Vehicles flows at the loading terminal of the airport.	Discrete Event	Plant Simulation
Norin, 2008	Turnaround process.	Discrete Event	Arena

2.4. Airport simulation software

The "airport simulation software" packages have almost all the properties of the "general purpose simulation software" packages that were already described above. These packages are called specialized, since the modelling concept, the functions of library blocks and all the terminology of the package are focused on the design and study of processes that occur in the airport facilities with the corresponding titles: airside, landside, apron and terminal (see part 2.1). The vast majority of modern packages provide the ability for a user to display the movement of an individual aircraft, vehicles or passengers on the so-called micro level. In this case, such modelling paradigms as "discrete event" or "agent based" are used.

A distinguishing feature of the "airport simulation software" packages is the provision of a user-friendly model for describing and encoding of the following model components:

- plans for the airport and terminal areas, for example, in the form of conventional CAD-drawings, which emphasize:
  - points and areas on the territory of the airport or in the terminal fascility, where operations on servicing aircraft, passengers or luggage are performed;
  - transport routes where airplanes, vehicles and passengers move;
- description of the airport's resources, namely, technical facilities and personnel, which will be used in the operations for servicing aircraft, passengers or baggage;
- description of the input and output flows of the model, taking into account the schedule of aircraft arrivals:
  - flow of arriving aircraft indicating the number of passengers on board;
  - flow of arriving passengers leaving the airport using land transport;
  - flow of transit passengers waiting for departure from the airport;
- description of the input and output streams of the model, taking into account the departure schedule of the aircraft:
  - flow of departing aircraft indicating the number of passengers on board;
  - flow of arriving passengers leaving the airport using land transport;
  - flow of transit passengers waiting for departure from the airport;
- ways to determine the parameters of the baggage flow based on the number of passengers and the statistical characteristics of specific flights;
- data on the carrying capacity and the operational time at all points of the airport where aircraft, passengers or luggage are serviced;
- rules about the aircraft movement in the airside and apron areas;
- rules about the movement of vehicles in the apron and landside zones;

– rules about dispatching and managing the flow of incoming and outgoing aircraft, the flow of arriving and departing passengers, as well as the flow of luggage that belong to these passengers.

Purely mathematical models of aircraft movement in the airspace and in the *airside* zone are apparently being developed since day one aerodromes existence in general, however the software packages that belong to the group of "airport simulation software" were intensively developed in the late 1980s of the last century, when in the era of personal computers it became possible to use the graphical user interface (GUI). Some of these packages have existed for a relatively short period of time, but there are several of them that were developing for almost 30 years.

Among the experts in the field of airport simulation it is a quite common belif that SLAM (Simple Landside Aggregate Model) package was one of the first of its kind (Brunetta et al., 1999). "The real imitation" package of SLAM can not be counted, because it did not use any of the above mentiond process modelling paradigms. SLAM is a set of analytical formulas that are combined with a common user interface. ANSI C and JAVA languages were used to program the package. The package allowed to estimate the capacity of various points of passenger handling on the territory of the terminal.

In the history of the development of airport simulation, there was the MACAD package (Mantea airfield capacity and delay model) (Stamatopoulos et al., 2004), in which the "discrete event" paradigm was used to simulate the movement of aircraft both in the airspace and in the airside zone. There is also an experiment to merge the SLAM package with the MACAD package to obtain a multi-tool that can simulate processes in both the airside and landside zones. Such a multi-tool was created within the framework of the OPAL project (Optimization platform for countries, including the concept of landside), the concept of which was developed in 2000 (Zografos, 2002).

Modern packages that belong to the "airport simulation software" group, the most famous of which are discussed below, usually allow a user to model processes in all zones, such as airspace, airside, landside, apron and terminal.

2.4.1. SIMMOD package

Working with the Simmod PRO package (Bertino et al., 2011), (Simmod URL, 2018) it is important to be able to support the dynamic decision-making mode by the user instructions for situations demonstrated by the model. Using such instructions, it is possible to control all stages of the processing of each individual aircraft taking into account the specific conditions that develop in both airspace and aerodrome. The package allows a user to the modelling of the following (Simmod URL, 2018):

– Dynamic airfield and airspace rerouting;
– Complex taxiing operations;
– Departure queue sequencing;
– Vehicles (e.g., towing, fueling, catering, baggage);
– Disruptive events (e.g., weather, system failures, runway closures, A380);
– Human resources and activities (e.g., controllers, pilots, airline);
– Advanced operating concepts;
– Complex interactions among neighboring airports.

2.4.2. TAAM package

The TAAM package (Total airspace and airport modeler) allows a user to model the following functionality (TAAM URL, 2018):

– Stands (Gates, Deice Stations, Long Term Parking Positions, Standoffs);
– Terminals;
– Pushback Paths;
– Taxiways;
– Runways;
– Aprons;
– Towing & Maintenance Operations.

The TAAM package allows a user to model the following airside functionality (TAAM URL, 2018):

– Terminal Airspace;
– En-route and Oceanic Airspace;
– Conflict Detection with separation requirements configurable by aircraft equipage;
– Flight Level Allocation System (CVSM / RVSM);
– Flow Management;
– In-trail separation;
– Wind (terminal and enroute);
– SIDs/STARs;
– Mixed IFR/VFR traffic, including circuit training and touch & go airport operations.

2.4.3. ArcPORT package

ArcPORT Airside module provides a platform for the evaluation of airfield and airspace processes such as stand allocation and capacity, the impact of different inbound and outbound routes on taxi times, terminal interfaces, apron management, delays, conflicts, ground service equipment deployment, de-icing, tow-off operations, terrain mapping and clearance, airspace routes, sectors and holds, obstruction surfaces, taxiway and runway management including take-off and landing sequencing, and much more (ArcPORT URL, 2018).

ArcPORT Landside module allows airport operators to evaluate the impact that landside processes have on airport operations. This includes queuing at intersections, adequacy of parking facilities, curbside operations, public transportation, taxi operation, airport access, exits and through traffic, locations for pick-up and drop-off curbsides for taxis, private cars, buses and other public vehicles, of different routes for different vehicles to and from the airport facilities, signalized versus non-signalized intersections, roundabouts versus intersections, number of shuttle buses needed for operations between parking lots and the terminals, and much more (ArcPORT URL, 2018).

2.4.4. CAST package

The CAST package utilizes the "agent based" modelling paradigm. Each mobile object (aircraft, vehicle or passenger) is represented in the model as an individual agent, which in each particular situation may act according to its own scenario and set of rules. The package contains supporting modules performing very important functions and make the process of user interaction with the model much easier, namely (ARC URL, 2018):

- Pax-Load-Generator (schedule-based generation of passenger load);
- Aircraft Load / Traffic Generator (schedule-based generation of aircraft load and ground handling traffic);
- Aircraft Stand Allocation (including Gantt-Chart visualization);
- Log-Analyzer (automated evaluation and presentation of results);
- Dashboard (online analysis and KPI visualization);
- Airport visualization / Virtual Airport (3D visualization of static and dynamic airport data).

CAST package additionally comprises three functional modules: *CAST Aircraft*, *CAST Vehicle* and *CAST Terminal*.

The main specialties of *CAST Aircraft* module are the following (ARC URL, 2018):

- Set-up of runway and taxiway network by predefined modules;

- Schedule based generation of flights;
- Dynamic stand allocation and aircraft routing;
- Runway utilization according to specific rules and restrictions;
- Accurate calculation of delays, taxi-times and other process parameters.

The main specialties of *CAST Vehicle* module are the following (ARC URL, 2018):

- Multi-agent fast time simulation of airside ground traffic;
- Traffic generation based on flight schedule and flight-specific load information;
- Vehicle allocation according to individual dispatching strategies;
- Sophisticated routing and driving behaviour features.

The main specialities of *CAST Terminal* module are the following (ARC URL, 2018):

- Analysis of various terminal layouts and operational strategies;
- Identification of potentials in capacity;
- Simple and straightforward modelling with predefined modules;
- Realistic passenger behaviour and highly detailed personal properties;
- Additional modules for the allocation of terminal resources including check-in counters and baggage reclaim.

2.5. The choice of tools for solving modelling problems that are formulated in this study

The pivotal task to be solved in this work is to study the impact of the vehicles' movement organization on the duration of turnaround process of an aircraft.

It is well-known that such an indicator is influenced by many factors, since the turnaround process includes up to 10 operations that are performed parallelly and sequentially between the "On block" and "Off block" events (see Figure 2.10).

Assuming that the aircraft occupies a stand in the apron zone, the following vehicles are associated with the service process (Alomar et al., 2017):

- buses for passengers' transportation;
- tugs with dollies for baggage transportation;
- other vehicles involved in the servicing of the aircraft (ladders, aircraft towing trucks, refueling tankers, catering, potable water service, wastewater service etc.).

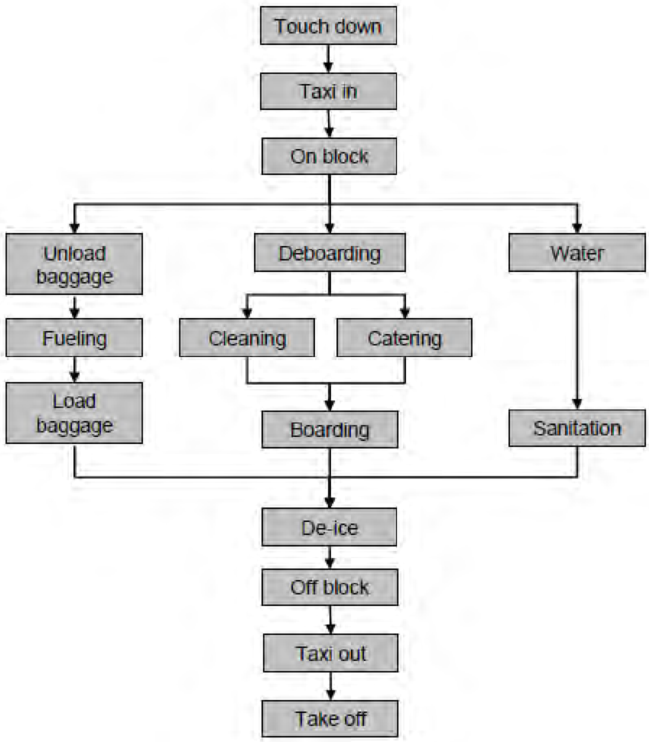


Figure 2.10. Turnaround process activities (Norin, 2008)

The work puts forward a very obvious hypothesis that delays in the movement of vehicles can increase the duration of the turnaround process. The objective of this work is to assess this influence at different levels of traffic generated by the movement of vehicles simultaneously serving several aircraft. It is quite obvious that such a task can be solved only for a specific apron zone for a given configuration of two intersecting transport networks: (1) network designated for the movement of aircraft and (2) network designated for the movement of vehicles. Since the timing of the turnaround process is influenced by the timing of specific events (for instance, when the bus arrives with passengers), this process with should be displayed in detail within the model for each aircraft in the parking lot.

Right prior to the development of specific simulation models to study the ground vehicle movement processes, it was essential to choose between the above groups of tools: “general purpose simulation software” and “airport simulation software”. Table 2.3 shows the distinguishing properties of both software groups, which are emphasized as positive or negative, taking into account the specific features of the task under consideration. Namely, the task to study the impact of the ground vehicles movement organization on the duration of ground service of the aircraft.

Table 2.3. Properties-wise comparative analysis of two simulation software groups

Properties of simulation software	**General purpose simulation software**	**Airport simulation software**
1. Prevalence and availability	Wide prevalence and decent availability (+)	Limited prevalence and poor availability (-)
2. Price	Prices in the range from 3 to 10 thousand of euros. PLE-like free version is also available (+)	Prices in the range from 10 to 100 thousand of euros. PLE-like free version is not available (-)
3. Opportunity to master the applications of package independently	Decent functionality. There is educational and scientific literature (+)	Developing company's employees is usually required (-)
4. Subject area orientation	Absent (-)	There are in-built means to display the vast majority of standard processes related to the aircraft service and passengers (+)
5. Degree of freedom in conceptual modelling of considered processes	Almost unlimited freedom because of the possibility of writing customized program code (+)	Limited freedom due to the necessity to apply standardized objects, processes and strategies (-)
6. Time required to develop models in the form of executable computer programs	Relatively time-consuming (-)	Relatively small amount of time is required to develop the standard processes related to the aircraft service and passenger (+)

Even from the brief glance on points 1, 2 and 3 the advantage of the "general purpose simulation software" group may be witnessed. It can be argued that the "airport simulation software" group packs are mainly suited to support large-scale projects aimed to analyse and improve standard processes at airports. However, for research purposes, it is better to use the "general purpose simulation software" packages, simply because they do not limit the analyst in the stages of the model's description and implementation (see clause 5 in Table 2.3).

