TRANSPORT AND TELECOMMUNICATION INSTITUTE

MARINA REBEZOVA

LOGISTICS AND OPTIMIZATION OF ANCILLARY AVIATION SERVICES ON AIR TRANSPORT

DOCTORAL THESIS SUMMARY

To obtain the scientific degree Doctor of Science in Engineering

Scientific area “Transport and Communications”
Scientific subarea “Telematics and Logistics”

Scientific supervisor:
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Aleksander Andronovs

RIGA - 2017

UDK 656.7.072
R 30

Transport and Telecommunication Institute

Rebezova M.

Logistics and optimization of ancillary aviation services on air transport: Summary of the promotion work. Riga: Transport and Telecommunication Institute, 2017.

In the submission kept the author’s style and design.

ISBN 978-9984-818-71-9

THE PROMOTION WORK PRESENTED TO THE TRANSPORT AND TELECOMMUNICATION INSTITUTE TO OBTAIN THE SCIENTIFIC DEGREE – DOCTOR OF SCIENCE IN ENGINEERING (Dr.sc.ing.)

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The defence of the thesis will be held at July 05, 2017 at 14.00 o'clock at the special Promotion Council of Transport and Telecommunication Institute on award of a doctor's degree at 1, Lomonosova Street, Conference Hall 130, Riga, Latvia, tel. +371 67100594, fax: +371 67100535.

CONFIRMATION

I hereby confirm that I have developed the promotion work that is presented to the Promotion Council of Transport and Telecommunication Institute to obtain the scientific degree of Doctor of Science in Engineering. The promotion work has not ever been presented to any other promotional council to obtain the scientific degree.

________, 2017 M. Rebezova

The promotion work is written in English, it contains an introduction, 5 chapters, conclusions, 22 figures, 42 tables, 148 pages, and 3 appendixes. Bibliography contains 105 sources.

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ABSTRACT

The thesis of Marina Rebezova «Logistics and optimization of ancillary aviation services on air transport». The scientific supervisor is Dr. habil. sc. ing., professor Alexander Andronov.

The main purpose of the research is to develop a methodology for making up a set of ancillary non-aviation services (AS) offered by air passenger transport enterprises (air carriers), the registration of which is carried out with the standard traffic documents of Global Air Transport Settlement Systems, as well as to optimize the logistics of processing such service sales figures.

The work describes the sales experience and management of financial settlements for ancillary non-aviation services in one of the world settlement systems, officially named by IATA (International Air Transport Association) «Air Transport Settlement System – Transport Clearing House» (ATSS – TCH). The required statistical and optimization studies were conducted; the obtained results were summarized; the mathematical models for selection and formation of the whole range of ancillary non-aviation services have been proposed; the scientific and methodological fundamentals for organizing sales of ancillary non-aviation services, logistics and technologies of financial settlements for sold ancillary non-aviation services have been developed; recommendations for practical implementation of the developed tools at air transport enterprises have been made.

The thesis materials contributed to the refinement of ATSS-TCH standards, Technology of settlements and upgrading of training manuals on ATSS-TCH for universities of civil aviation.

The results obtained are of universal nature; they can be applied by carriers of other transport modes.

The main research results were presented at 5 international scientific and research conferences and formulated in 18 scientific publications.

ABBREVIATIONS

AA	Accredited Agency
ACCS	Airline Control Council of Settlement
AT	Air Transport
ATSS-TCH	Air Transport Settlement System – Transport Clearing House
CA	Civil Aviation
CET	Centre of Electronic Ticketing
CRS	Computer Reservation System
EMD	Electronic Miscellaneous Document
ET	Electronic Ticket
GDS	Global Distribution System
IPS	Internet Point of Sale
IS TCH	Information System of Transport Clearing House
IT	Information Technologies
MCO	Miscellaneous Charges Order
SII	System of Interactive Interchange
SIR	System of Interactive Reporting
SRSS	System of Rail Service Sales
SSC	Settlement System Conference
STD	Standard Traffic Document
TCH	Transport Clearing House
WSS	World Settlement System

1. THE PROBLEM STATEMENT AND RESEARCH JUSTIFICATION

At present, multi-level channels for distribution of services under various logistics schemes, one of which is «airline - consolidator - agent», are widely used on air passenger transport. In recent decades, the most effective consolidators are the world settlement systems (WSS). Their distinctive features are as follows:

- usage of their own standard traffic documents (STD), neutral in relation to carriers, introduced by the relevant resolutions of IATA (International Assotiation Air Transport), used for issuing sold services and accepted by all participants of the corresponding WSS (airlines and accredited with WSS travel-agents (hereinafter – agents));
- booking and selling services only through the global distribution systems (GDS), that are accredited with WSS and don't provide competitive advantages regarding service retailing for none of WSS participants;
- usage of unified information technologies (IT) to carry out financial settlements for sold services between WSS participants within each WSS.

WSS provide significant cost saving for airlines, when creating their own representative and agency environment.

Currently there exist three WSS in the world:

- ASP (Area Settlement Plan) – operating mostly in the USA and the Virgin Islands under the control of the U.S. corporation ARC (Airlines Report Corporation);
- BSP (Bank Settlement Plan) – operates under the authority of IATA (International Air Transport Association) and almost worldwide, except for the USA;
- ATSS-TCH (Russian Air Transport Settlement System) – operating mostly in the CIS under the leadership of Transport Clearing House (TCH).

Each of these systems emits its own standard traffic documents (STD forms). The following traffic document are the main:

- Electronic Tickets (ET) used for issuing the basic service – passenger transportation;
- Electronic Miscellaneous Documents (EMD) used for issuing ancillary aviation and non-aviation services.

Over 60% of services of the world air passenger transport are sold on the amount of more than $600 billion through the settlement systems' channels («accredited agency – sub-agent»/GDS).

The world air passenger transport continues to develop sustainably with average annual increase of up to 5%. However, the financial status of traditional airlines is very bad. The reports of General Director of IATA at the annual general meeting shows, that over the past period traditional airlines have accumulated debts at a rate of about $200 billion, of which about $50 billion over the past decade.

At the same time, discount (low-cost) airlines, not included in IATA's statistics, show increasing volume (currently up to 25% of the total passenger transportation volume) of carriage and profitability of their activities in contrast to traditional airlines. Such a result is achieved by using new business models that are characterized mainly by the following:

- «total» minimization of expenditures for all types of intercompany activity and aviation services;
- usage only of direct channels for service distribution through its own branches and representative offices in the online and offline modes;
- excluding some services, previously added to the main package at the base fare, and offering these services separately, as chargeable ancillary ones;
- qualitative expansion of the range of ancillary non-aviation services.

Traditional airlines cannot fully take the «way of discount airlines» and use their business models, as they have their own passenger cohorts with their needs and habits, service quality standards and greater financial abilities. However, traditional airlines have begun to borrow some new business-models' options for passenger service. Such options include the following:

- excluding some services (excessive baggage, online check-in, meal on the board, a seat at the window, etc.), from the standard service package and granting them to passengers separately, as chargeable ancillary ones;
- expansion of the range of ancillary non-aviation services, including transportation by adjacent modes of the ground transport, hotel booking, car rental, insurance services, etc.

It should be noted, that in 2009 many airlines started to distribute the content of their ancillary service packages in XML format through their web-sites. The sphere saw the opening up of a new market of ancillary aviation services on passenger transport, which allowed traditional airlines to gain more than $50 billion of additional profit only within the year of 2014.

Thus, nowadays, the expanding range of ancillary aviation and non-aviation services, created and sold by both airlines themselves through their direct channels with issuing their own traffic documents and through settlement systems' channels with issuing STD forms, is one of the main ways to increase the profitability of traditional airlines, as well as to develop settlement systems' business and their accredited agencies.

IATA resolution 787 of 2012 concerning the NDC (New Distribution Capability) project emphasizes the significance of the issue being discussed. This resolution is mainly aimed at elaborating a new standard for message and product exchange to ensure the technological support for reservation and retailing of ancillary services on air passenger transport.