It should also be noted that SIMMOD, TAAM and ArcPORT are mainly focused on the movement processes of the aircraft. Only in the CAST package there is a special *CAST Vehicle* module, which provides opportunities to model various strategies for controlling moving vehicles. However, choosing strategies to work with is conducted with setting up parameters in the corresponding dialog-box (Figure 2.11). Developers did not provide free programming of own strategies for the package users. This restriction turns out to be especially significant in cases when it is necessary to consider the relative or absolute priority levels of specific vehicles, which should receive the priority to pass the intersections.

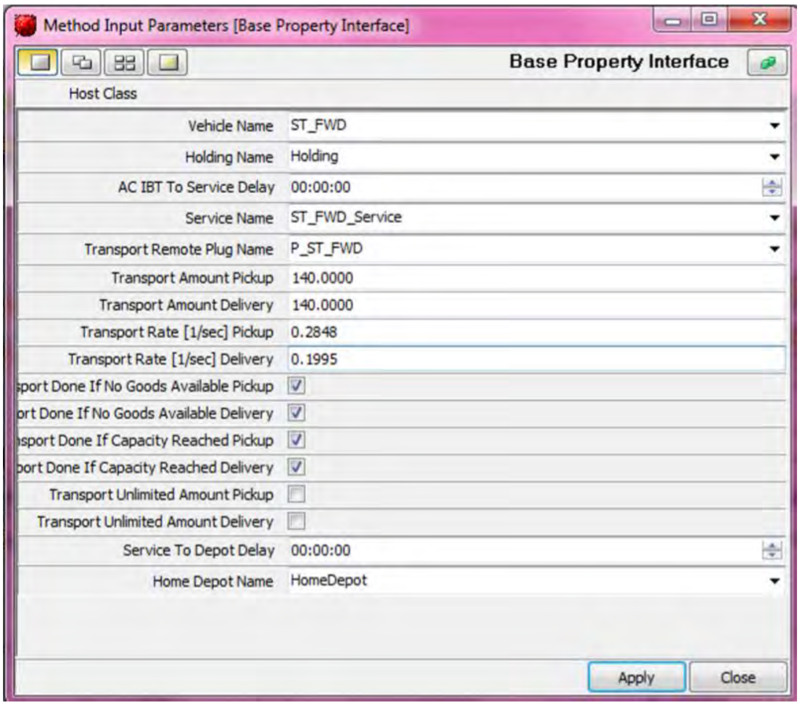


Figure 2.11. The dialog-box example of the *CAST Vehicle* module (Sanz de Vicente, 2010)

Based on that, it is decided to use the “general purpose simulation software” packages to solve the problem of studying the impact vehicles’ traffic during the turnaround process of aircraft. The options to solve this problem with the *AnyLogic* and *Plant Simulation* packages are presented in the next chapter.

3. SOLVING THE PROBLEMS OF GROUND VEHICLE MOVEMENT ANALYSIS USING SIMULATION

This chapter describes the application of simulation for solving two different tasks related to the vehicles movement at the airport. The first task is to study the impact of ground transportation traffic during the turn-around process of aircraft carrying passengers. The second task is related to the study and interpretation of information flows at the cargo terminal of the airport, assuming that there is a technical possibility to register all possible events related to both vehicles and units of cargo such as ULD (Unit Load Devices). For both described tasks, all three phases of model-related work are described, namely, the development of a conceptual model, the development of a computer program, and the conduction of experiments with the model.

3.1. Conceptual model of ground transport processes in a passenger terminal

Such a conceptual model is used as the basis to construct two simulation models of aircraft ground handling processes described below. For each of these models, a separated version of the conceptual model was designed by introducing alterations and additions to the initial model.

One of the aprons of the Riga International Airport was chosen as an "experimental polygon" for solving the tasks related to ground handling processes study. The general view of the landside zone including the transport networks for the aircraft (AC) and ground vehicles (GV) movement is shown in Figure 3.1. The model includes parking stands with numbers 311-317 and 321-327.

Figure 3.2a presents the location of taxiways along which the aircraft move between the runway and 14 parking spaces with numbers 311-317 and 321-327 respectively. Figure 3.2b also demonstrates the GV path in this flight area. On sections 10-2 and 11-19, only one-way traffic is allowed. On the other sections two-way traffic is allowed. The permitted speed of movement for vehicles in all these sections is 30 km/h. The GV intersect with taxiways, along which the AC moves at points 3-9, 12-18, 20 and 21. Points 1, 2, 10, 11, 19, 22, 23 and 24 are three-sided intersections on which the GV's paths may intersect.

The moving objects that are displayed in the model are AC and GV. The following types of objects are defined within GV:

- buses for passengers' transportation;
- dollies (carts for baggage transportation);
- tugs (tractors for transportation of dollies);
- other vehicles involved in the servicing of aircraft (refuelling tankers, catering, potable water service, wastewater service etc.).

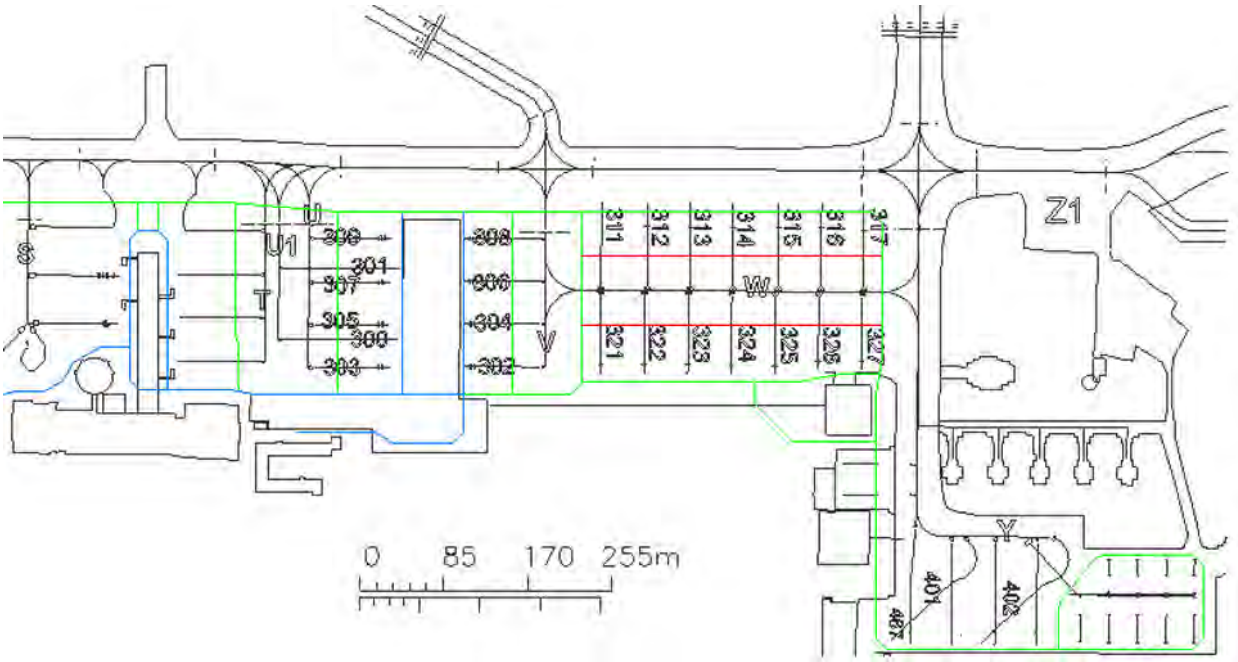


Figure 3.1. Plan of the landside zone at Riga International Airport (ICAO)

In the case in which AC and GV cross the same paths of motion, AC has absolute priority, for example, the movement of all GVs the path of which intersects the path of AC, are blocked for a certain time.

a) b)

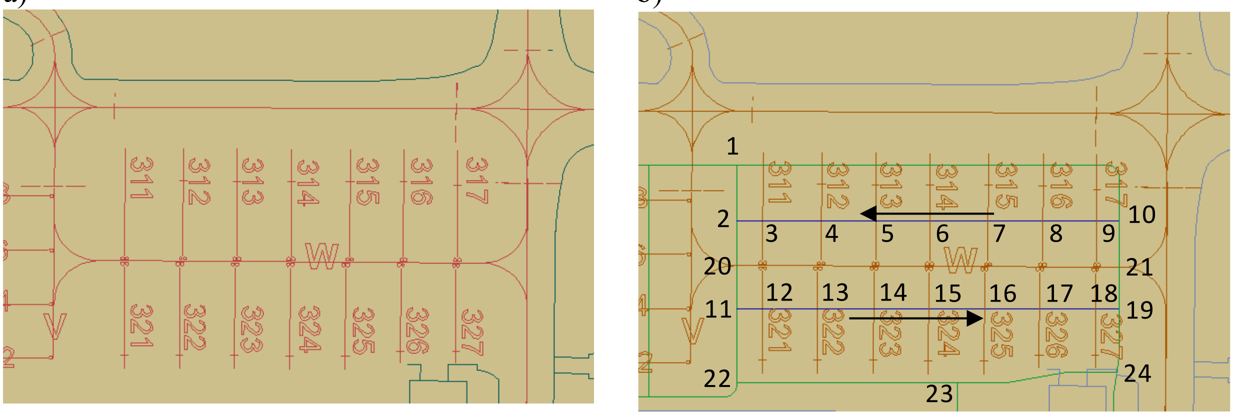


Figure 3.2. Modeled fragment of the aerodrome ground movement network

In both of the simulation models described below, the AC movement path is implemented, in such a path the AC starts in the apron at intersection 1 and after crossing the track for GV at point 20 moves to one of the parking places numbered from 311 to 317 or from 321 to 327. Right after the service is completed, AC is taken out to route segment 20-21 by pushback tug and leaves apron on its own, passing through point 21 and leaving the left side of stand 317.

During the service of a particular AC, the corresponding GV group initially moves from the starting position to the parking place where the AC under service is located moving in the opposite direction right after the service is finished. Since the model does not reflect the whole Riga airport transport network, however only one of its segments, the starting points where GV starts and ends are not shown in Figure 3.2. In both of the simulations, the following assumption is made. The passenger busses and tugs with dollies appear before intersection 1 moving toward the parking lot. As it shown at Figure 3.2, after the corresponding maintenance operation is completed, these vehicles leave the transport network also through intersection 1. For the other GVs, the intersection 24 is used as the starting and ending points of the route. This literally means that all the other GVs (refuelling tankers, catering etc.) appear in the model before the intersection 24 and after the completion of the AC service they leave the transport network also through the intersection 24.

3.2. Rough model for the study of apron throughput

This model is called rough, since it considers the influence on the AC service time by only one type of GV, namely, buses that transport passengers both from the arriving AC to the terminal of the airport, and in the opposite direction. It is assumed that the number of such buses may be limited, so that in condition of the most stands are occupied by aircraft, the bus fleet may become the bottleneck for apron throughput, which is measured as the average number of ACs processed per hour.

3.2.1. Refinement of the conceptual model

The conceptual model comprises of a processes description that include both the AC maintenance operations performed on a particular stand, and the transport operations associated with them. This part of the conceptual model is presented in the form of three process chains (see Figure 3.3). The first chain shows AC service phases in a generalized form. The second chain demonstrates the processes related to the transportation of passengers and their luggage. The third chain shows the processes related to the delivery of departing passengers on the AC's board and the transportation of the corresponding luggage.