2. THE OBJECT AND SUBJECT OF THE RESEARCH

The objects of research are pre- and post-sales processes in the back offices of airlines and settlement systems for the formation of ancillary services and strategies for their promotion in the market, development of technologies and project networks for document processing (when retailing these services along with air transportation ones), settlements, monitoring and assessment of risk level of travel agencies’ financial insolvency.

The subjects of research are the models and methods for optimization of pre- and post-sales processes in the airlines’ back offices and settlement systems along the whole chain: «formation of optimal sets of ancillary services offered for sale → processing the outcome of ancillary services sales → mutual settlements for sold ancillary services → monitoring of travel agencies’ activity».

3. THE PURPOSE AND OBJECTIVES OF THE RESEARCH

The purpose of the research is to develop a methodology to optimize the development of ancillary non-aviation services sold in conjunction with aviation services, their logistics and processing of the sales outcome.

To meet the target, the following **tasks** of the research subject have been tackled:

1. To develop a methodological foundation for logistics of AS sales on air transport and a technology of financial settlements for the sold services, with regard to airlines and agencies retailing services in the neutral environment of ATSS-TCH.
2. To conduct a statistical analysis of AS forming and selling in the international market of travel and tourism services.
3. To identify the thorny issues arising, when forming non-aviation AS in conjunction with aviation services and optimizing their content, as well as the processes and technologies of mutual payments.
4. To develop an optimization stochastic model for project selection called for forming non-aviation AS along with aviation services at air transport enterprises (airlines, settlement systems), taking into account restrictions for total expenditures over the planning period and cost synergy to reduce expenses on simultaneously retailed basic and ancillary services.

5. To build a mathematical model for solving the problem of settlement of mutual liabilities, while making mutual payments in case of combined retailing of aviation services and ancillary non-aviation ones on an air transport enterprise.
6. To design a mathematical model for solving the problem of allocating time to complete all the tasks of the project network needed to make mutual payments for joint retailing of aviation services and ancillary non-aviation ones.
7. To develop a stochastic model for provisionally estimating the risk level of agency's insolvency, taking into account both external and internal factors with respect to a particular agency.
8. To develop computer programs and to conduct numerical experiments with the use of the constructed mathematical models on the ground of actual data regarding ATSS-TCH.

So, the essence of the **conceptual approach** is as follows: on the ground of the statistical analysis of AS sales, trends, problems and prospects of their development, to develop corresponding mathematical models, to analyze and to apply them for solving the considered problems at an air transport enterprise, as exemplified by AS sales in the neutral environment of ATSS-TCH.

4. THE SCOPE OF THE THEME ACADEMIC COVERAGE

The complexity of solving the research tasks for the stated problem consisted in the following aspects:

1. The lack of experience in organizing, designing statistical and economic models of retailing ancillary non-aviation services in the neutral environments of the international leading settlement systems – BSP IATA and ASP ARC.
2. The restricted access to theoretical research materials of the world leading settlement systems – BSP IATA and ASP ARC, due to commercial confidentiality.
3. The need for generalization of the initial experience of AS sales and settlements for sold services in the ATSS-TCH neutral environment, selection of appropriate models to put forward an operation research theory and their application for solving the stated optimization problems.

Thus, the following problems were solved in ATSS-TCH, with the author's participation:

- first, the problems of establishing methodological principles for organizing, ensuring logistics and working out the technology of mutual payments for the sold ancillary non-aviation services;
- then, the problems of statistical and optimization studies,

- further, the problems of summarizing the obtained results and analyzing possibilities of their future application by other WSS and airlines.

It must be noted, that the fundamentals for the ATSS-TCH organization (initially titled as «Airlines Clearing House»), originally based on the ASP ARC solutions, were laid down in 1990 by the team of scientists led by A. Fraiman in the former Central Scientific Research Institute of Automated Control Systems of Civil Aviation (Riga). The formation history, maintenance means and the current state of ATSS-TCH have been described in detail in the TSI textbook «The fundamentals of the ATSS-TCH» (the author's self-translation) edited by E. Maharevs and in the textbook for students of Russian Universities «An introduction to the ATSS issues» (the author's translation) edited by E. Maharevs, S. Ilichev. The materials provided by the author of the thesis have been included into several sections of these textbooks. Some methodological issues have been investigated in the works by E. Drozd, V.Klubov.

The regulations governing the ATSS-TCH activity are based on approximately 100 TCH standards applied for service reservation and making mutual payments by all ATSS-TCH participants, including Latvian Airline «Air Baltic», other EU airlines and some accredited EU agencies. The idea to organize the retailing of ancillary non-aviation services in ATSS-TCH has been based on the regulations and technologies specified in the relevant IATA resolutions, regarding the introduction and processing of the neutral Miscellaneous Charger Order (MCO) in 2006, the electronic Miscellaneous Charger Order (EMCO) in 2008 and the neutral Electronic Miscellaneous Document (EMD).

Despite the adoption of the mentioned IATA resolutions, especially on such an important document as EMD, BSP IATA and ARC have not applied EMD for retailing ancillary non-aviation services in their neutral environments until now.

The methods and technologies used for retailing ancillary non-aviation services, such as services offered by passenger railway companies or major US tour operators in ASP ARC, are corporate ones, that is the sale is not made using the technologies of a neutral environment. As a result, the majority of methods and technologies, governing the retail sphere of ancillary non-aviation services, turns out to be of a corporate (not neutral) nature. Theoretical substantiations of the optimization problem solutions in this area remain confidential and are not available in the open press. The first ancillary aviation services issued on EMD ARS and EMD BSP date back to late 2011. In its turn, ATSS-TCH has become the first settlement system in the world that implemented the option of issuing ancillary non-aviation services on EMD in late 2008 already.

In general, it is clear, that the methodological principles to organize the retailing of ancillary non-aviation services and payments for the sold services in the WSS neutral environment should be based on the existing methods for retailing and payment processing technologies. It is dictated by both technological and economic considerations. Principles and Technologies for organizing sales of ancillary aviation services and processing mutual payments for the sold services are thoroughly elaborated and reflected in the corresponding resolutions of IATA and IATA's Conference papers devoted to: passenger transportations handled with electronic tickets and EMD, as well as providing ancillary aviation services in conjunction with passenger transportations. These documents have been developed by IATA experts, commercial specialists of world's leading airlines, as well as experts of GDS, such as Amadeus, Galileo and Sabre. It should be emphasized, that the coordinating role in approaching this problem belongs to the experts and heads of IATA departments: Brian Pearce, Eric Leopold, Sebastien Touraine, David McEwen, Jane Watkins, Thibant Ruy, Daniel XU, Enrique Wallace.

Based on the above mentioned, the problems of creating, combining, supporting and controlling the processes of introducing, implementing, as well as development prospects of ancillary services sales in ATSS-TCH, came to the forefront and demanded a detailed study in due time. The methodological study of the problems, regarding the management of retailing air passenger transport services and international IT of IATA, ATSS-TCH standards developed on the basis of IATA standards and IT of IATA have been the initial methodological base for organizing the retail and processing financial settlements for the sold ancillary services in ATSS-TCH. Since 2007 the regulatory base regarding the retail of ancillary non-aviation services in ATSS-TCH has been replenished by dozens of standards and IT. These normative-technological documents have been drafted under the authority of TCH experts (including the author of the thesis) and under the leadership of A. Russ, T. Traschenko, T. Kondrakhina, as well as by experts of the private limited liability company «IT for civil aviation» (the author's self-translation) under the direction of S. Gorin and V. Mogilin.