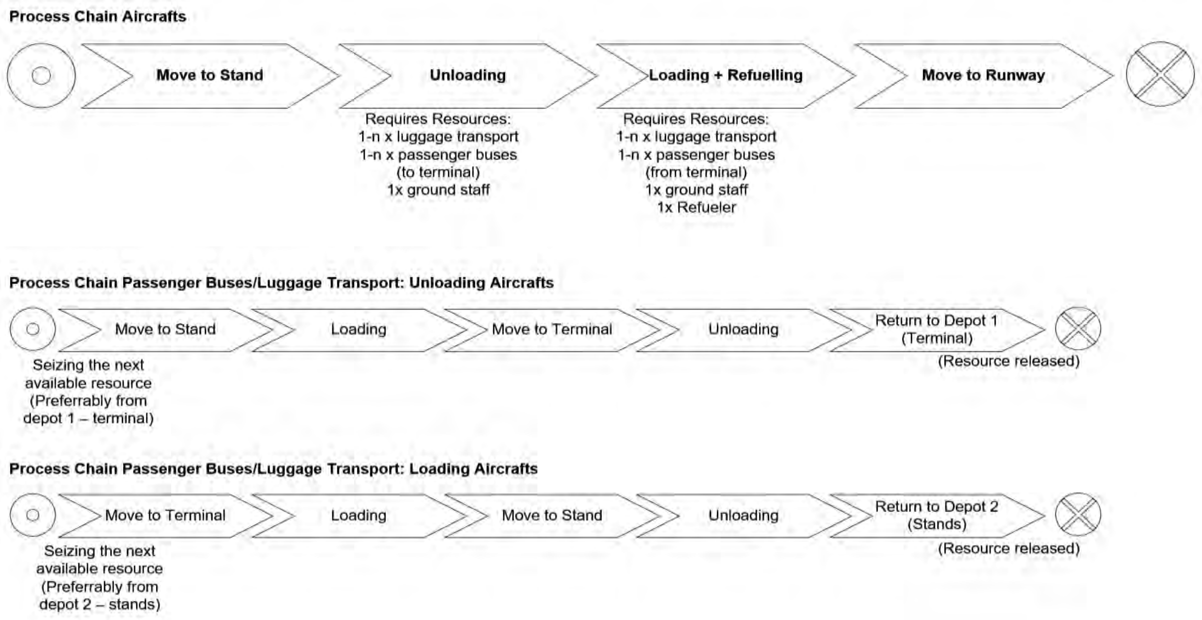


Figure 3.3. Aircraft handling process chains

As it was already mentioned above, this version of the model considers the real availability of only buses for the passengers' transportation in both directions, while the availability of other resources used to service AC is considered to be unlimited. Additionally, the conceptual model does not yet consider the mutual influence of the execution time of maintenance operations. One part of such operations can be executed in parallel to each other, and the other part can begin only if certain operations are completed. It is assumed that in the absence of delays due to the waiting of buses, the average service time of one AC τ_{serv} equals 25 minutes. If the AC is constantly on all n=14 stands, then the maximum value of apron throughput will be the following:

$$\mu_{apron}^{max} = \frac{n*60}{\tau_{serv}} = 33{,}6\ [AC/h].$$

If the bus pool is not sufficient for simultaneous servicing of all 14 stands or buses will be delayed while driving along the transport network and arrive late at the corresponding stands, the value of μ_{apron} will be less than the upper limit of μ_{apron}^{max}. The model includes a variable m that is equal to the number of buses that can be used to service the AC. In this regard, the main goal of the experiments conducted with this model may be described by the expression $\mu_{apron} = f(m)$, namely, the dependence of apron throughput on the number of available buses will be studied.

3.2.2. The simulation model design

The simulation model was designed using the simulation software Anylogic7 according to the “agend based” modeling paradigm. The subtlety of the model based on the fact that it utilizes blocks (graphic elements of of flow charts) from two different libraries: *the Process Model Library* and *the Road Traffic Library*. The main flowcharts are shown in Figure 3.4 and Figure 3.6.

Figure 3.4 presents the model of the first phase of AC maintenance. AC takes one of 14 stands, a bus is called to arrive, passengers take the bus and transported to the arrival zone. The available 14 stands are set in the r*esourcePoolStands* block, and the bus fleet size is specified in the *busesResource* block. Light blocks such *as seizeStand* or *unloadAC* refer to *the Process Modeling Library*, dark blocks such as *moveToStand* or *moveToArrival* belong to *the Road Traffic Library.* The chain at the bottom of the Figure 3.4 serves to simulate all the actions of a particular bus, including its journey in the transport network. The first element in the chain is an *enter* block. Blocks from *the Road Traffic Library* controls the flow of buses in the transport network automatically according to the regular driving rules. In cases of dense traffic, congestion may occur, causing buses to delay.

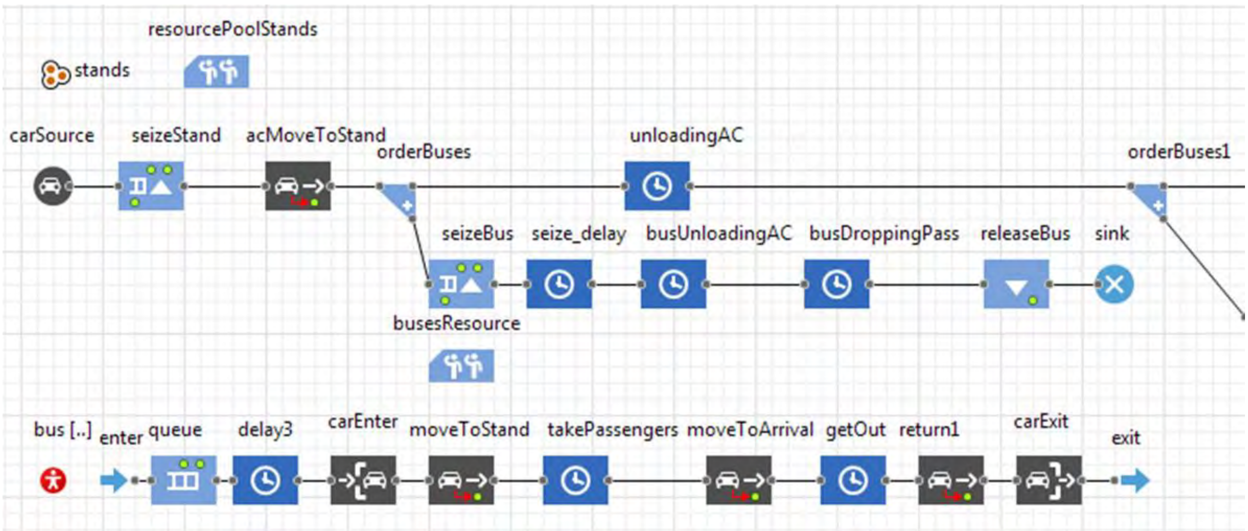


Figure 3.4. The model of disembarkation from AC and transportation to the terminal

Figure 3.5 shows a fragment of the transport network that is modeled by *the Road Traffic Library*. This fragment is designed using such standard markup elements as *Road, Intersection* and *Stop Line*.

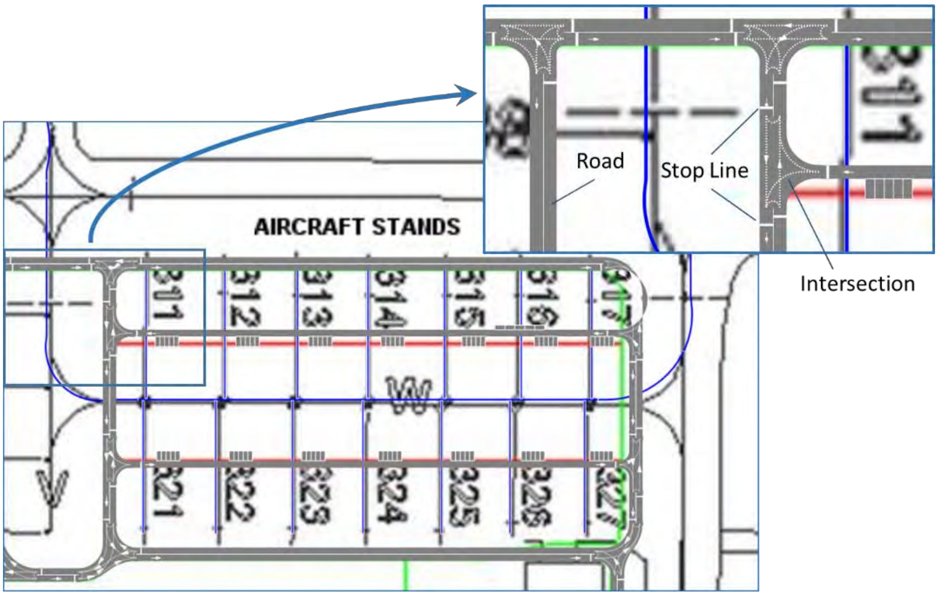


Figure 3.5 The transportation network fragment designed with the *Road Traffic Library*

Figure 3.6 demonstrates the model of AC maintenance in the second phase. The bus transports passengers from the terminal to the AC, after that they board the plane. In this part of the model the same blocks taken from the AnyLogic libraries as in the first part are utilized (see Figure 3.4).

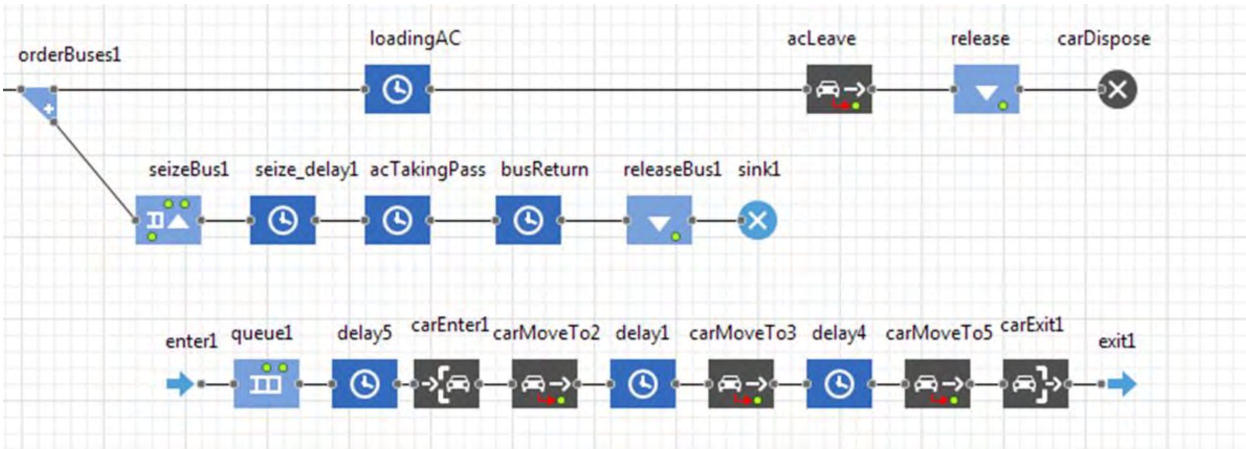


Figure 3.6. The model of passangers' transportation from the terminal to the point of boarding

3.2.3. Experiments with the model

In the model the movement of AC and busses in the form of 2D or 3D animation was observed (see Figure 3.7). Animation was primarily used as an effective mean of the model verification. In addition, with it allowed to observe both congestion in the transport network, and AC waiting some time for the arrival of buses.

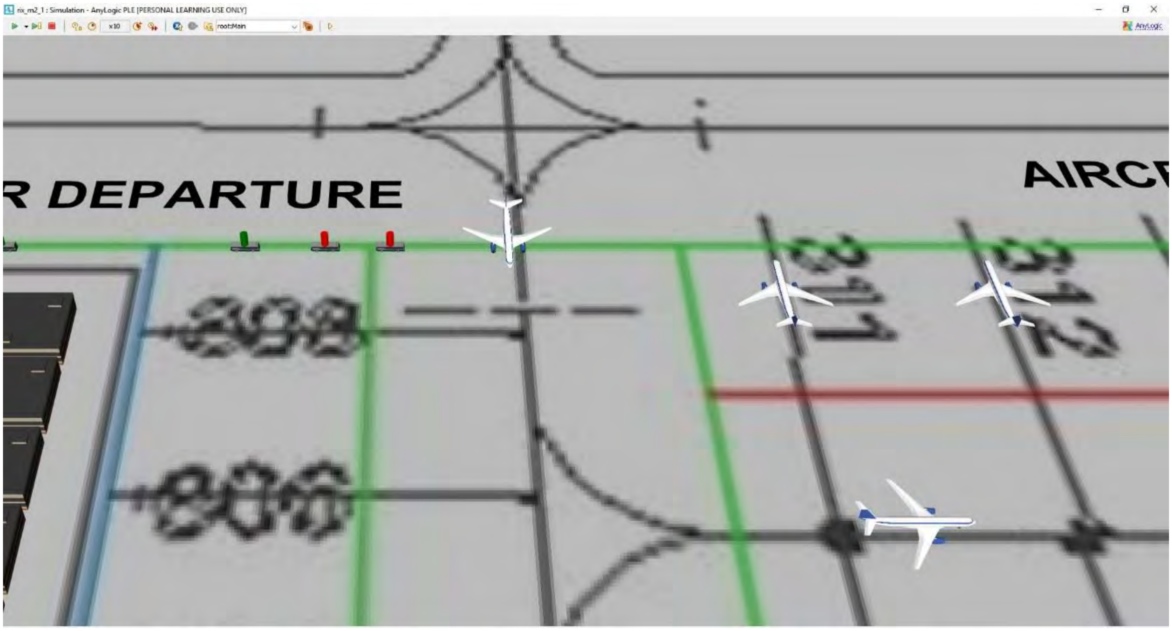


Figure 3.7. The example of 3D-animation for transport processes in landside zone

The key quantitative result of simulation in the form of the $\mu_{apron} = f(m)$ dependence is shown in Figure 3.8. The number of available buses m varied from 1 to 80. The indicator apron throughput μ_{apron} depends linearly on the number of available buses m approximately to the frontier m=30. The effect of decreasing the average speed of buses appears because of congestion in the transport network. Theoretical value of $\mu_{apron}^{max} = 33{,}6\ [AC/h]$ for the real apron throughput is not reachable at all. The maximum value of the order equals 29.1 [AC/h] observed with the number of buses m=75. With further increase of this number, the indicator apron throughput deteriorates as buses are frequently delayed in congestion.

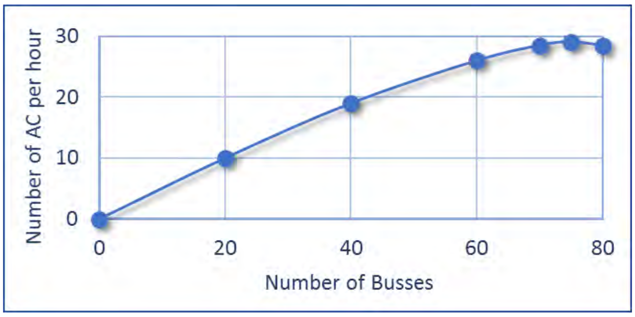


Figure 3.8. Average number of served AC per hour as a function of the number of available busses

The reverse interpretation of the simulation results shown in Figure 3.8 is also useful. Since the “ideal” average service time for one AC is known $\tau_{serv} = 25\ [min]$, it is also possible to calculate the maximum recommended number of simultaneously occupied stands depending on the apron throughput indicator:

$$n^{max} = \frac{\tau_{serv} * \mu_{apron}}{60} \ [stands].$$

Since μ_{apron} depends on the number of buses m, it is possible to make a table for the estimation of value of n^{max}, which depends on the number of available buses m (see Table 3.1 and Figure 3.9).

Table 3.1. n^{max} value calculation depending on the number of available busses m

m	$\mu_{apron}\ [AC/h]$	n^{max}	n^{max} (roughly)
0	0	0	0
20	10	4,16	4
40	19	7,91	7
60	26	10,83	10
70	28,5	11,87	11
75	29,1	12,12	12
80	28,5	11,87	11

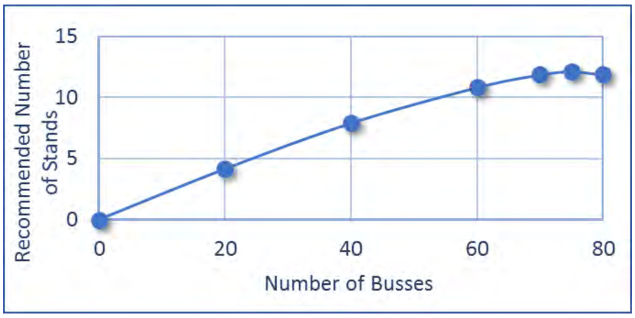


Figure 3.9. The recommended maximum number of ocupied stands depending on the number of buses available

According to the Table 3.1, even with the maximum number of buses m=75, the number of simultaneously occupied stands should not exceed 12. Only with this condition, delays in traffic of buses will not affect the average service time τ_{serv}.

Figure 3.10 represents additional simulation results that were obtained using the AnyLogic *Road Traffic Library*. The notion of fast and slow movement of buses in the transport network was introduced. The speed limit was set at 3 m/s. Since the model records periods of acceleration and deceleration in the movement of each bus automatically, it was discovered that even a single bus that does not fall into congestion spends about 7% of the time in a state of slow motion. The dependence of time shares, which correspond to the states of fast and slow traffic, from the number of buses taking a part in the traffic is shown in Figure 3.10. These shares are calculated with regard to the total time during which the buses are in a moving state.

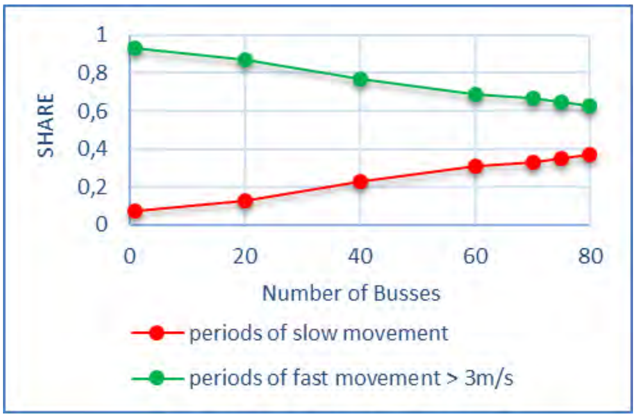


Figure 3.10. Share of periods of faster and slower ground vehicle movements

3.3. A detailed model for the study of the aircraft ground handling time

In this model, at a very detailed level, all the processes that are related to AC maintenance in the apron zone under consideration are displayed. therefore, this model simulates the movement of all types of GVs that arrive to the stand andthat are involved in servicing of each particular AC. The movement of GV in the transport network is considered at a microscopic level. Especially detailed are the representations of the crossroads. Such processes can be influenced by introducing a system of relative or absolute priorities for certain GV groups. Additionally, all the operations, which are provided by ground maintenance technology of AC, are also modeled in detail. The main indicator estimated using simulation is the distribution of the AC service time, which is also referred to as "turnaround time".

3.3.1. Refinement of the conceptual model

Figure 3.11a presents the conceptual model of the intersection point of the AC and GV pathways. At the moment when the mobile object (AC or GV) reaches the appropriate decision stage, the driver receives from the controller one of two directions for further action, either continue the movement or stop before waiting point. Stopping before waiting for the driver waits for permission to proceed. Of course, the option to stop before waiting point refers almost exclusively to the movement of the GV. It can be also used for AC, for example, in the event of a GV emergency stop in the crossing point. The permission condition for the crossing point for the GV in general form is formulated in the following way. There is no danger of collision with the AC and there is enough room to enter into the next segment. The model displayed in Figure 3.11a should be applied at points 3-9, 12-18, 20 and 21 (see Figure 3.2b). In this case, at points

3-9 and 12-18, it is necessary to consider the fact that ACs can pass through the crossing point in two directions. At points 20 and 21, both AC and GV may move freely in both directions.

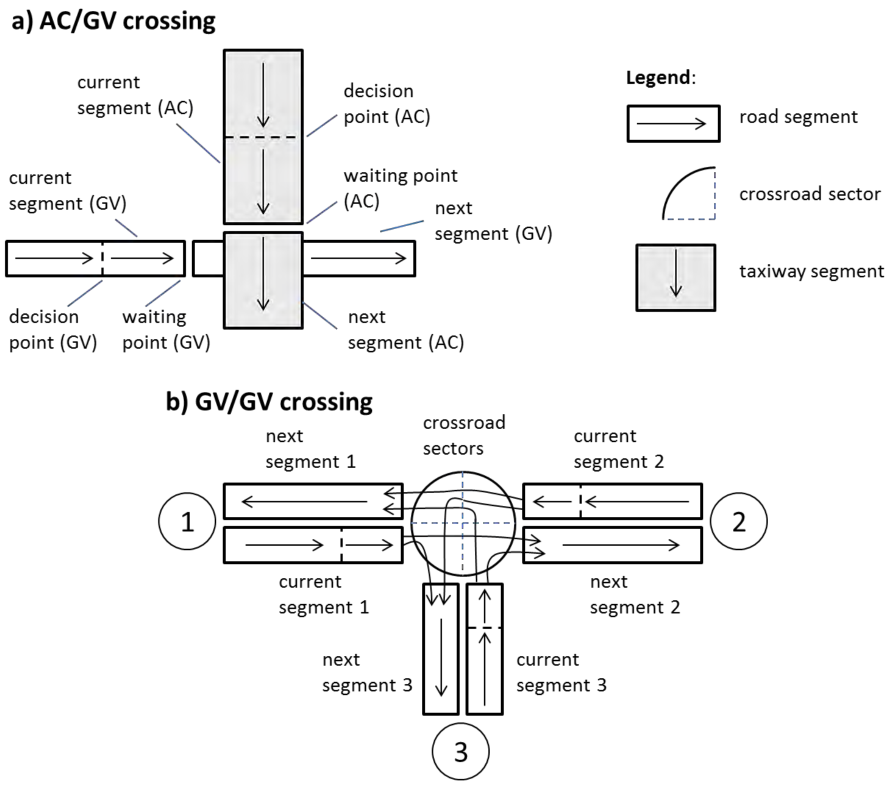


Figure 3.11. Conceptual models of aerodrome crossing points

Figure 3.11b displays a conceptual model of a three-way intersection, in which only GVs are found. At decision point and waiting point, the actions are the same as those described above. The model includes four sectors of the intersection, which are called crossroad sectors. The condition to get the permission to moe throug the intersection for GV is generally stated as follows: the required sectors of the crossroad are free and there is enough space for entry into the next segment. The model demonstrated in Figure 3.11b should be applied at points 1, 2, 10, 11, 19, 22, 23 and 24 shown in Figure 3.2b. In this case, points 2 and 19 along the direction 3 (see Figure 3.11b) are used to simulate only those arriving at the intersection of GV, and points 10 and 11 are involved into the simulation of only those GVs that leave the intersection after its passage.

The model introduces the concept of the priority level for GV, which is considered passing through the intersection:

- priority 1 means that at the release time of the sectors claimed by several GVs, such sectors are allocated to the GV that arrived at the intersection before the others, in other words, the FIFO rule is implemented;

– priority 2 means that at the release time of the sectors, they are allocated to the GV that has this priority, even if it did not stop before the other GVs at the waiting point before the intersection;
– priority 3 means that there is a special overtaking line at the intersection (see Figure 3.12), which may be used only by GVs with this priority; at the release time of sectors, they are allocated to the GV, which stands before the intersection at the end of the overtaking line.

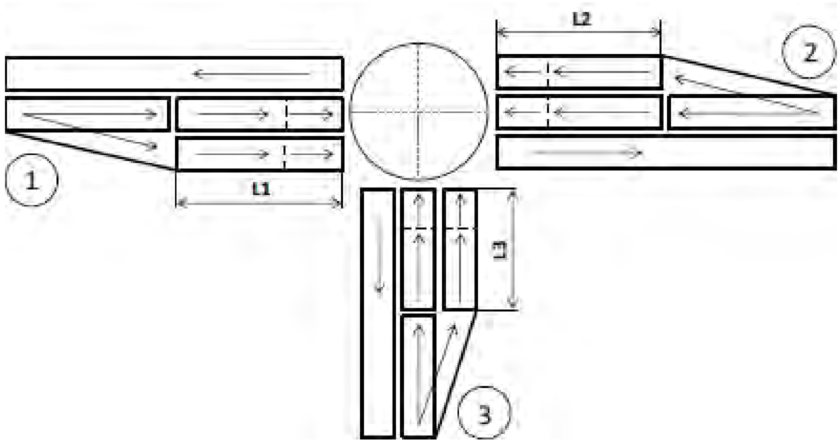


Figure 3.12. Conceptual model of the intersection with the overaking line

Using priority 2 means introducing relative priorities, since GVs with this priority take advantage only when they appear in the waiting point before the intersection. In case of a congestion, such GVs will be delayed along with those GVs that have priority 1. Introduction to the intersection of the overtaking line means the use of absolute priorities, as the result GVs that have priority 3 can bypass the mash on the right side and as the first get access to the free sectors of the intersection.

The model shows all GV of all types, which were listed in p. 3.1:

– buses for passenger transportation;
– dollies (carts for baggage transportation);
– tugs (tractors for transportation of dollies);
– other vehicles involved in the servicing of aircraft (refueling tankers, catering, potable water service, wastewater service etc.).

In order to get more realistic GV traffic, the concept of “background vehicles” (BV) was introduced into the model. Such GVs that are not related to AC servicing on the apron are necessarily present in the real transport network. The model assumes that the specified number of BVs is evenly distributed over the four ring routes: 1-10-2-1, 1-2-11-19-10-1, 24-19-10-2-11-22-23- 24 and 24-23-22-11-19-24. All GVs that belong to the BV with the priority 1.

Figure 3.13 presents all ground handling operations that are performed in the simulation. The keyindicator, which is determined in the model for each served AC, is

handling time = ground handling end time – ground handling start time

or

$$\tau_{handling} = t_{end} - t_{start}.$$

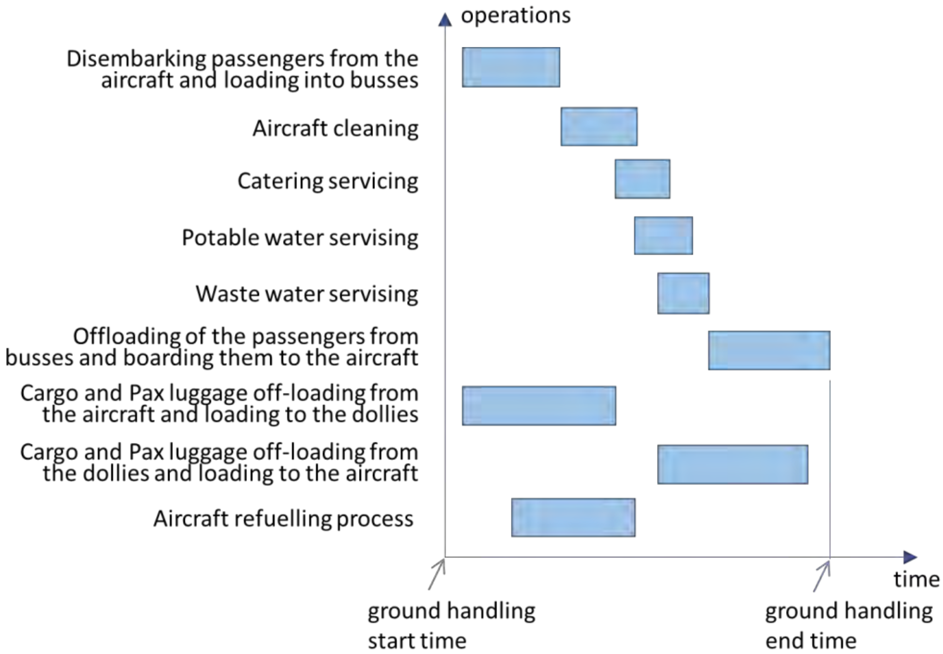


Figure 3.13. Aircraft ground handling operations

3.3.2. The development of the simulation model

The simulation model was built using Plant Simulation software according to the “discrete event” modeling paradigm.

Model layout

Figure 3.14 shows a fragment of the model that includes points 1-10 and the connecting segments of the transport network presented in Figure 3.2b. The points 1, 2 and 10 shown in Figure 3.14 are three-way intersections that are implemented in the simulation model according to Figure 3.11 and Figure 3.12. The main part of the model is constructed using only the four types of blocks shown in Table 3.2.

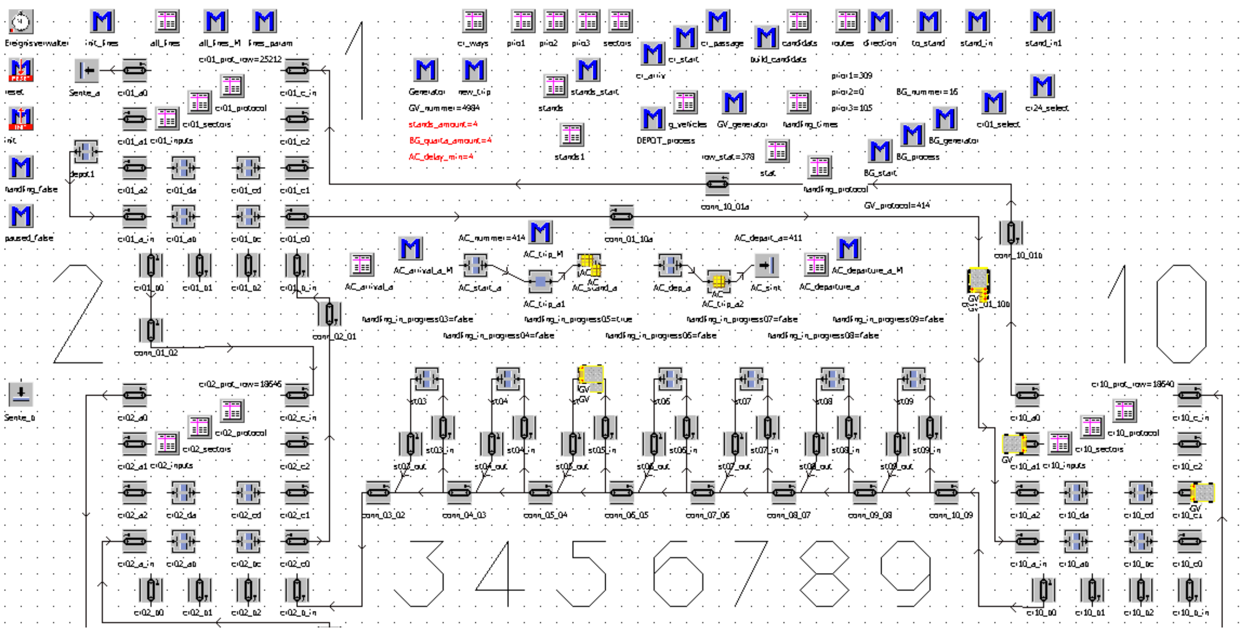
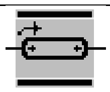
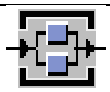
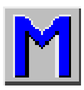
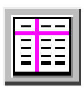


Figure 3.14. The fragment of the simulation’s structure

Table 3.2. The main blocks of the simulation model

Graphic image	Block name	Executed functions	The number of blocks in the model
	***Line***	– way segments in transport network – segments of intersections	154
	***ParallelProc***	– places of GV’s stops near stands – sectors of the intersections	46
	***Method***	– programs for GV’s movement control in transport network – programs running the aircraft ground handling operations – programs for statistical data collection	28
	***Table***	– tables with the initial data of the model – tables with the modelling results – tables with the current data on the intersections’ state	38

The key initial data of the model

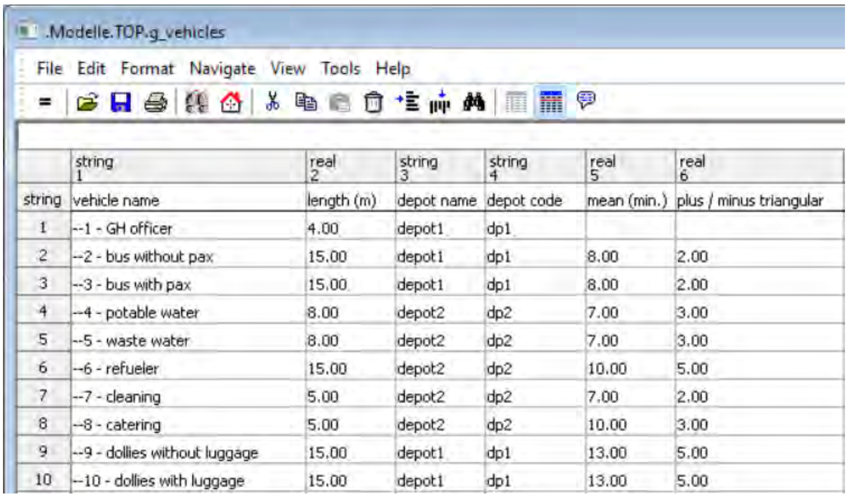
Figure 3.15 represents the stands table, which describes 14 stands in the apron zone under consideratio. As an example, an option in which the AC can occupy seats only on stands with numbers 313, 315, 323 and 325 is shown. All GVs that service stand with number 313 receive priority 3 to get an advantage for crossing the intersections, while all the remaining stands are serviced by GV with priority 1.

	string 0	string 1	string 2	integer 3
string	stand no.	point no.	busy (yes, no)	priority (1, 2, 3)
1	311	03	no	1
2	312	04	no	1
3	313	05	yes	3
4	314	06	no	1
5	315	07	yes	1
6	316	08	no	1
7	317	09	no	1
8	321	12	no	1
9	322	13	no	1
10	323	14	yes	1
11	324	15	no	1
12	325	16	yes	1
13	326	17	no	1
14	327	18	no	1

Figure 3.15. *Stands* table for the variant of stands' use discription

Figure 3.16 shows the *g_vehicles* table, which describes the parameters of ten GV types and the parameters for the duration distribution on operations for which these GVs arrive at the stands. The *depot1* parameter means that this type of GV appears in the model and then exits from it at point 1 of the transport network (see Figure 3.2b). If *depot2* is used, it means that the corresponding GVs appear in the model and then exit from it at point 24 of the transport network. In order to simulate the duration of operations, a symmetric triangular distribution is used which parameters are specified in the columns "mean (min.)" And "plus / minus triangular".

Using a separate parameter *BV_quarta_amount* in the model, a user can set the number of BVs constantly in transit along each of the four ring routes (see section 3.3.1). The parameter *AC_delay_min* is used to specify the time (in minutes) during which a moving AC blocks the movement of GVs at the intersection point.



.Modelle.TOP.g_vehicles

File Edit Format Navigate View Tools Help

	string 1	real 2	string 3	string 4	real 5	real 6
string	vehicle name	length (m)	depot name	depot code	mean (min.)	plus / minus triangular
1	--1 - GH officer	4.00	depot1	dp1		
2	--2 - bus without pax	15.00	depot1	dp1	8.00	2.00
3	--3 - bus with pax	15.00	depot1	dp1	8.00	2.00
4	--4 - potable water	8.00	depot2	dp2	7.00	3.00
5	--5 - waste water	8.00	depot2	dp2	7.00	3.00
6	--6 - refueler	15.00	depot2	dp2	10.00	5.00
7	--7 - cleaning	5.00	depot2	dp2	7.00	2.00
8	--8 - catering	5.00	depot2	dp2	10.00	3.00
9	--9 - dollies without luggage	15.00	depot1	dp1	13.00	5.00
10	--10 - dollies with luggage	15.00	depot1	dp1	13.00	5.00

Figure 3.16. *G_vehicles* table to describe GV parameters and service operations of AC

Key modelling results and stopping condition

Figure 3.17 presents a fragment of the model with elements of 2D animation. Such elements are automatically created by means of the Plant Simulation package. Animation allows a user to observe both the movement and stops of all moving objects in the model. Namely, all AC and all GVs. For example, objects of the GV type in the blocks *conn_08_07*, *conn_06_05* and *conn_05_04* represent the GV in the state of movement horizontally from point 8 to point 4 in the transport network diagram (see Figure 3.2b). Objects of type GV located between *st07_in* and *st07_out* correspond to those GVs that are currently in the region of the network point 7, namely in the stand with number 315.

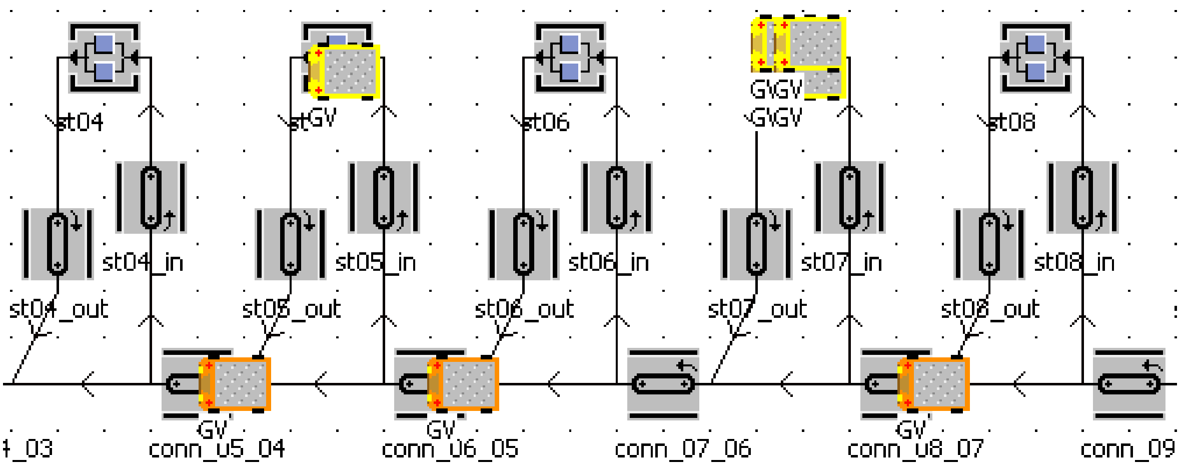


Figure 3.17. The model fragment with elements of 2D animation

The pivotal estimated indicator of the simulated process is the duration of the AC's ground service process. Figure 3.18 displays the results of such servicing, namely, the first 12 ACs for which all associated GVs have priority 1. Similar data is accumulated independently for all three possible GV priority levels (1, 2 and 3). After the transitional state in a model with duration of 10 hours is over, the record of service time data begins. After that, such data is exported to the MS Excel environment for statistical processing. The run of the model is completed, if for each GV priority class at least 100 observations have been accumulated.

.Modelle.TOP.handling_times

File Edit Format Navigate View Tools Help

	real 1	real 2	real 3
string	begnning time 1	ending time 1	duration 1 (min)
1	1500.00	3597.66	34.96
2	2400.00	4686.00	38.10
3	3300.00	5536.37	37.27
4	5397.66	7628.72	37.18
5	6486.00	8978.34	41.54
6	7336.37	9636.74	38.34
7	9428.72	11584.44	35.93
8	10778.34	13185.77	40.12
9	11436.74	13714.79	37.97
10	13384.44	15372.51	33.13
11	14985.77	17297.50	38.53
12	15514.79	18227.87	45.22

Figure 3.18. The table with values of AC's services duration for priority 1 class

3.3.3. Experiment 1: assessing the impact of traffic on the duration of AC service

Table 3.3 shows the sets of input data under study, which include three variable parameters:

- number of active stands, namely such stands, which can simultaneously hold AC under the service (2, 4, 6, 8 or 10 stands);
- number of BV, namely such GVs that are constantly on the ride on four ring routes (8 or 16 BV);
- the time when the moving AC blocks the GV at the intersection points of their routes preventing the movement (2, 3 or 4 minutes).

Table 3.3. The sets of initial data under the study during the experiment 1

Number of the input data set	**Amount of the active stands**	**Amount of the background vehicles**	**Blocking time (minutes)**
1	2	8	2
2			3
3			4
4		16	2
5			3
6			4
7	4	8	2
8			3
9			4
10		16	2
11			3
12			4
13	6	8	2
14			3
15			4
16		16	2
17			3
18			4
19	8	8	2
20			3
21			4
22		16	2
23			3
24			4
25	10	8	2
26			3
27			4
28		16	2
29			3
30			4

Conducing the described experiment 1, 30 runs of the model were performed totally. In each run at least 100 AC were serviced. In this experiment, only priority class 1 was applied for all GVs.

The results of runs 4-6, 16-18 and 28-30 are shown in the form of two diagrams in Table 3.4. In such runs the maximum number of BVs that equals 16 was used. The first “Handling time of each aircraft” diagram presents the specific handling time values for all 100 ACs fixed in the model after the transition state is over. Each sample of such kind was statistically processed and presented as a “Histogram of the handling time distribution”. It can be witnessed that with a minimum number of active stands the blocking time does not significantly affect the value of $\tau_{handling}$, however in the “10 active stands” variant it reached even 91 minutes. Numerical values f the statistical results for runs 4-6, 16-18 and 28-30 are also demonstrated in Table 3.5.

Table 3.4. The modelling results with different amount of the active stands

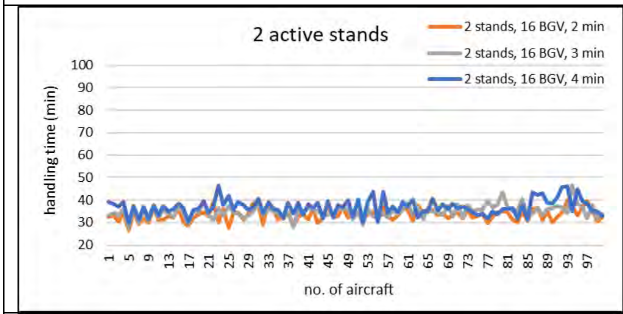
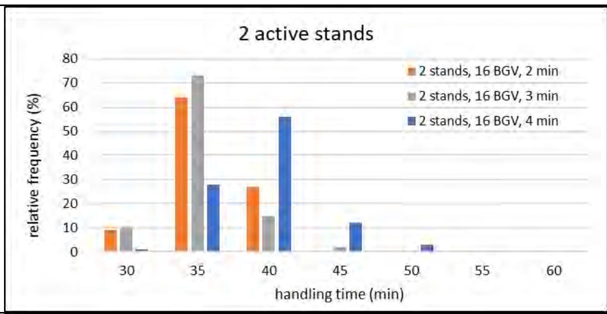
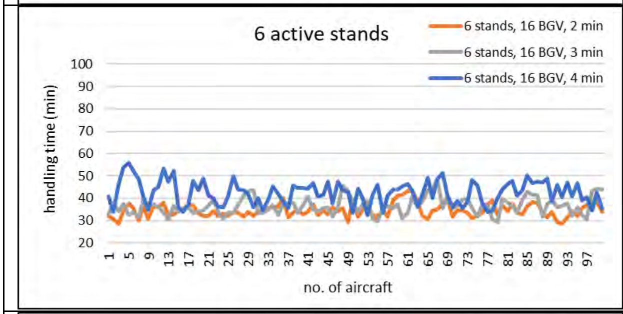
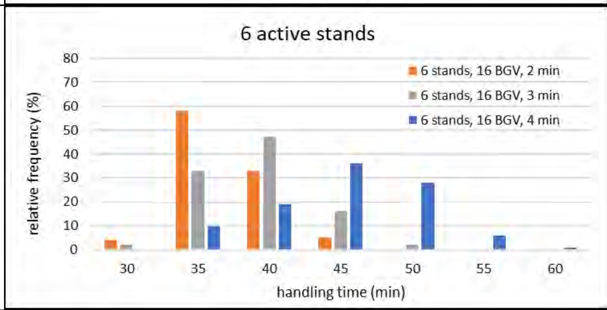
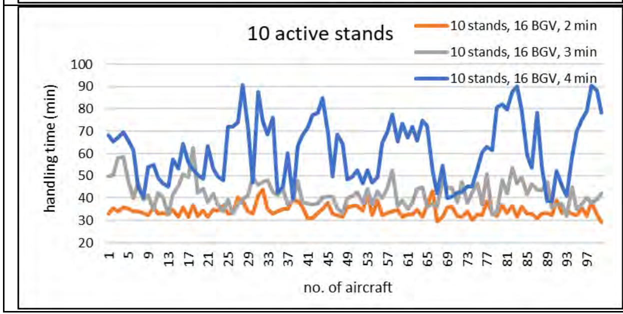
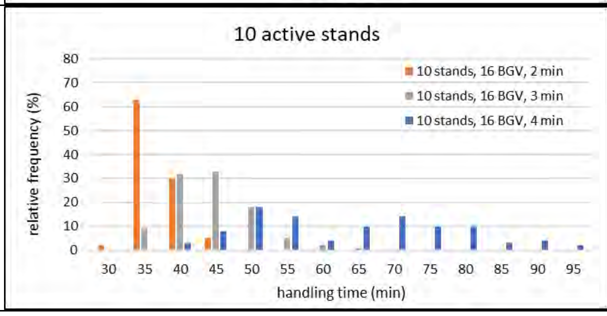
<table>
<tr><th>Handling time of each aircraft (minutes)</th><th>Histogram of the handling time distribution</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

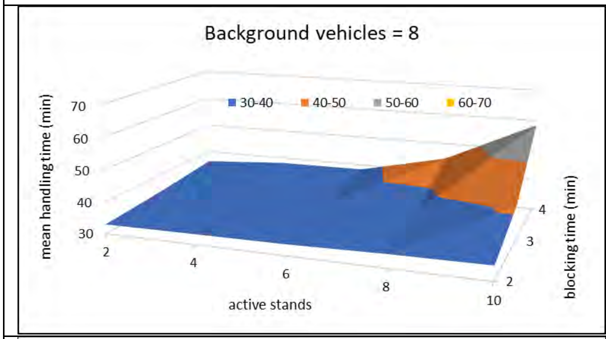
Table 3.5. Numerical values of runs 4-6, 16-18 and 28-30

Input parameters									
Data set no.	4	5	6	16	17	18	28	29	30
Amount of the active stands	2	2	2	6	6	6	10	10	10
Amount of the background vehicles	16	16	16	16	16	16	16	16	16
Blocking time (minutes)	2	3	4	2	3	4	2	3	4
Simulation results (handling time in minutes)									
Min	26.55	27.74	29.75	28.61	29.33	32.35	29.12	31.93	38.47
Max	39.90	46.31	46.50	43.25	48.38	55.94	43.72	62.46	90.65
Mean	**33.47**	**34.89**	**36.89**	**34.62**	**36.62**	**42.58**	**34.42**	**42.03**	**61.38**
St. deviation	2.71	2.83	3.60	3.04	3.91	5.30	2.82	5.88	14.23

Both Table 3.6 and Table 3.7 show the results of all 30 runs of experiment 1. It can be seen that the number of "Background vehicles" which took values 8 and 16 had basically no effect on the *τ_handling* indicator. On the other hand, AC service performance deteriorates sharply in situations when the number of active stands is greater than 6, and the blocking time is more than 3 minutes.

Table 3.6. Modelling results of the dependence between handling time and three parameters

<table>
<tr><th>Mean handling time (minutes)</th><th>St. deviation (minutes)</th></tr>
<tr><td>



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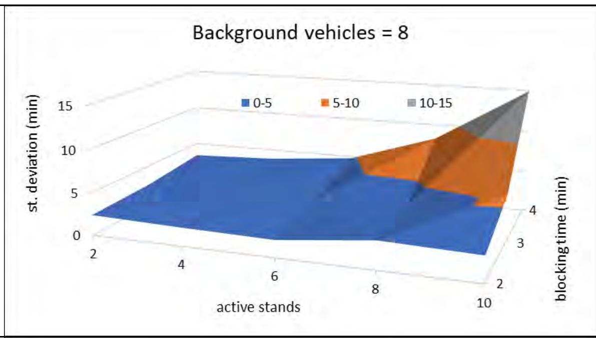
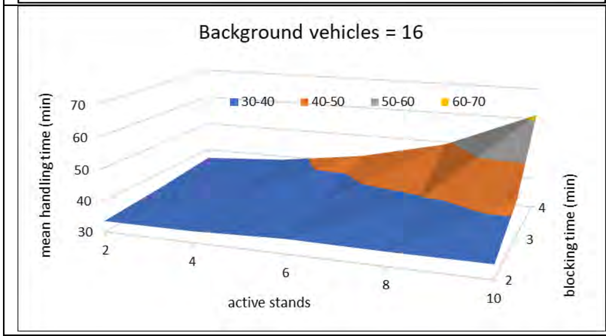
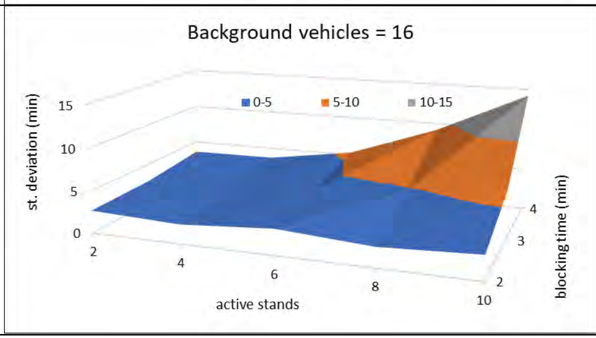


</td></tr>
<tr><td>



</td><td>



</td></tr>
</table>

Table 3.7. Numerical values of all 30 runs in experiment 1

Input parameters										
Data set no.	1	2	3	4	5	6	7	8	9	10
Simulation results (handling time in minutes)										
Min	27.43	27.33	28.37	26.55	27.74	29.75	27.58	27.75	28.96	29.14
Max	40.55	42.37	46.68	39.90	46.31	46.50	39.02	42.51	46.83	41.27
Mean	32.98	34.36	36.31	33.47	34.89	36.89	33.27	35.20	38.17	33.56
St. deviation	2.41	2.62	3.34	2.71	2.83	3.60	2.16	2.80	3.78	2.28
Input parameters										
Data set no.	11	12	13	14	15	16	17	18	19	20
Simulation results (handling time in minutes)										
Min	30.22	31.82	29.91	30.55	31.06	28.61	29.33	32.35	27.35	29.46
Max	43.60	50.07	40.47	43.61	57.74	43.25	48.38	55.94	44.68	49.06
Mean	36.17	38.71	33.51	35.97	38.38	34.62	36.62	42.58	34.18	36.85
St. deviation	2.85	3.68	2.00	2.90	4.76	3.04	3.91	5.30	3.25	3.47
Input parameters										
Data set no.	21	22	23	24	25	26	27	28	29	30
Simulation results (handling time in minutes)										
Min	32.78	30.00	31.27	33.85	28.52	30.16	35.08	29.12	31.93	38.47
Max	63.44	43.40	54.79	77.22	45.59	56.64	88.79	43.72	62.46	90.65
Mean	44.81	34.35	39.30	49.16	34.54	41.08	58.51	34.42	42.03	61.38
St. deviation	8.27	2.32	4.88	9.13	2.96	5.64	14.89	2.82	5.88	14.23

3.3.4. Experiment 2: evaluating the GV priority level's influence on the duration of the AC service

As it was mentioned in the description of the conceptual model (see the section 3.3.1), it is quite possible in the simulation model to assign one of the priorities (1, 2 or 3) to the GV groups that serve a certain stand. All runs of the experiment 1 were performed with the same priority 1 for all active stands. The purpose of the experiment 2 is to test the effect of the priority level on the main AC service indicator, namely, the value of $\tau_{handling}$.

If GV has a priority 2 and it is already queued in the first place, and the others waiting for GV in different queues have priority 1, then releasing the corresponding sectors of the intersection, this GV will be skipped as the next one. As the trial runs of the model showed, the actual frequency of such situations to occur is very low, therefore, the service indicators of stands with priority 2 were practically the same as for those with priority 1. Such effect is explained by that fact that those trapped in a GV with a priority of 2 remain in this traffic-jam along with the remaining GVs with priority 1 or 2.

The introduction of Priority 3 provides a fundamentally new opportunity to overcome congestion at intersections. GVs with priority 3 simply do not stand in the common queue sharing it with GVs of priority 1 or 2, on contrary, GVs with priority 3 would use an additional overtaking line (see Figure 3.12). In experiment 2, it was assumed that priority 3 is obtained by GVs that serve only one particular stand, and the remaining GVs have priority 1. For this reason an attempt to check whether shorter time $\tau_{handling}$ may be provided for such ACs that must leave the airport as soon as possible, for example, due to the current flight delays. The results of this analysis are presented in Figure 3.19.

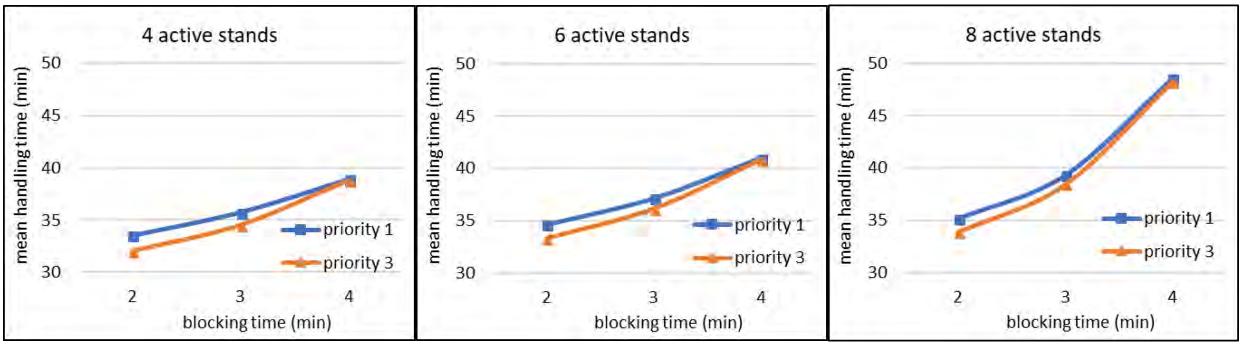


Figure 3.19. The priority level assessment for AC's service time

The simulation results demonstrated in Figure 3.19 indicate that a minor effect from the introduction of priority 3 is observed only if the blocking time does not exceed 3 minutes. Even such an effect cannot be considered as significant, since the value of "mean handling time" decreases by only 2-3 minutes. For large values of blocking time, the GV delay is affected mainly by the pauses that occur during a moving AC is missing. However, the intersection strategy does not give arise to such an effect. At small values of blocking time, the effect is also small, since the probability of situations when GV with priority 3 is actually overtaking other waiting GVs is insignificant.

3.4. Conceptual model of ground transport processes in a cargo terminal

The object of modeling are the processes of handling cargo flows in a large aviation hub. In such a hub, the “cross-docking” principle is applied for the cargo flows’ reception and distribution between several spatial locations. Each single night, approximately 50 cargo planes are loaded with cargo containers (the so-called ULDs). The cargo is first transported to the warehouse premises, and then loaded into the corresponding aircraft. Depending on the type of aircraft 30 to 60 ULD are loaded on the board.

The model displays the following types of moving objects: airplanes, ULDs, Dolly carts for ULD transportation and Tug tractors, which pull "trains" made up of several Dollys. The following types of static objects are defined in the simulated space: Dolly Pool, Tug Pool, Transport Channels for Aircraft, Transport Channels for Tugs, Stands and Warehouse. This set of static objects is shown a symbolic form in Figure 3.20.

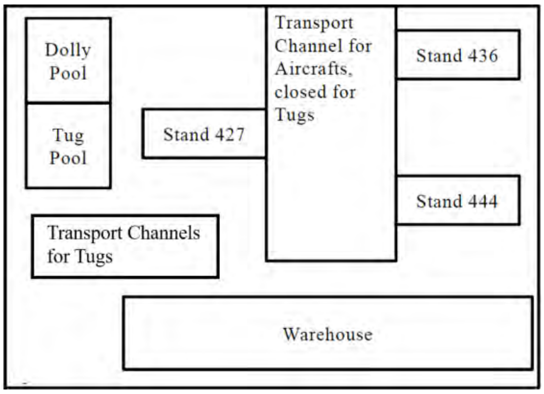


Figure 3.20. The structure of model’s strategic objects (Brandau and Tolujevs, 2013)

The logistic goal of the simulation was, firstly, the estimation of the time for performing all cargo transshipment operations and, secondly, the verification of the possibility to send all the loaded aircraft according to the available schedule.

The main modeling task is related to the study and interpretation of information flows on the cargo terminal of the airport, assuming that there is a technical capability for recording all possible events related to both vehicles and cargo units of the ULD type. Under such events the meaniug first of all, changes in the location of any mobile objects. Events are recorded in the form of protocols, each entry in which (the protocol line) contains a timestamp, along with the information about the event type and the list of objects participating in it. The data set in the time intervals between events describes the current state of both mobile and static objects. In this regard, the concepts of event and state are leading in procedures for interpreting the processes of cargo handling at the airport. It is assumed that the flow of event-related data can be processed automatically, which will allow the dispatcher managing cargo flows to make decisions more quickly and reasonably.

In simplified form, the goal to model the data flows can be defined as follows. To have access to a complete information at anytime (a) on the location of all mobile objects (cargo and vehicles) and (b) on the current contents of both vehicles and static airport facilities.

The goods' conditions of type ULD means that they belong to one of the moving or static objects. The state of vehicles such as Aircraft, Tug and Dolly is determined by two parameters. Firstly, the current location and, secondly, the number of other mobile objects associated with them. The state of static objects is determined by the number of mobile objects in their space. Each event gives a rise to a change in the state of at least two objects: the mobile object changes its location, and one or two other objects change their current content. The structure of the spatial relationships between all types of objects in the model is demonstrated in Figure 3.21.

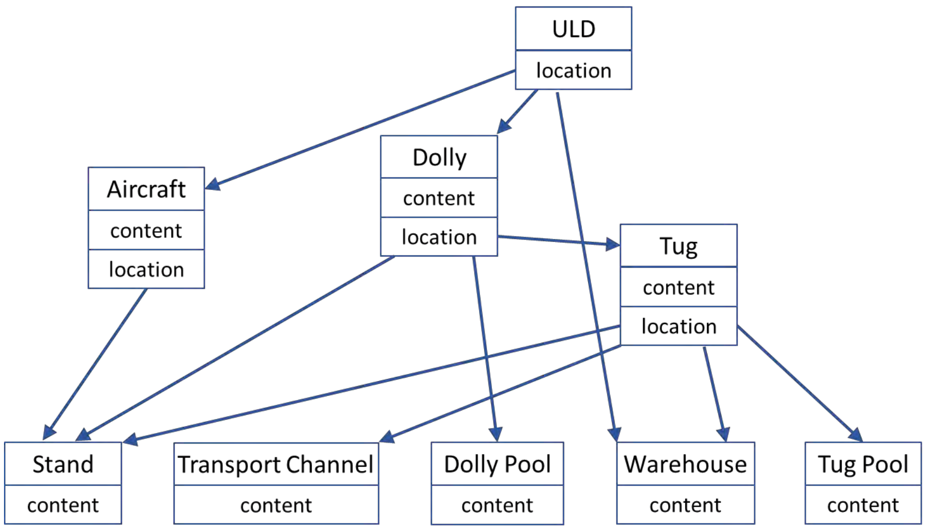


Figure 3.21. The structure of the spatial relations between models

Examples of values for the "location" parameter for objects of type ULD are the following:

– ULD is on the board of the Aircraft;

– ULD is on the board of the Dolly;

- ULD is inside the Warehouse.

Examples of values for the “location” parameter for objects of type Dolly are the following:

- Dolly is on one of the Stands;
- Dolly is inside the Dolly Pool;
- Dolly is attached to one of the Tugs.

With the same approach values for the “location” parameter for objects of type Aircraft и Tug are defined.

For example, the following two events can be considered:

- ULD is replaced from the board of Aircraft to Dolly, as the result the states of the following objects change:
  - the “location” parameter for a particular ULD changes;
  - the number of objects decreases, namely, the “content” parameter of Aircraft changes;
  - the number of objects increases, namely, the “content” parameter of Dolly changes.
- Tug with the attached Dollies starts the movement from Stand to the Warehouse, as the result the states of the following objects change:
  - the “location” parameter for a particular Tug changes;
  - the number of objects decreases, namely, the “content” parameter of Stand changes;
  - the number of objects increases, namely, the “content” parameter of Transport Channel changes.

The model assumes that AC occupies a certain Stand, after which two phases of service are executed:

- All the ULDs delivered by this AC are unloaded and transported to the Warehouse facility using Dolly and Tugs;
- After some time, other ULDs are transported from Warehouse to this Stand using the Dolly and Tugs. Loading of the AC follows next, after which AC leaves Stand.

As it was mentioned above, the simulation model should provide complete information about the events and the state of mobile and static objects as the modeling result.

3.5. Modelling and interpretation of data flows reflecting processes in the ground transportation system

In the simulation model, only those AC maintenance operations that are related to Stand 427 and Stand 436 are taken into account (see Figure 3.20). In this regard, only four paths are defined as Transport Channels for Tugs:

- St427-W and W-St427 ways for trips from Stand 427 to Warehouse and vice versa;
- St436-W and W-St436 ways for trips from Stand 436 to Warehouse and in the opposite direction.

In order to reduce the volumes of data in the event and state logs, the model shows no events related to the application of such static objects as Dolly Pool and Tug Pool.

3.5.1. The development of the simulation model

The simulation model was developed with using simulation software according to the "discrete event" process modeling paradigm. The model's layout is shown in Figure 3.22. The main part of the model is developed using only four types of blocks, shown in Table 3.8.

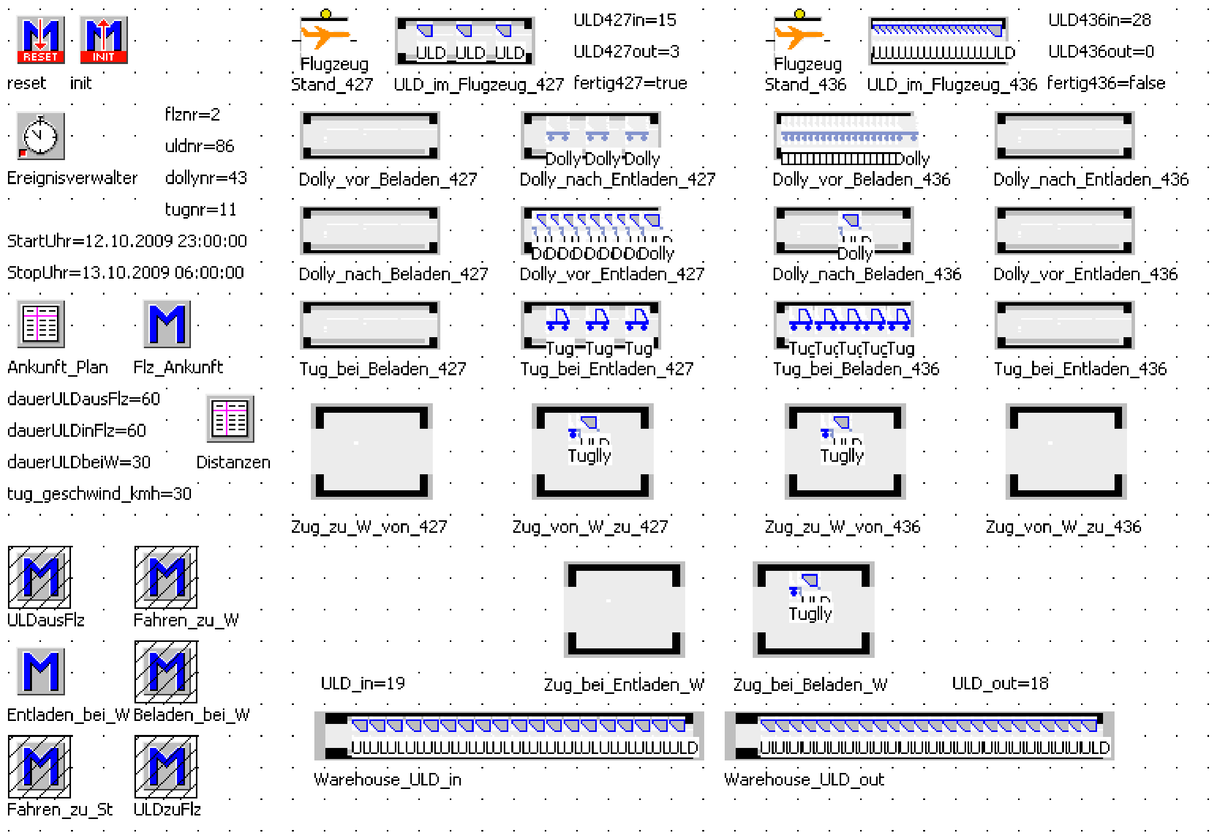
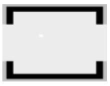
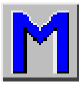
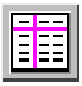


Figure 3.22. The structure of of a cargo terminal's simulation

Table 3.8. Main blocks of a cargo terminal's simulation model

Graphic image	**Block name**	**Executed functions**	**The number of blocks in the model**
	***Place***	– stand, i.e., a place in a model that can occupy one AC	2
	***ParallelProc***	– space inside the AC, in which ULDs can be located – place near the Stand to accommodate any number of Dolly waiting for the loading or unloading – place near the Stand or Warehouse to accommodate any number of Tugs waiting for loading or unloading of the Dollies attached to them – Transport Channel, i.e. The way in which any number of Tugs with Dollies attached to them are allocated – the space inside the Warehouse in which the ULDs delivered from the AC or intended to be sent to the AC are located	22
	***Method***	– program to control the arrival of AC on various Stands – program management software for loading and unloading Dollies near Stands or Warehouse – the traffic generation and traffic management programs for "trains" consisting of Tugs and Dollies	9
	***Table***	– AC arrivals schedule – table of distances between the points of the transport network	2

All the programs encoded in blocks of type *Method* not only control the movement of AC, ULDs, Tugs and Dollies, but also provide data collection in the form of event logs and states of model objects. Such protocols are generated and stored in text format.

3.5.2. Experiments with the model

The simulation model that was developed using Plant Simulation software allows user to observe all the changes in the location of mobile objects of the model in the form of 2D animation. Figure 3.22 shows a situation that may be interpreted the following way:

– there is AC with the name *FLZ1* on Stand_427;

– 15 ULDs are uploaded from *FLZ1* (the value of the variable *ULD427in* = 15)

– the ULD transportation process from *Stand_427* to Warehouse has already been completed, since all model blocks (*Dolly_vor_Beladen_427* and others) created for this are empty;

- the ULD transportation process from Warehouse to *Stand_427* is currently underway, since icons of mobile objects Tug and Dolly can be observed in the model blocks assigned to this (*Dolly_nach_Entladen_427* and others);
- 3 new ULDs are already on board of *FLZ1*; they can be seen in the *ULD_im_Flugzeug_427* block; this number also shows the variable ULD427out = 3;
- the *Warehouse_ULD_in* block shows the number of ULDs received from AC, such a number is shown by the variable *ULD_in = 19*;
- the *Warehouse_ULD_out* block shows the number of ULDs transported for loading onto the AC. Such a number is presented by the variable ULD_out = 18;
- the *Stand_436* includes AC with the name *FLZ2*, which has delivered 28 ULDs; For *FLZ2* operations are carried out in order to transport ULD to Warehouse.

Simulating the processing of only two ACs on Stand 427 and Stand 436, thousands of events were recorded in the protocols. Table 3.9 and Table 3.10 demonstrate examples of simulation results that include the following:

- only to one AC with the title *FLZ1*, which is located on the Stand 427;
- only to one Tug with the title *TUG1*;
- only to one Dolly with the title *DO1*.

In a joint analysis of the data from Table 3.9 and Table 3.10, the relationship between events and the new states that arise after them may be seen.

For *FLZ1* the following relationship between the first events and the corresponding states shown in Table 3.9 and Table 3.10 may be defined:

- at the moment of time 23:00:00 the event "*FLZ1-Arrival-St427*" is recorded; the result of such an event is the state "*FLZ1-St427-Waiting*";
- at the moment of time 23:00:00 the event "*FLZ1-Start-Unloading*" is recorded; the result of such an event is the state "*FLZ1-St427-Unloading*";
- at the moment of time 23:01:00 the event "*FLZ1-ULD out-AAY*" is recorded; the result of such an event is deleting of one ULD of the type AAY from *FLZ1*, which is presented in decrypted states' protocol.

For *TUG1*, the following relationship between the first events and the states from Table 3.9 and Table 3.10 may be described:

- at the moment of time 23:04:00 the events of the type "*TUG1-Dolly in-DO1*" are recorded for Dollies with the titles *DO1-DO4*; the result of such events is the state "*TUG1-St427-Stands with 4 Dollies*";

– taking in to account the fact that one Tug can carry no more than 4-x Dolly, at the moment of time 23:04:00 the event “*TUG1-Departure-Way St427-W*” is recorded; the result of such an event is the state “*TUG1-Way St427-W-Drives with 4 Dollies*”, which literally means the beginning of *TUG1’s* ride with the corresponding *Dollies* to Warehouse along the way *Way St427-W*.

Table 3.9. Extract from the model event protocol

Timestamp	ID	Event	Parameter
	Aircraft FLZ1		
12.10.2015 23:00:00.0000	FLZ1	Arrival	St427
12.10.2015 23:00:00.0000	FLZ1	Start Unloading	
12.10.2015 23:01:00.0000	FLZ1	ULD out	AAY
12.10.2015 23:02:00.0000	FLZ1	ULD out	AAY
. . .			
12.10.2015 23:15:00.0000	FLZ1	End Unloading	
12.10.2015 23:15:57.8400	FLZ1	Start Loading	
12.10.2015 23:16:57.8400	FLZ1	ULD in	AAY
12.10.2015 23:17:57.8400	FLZ1	ULD in	AAY
. . .			
12.10.2015 23:30:57.8400	FLZ1	End Loading	
	Tug TUG1		
12.10.2015 23:04:00.0000	TUG1	Dolly in	DO1
. . .			
12.10.2015 23:04:00.0000	TUG1	Departure	Way St427-W
12.10.2015 23:04:58.9200	TUG1	Arrival	W
	Dolly DO1		
12.10.2015 23:00:00.0000	DO1	Arrival	St427
12.10.2015 23:01:00.0000	DO1	ULD in	ULD1
12.10.2015 23:04:00.0000	DO1	Departure	Way St427-W
12.10.2015 23:04:58.9200	DO1	Arrival	W
12.10.2015 23:05:28.9200	DO1	ULD out	ULD1

Table 3.10. Extract from the model state protocol

ID	From the time	Location	State
Aircraft FLZ1			
FLZ1	12.10.2015 23:00:00.0000	St427	Waiting
FLZ1	12.10.2015 23:00:00.0000	St427	Unloading
FLZ1	12.10.2015 23:15:57.8400	St427	Loading
FLZ1	12.10.2015 23:30:57.8400	St427	Ready
Tug TUG1			
TUG1	12.10.2015 23:00:00.0000	St427	Stands with 0 Dollys
TUG1	12.10.2015 23:04:00.0000	St427	Stands with 4 Dollys
TUG1	12.10.2015 23:04:00.0000	Way St427-W	Drives with 4 Dollys
TUG1	12.10.2015 23:04:58.9200	W	Stands with 4 Dollys
TUG1	12.10.2015 23:08:58.9200	Way W-St427	Drives with 4 Dollys
TUG1	12.10.2015 23:09:57.8400	St427	Stands with 4 Dollys
Dolly DO1			
DO1	12.10.2015 23:00:00.0000	St427	Stands Empty
DO1	12.10.2015 23:01:00.0000	St427	Stands with ULD1
DO1	12.10.2015 23:04:00.0000	Way St427-W	Drives with ULD1
DO1	12.10.2015 23:04:58.9200	W	Stands with ULD1

For *DO1*, the following relationship between the first events and the states demonstrated in Table 3.9 and Table 3.10 may be defined:

– at the moment of time 23:00:00 the event “*DO1-Arrival-St427*” is recorded; the result of which is the state “*DO1-St427-Stands Empty*”, namely an empty *DO1* is located near the *St427*;

– at the moment of time 23:01:00 the event “*DO1-ULD in-ULD1*” is recorded; the result of which is the state “*DO1-St427-Stands with ULD1*”, namely an empty *DO1* took ULD with the title *ULD1* on its board;

– at the moment of time 23:04:00 the event “*DO1-Departure-Way St427-W*” is recorded; the result of which is the state “*DO1-Way St427-W-Drives with ULD1*”, which means the beginning of the ride with the corresponding *TUG1* to Warehouse along the way *Way St427-W*.

Based on the protocols demonstrated in Table 3.9 and Table 3.10, employees of cargo terminal services can solve the following tasks:

1) to assess the current location of goods and vehicles along with content of Warehouse in order to make operative decisions on resource allocation (Dollies and Tugs) and to manage the flows of incoming and outgoing ULDs;
2) to perform short-term forecasting for the occurrence of control events that affect the execution of a specified schedule for processing of the received and sent ULDs;
3) to conduct a retrospective analysis of the processes of cargo handling and the movement of ground vehicles organization.

The example of operational solutions in case 1 is the redistribution of free Dollies between several Stands. If one of the Stands has an BC with a small number of ULDs, some of the free Dollies may be transported from this Stand to others. In case 2 the ending time of the unloading or loading of a particular BC may be calculated in advance, considering the ULD’s transportation rate. If this time is significantly less than the set schedule, the number of Dollies and Tugs can be increased to speed up the processing of this particular BC.

In case 3, for a specific night shift, a visualization of the processes of handling cargo flows may be created along with the movement of ground vehicles in the form of an animation film. It will be possible to observe both the processes of delay and accumulation of vehicles at different points of the cargo terminal as well as the waiting states in which the aircraft may be located, if there are not enough resources allocated for the processing. All the processes of movement and accumulation of goods and vehicles may be estimated by quantitative indicators calculated using the methods of mathematical statistics.

CONCLUSION

1. The research is dedicated to the development of methods and tools which allow simulating and evaluating the characteristics of the ground handling transport system in the airports over different ways of movement management of individual ground handling vehicles.
2. The research rewiews objectives related to the development of the transport processes in the airports within the framework of national and international projects, as well as the activities and researches of individual scientists and specialists in this field. The aircraft (AC) flight delays were stated as the main problem, due to lacking efficiency of operation with the ground handling vehicles (GV), which take a part in handling of the AC and preparing it to the next flight.
3. The research demonstrates that in case of resources sufficiency that are required for handling of the AC, particularly the improvement of transport process could positively affect the maintaining of preplanned handling time. In its turn, under the specified configuration of transport network, the establishment of new management principles which are based on constant monitoring of the location and state of each vehicle were used as a method to influence the transport process.
4. The task to study the dependence of AC handling time on the ways of traffic organization of GV was formulated. And the substantiation of the necessity of using the computer simulation methods was given as the task solution.
5. This reaserch outlines an comprehensive review of all types of the ground handling transportation support processes at the airports at which the computer simulation was used for the task solution. The simulation paradigms which were used to create the models of transport processes in the airports are described in detail. These paradigms appertain: “continuous”, “discrete event” and “agent based”.
6. Two classes of software were considered. In such simulation software that may be used to create such models and to the justify the decision of selecting the General Purpose Simulation Software as a tool for solving problems of alternative management methods analysis of the movement of ground vehicles It is shown that this class of software has advantages over the Airport Simulation Software, mainly in the case where by using the model, a new non-standard movement management algorithms of ground vehicles GV should be investigated.
7. By using the computer simulation, three main tasks of the ways to organize the ground vehicles movement in airports were analyzed:

- assessment of the impact of the size of the bus fleet of passenger’s transportation on the time of aircraft handling;
- assessment of the impact of traffic parameters and the ways of organizing passing the intersections in the transport network of the aerodrome on the time of aircraft handling;
- deriving and interpreting traffic data on the movement of vehicles and cargo at the airport's cargo terminal.

8. Creation of each model starts with the development of detailed conceptual model of the researched processes. Furthermore, the decision on using certain simulation software was made, then the programming of the model was done. After testing the created model, it was used for performing numerical experements and then a semantic interpretation of the results of experements was given.
9. The experience of applying simulation modeling, obtained by solving problems of analyzing the ways of GV movement organization in airports, confirms the effectiveness of General Purpose Simulation Software application. In both developed models all the factors which were chosen for the analysis that affect the handling time of the aircraft used for transportation of passengers were taken into account. In the model of a cargo terminal is shown a way of obtaining of event and state protocols of both vehicles and cargo units at the highest possible level of detail. The main objective of obtaining this kind of data flows is the development of fundamentally new methods and tools to support the work of ground handling managers responsible for cargo handling at the airport
10. As a further study, the development of the models for the transport process for the Riga International Airport is expected, taking into account the plans for expanding its territory and its transport connection with the Rail Baltica infrastructure.

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