Almost five years' experience of sales and financial payments for the sold ancillary services has been generalized methodologically and statistically. As a result, the tasks of optimizing processes, selecting and applying the corresponding mathematical methods of Operation Research for solving the optimization tasks and developing software for the numerical analysis of the results have been formulated. When formulating and setting the optimization tasks, the author of the thesis was guided by the fundamental works providing an insight in the Theory of Operating Research and Graph Theory (by M. Krass and B. Chuprinov, B. Murtagh, N. Christofides, M. S. Swamy, K. Thulasiraman, M.E. Porter, P.C. Gilmore and R. Gomory, T. Hu), R.Braudly, M. Vanhoucke, S.Mukherjee and K. Basu, R. Wadzinski, O. Ore, S. Kotz, S. Nadarajah). The problems, which are close in formulation to the tasks considered in the thesis (the tasks of revenue management and network planning for air transport, the tasks of clearing operations in general), have been investigated in the works by A. Andronovs, R. Cross, R. Shumsky, W. Simon and S. Netessine, R. Surinov, L. Zamkova, N. Kalitkin, D. Burian, S. Veremeenko, M. Lunev, S. Zuhovickiy (the corresponding references can be found in the text of the thesis).

When describing the reservation processes, the author of the thesis also turned to Mrs. K. Gitendorf, General Manager of Amadeus Latvia and President of Association of Latvian Travel Agencies, for advice and practical assistance.

While conducting the research, the author became aware of the necessity to reformulate some standard problems. So the classical knapsack problem, that was applied when selecting development projects in the sphere of air transport services for the planning period in conditions of limited investments, has been formulated regarding the synergetic effect from jointly implemented projects. Moreover, the classical knapsack problem has been formulated in the stochastic setting. Solving the problem in such formulation showed the ambiguity of optimal decisions depending on the selected criteria: maximization of the average income or minimizing the ruin probability.

The very difficult task of optimizing mutual settlements between numerous participants has been reduced to a simpler task of repayment of mutual liabilities on a graph, which can be solved by the standard linear programming packages.

A distinctive feature of the developed model, aimed at obtaining activity time distributions for all the activities at a network diagram of processing mutual settlements for combined retailing of aviation services and ancillary non-aviation services in the WSS neutral environment, is the application of polynomial approximation. The introduction of this aspect has allowed to describe different activity time distributions on both performing individual tasks, as well as their combinations, in a uniform manner.

For the first time, a financial risk assessment tool for airlines and settlement systems has been presented. This tool allows to assess risks, that can arise from travel agencies' activity, using the method of multifactorial analysis of the corresponding indicators.

5. METHODOLOGY AND THE METHODS OF INVESTIGATION

Methods of mathematical statistics and operations research have been mainly used in the thesis for setting and solving problems. In particular, in the conducted researches the following mathematical models are applied:

- processing of statistical data;
- graphs;

- network planning and management,
- multivariate analysis.

The following methods have been used for solving the set tasks:

- Graph Theory;
- Regression Analysis;
- Linear programming;
- Integer programming.

Various relevant researches, including scientific literature, methodological and educational literature, scientific and technological literature, collections of scientific papers and the proceedings of international conferences of Transport and Telecommunication Institute (Riga), international IT standards regarding settlements and e-Commerce on air passenger transport in the WSS neutral environment, IT standards of ATSS-TCH, the materials of IATA's general annual meetings and materials of public debates in the mass media, regarding the acute problems of developing the world air passenger transport, have afforded ground for the thesis.

The normative documents; information and analytical material and standards of IATA, ATSS-TCH and GDS services providers have constituted the information base of investigations.

Numerical experiments were conducted to verify the adequacy of the problem formulations and methods for solving them were proposed. Herewith the software developed by the author of the thesis and coded using the MathCAD software package was applied. Additional calculations using standard linear programming packages were performed.

6. SCIENTIFIC NOVELTY OF THE RESEARCH

A scientific and methodological basis for handling the retail of ancillary non-aviation services and settlements for the sold services has been developed. The work's scientific novelty consists in the following:

1. A complex analysis of processes of managing the retail of ancillary non-aviation services and settlements for the sold services in the ATSS-TCH neutral environment has been performed. The results obtained can also be used for developing other international air transport settlement systems, as well as airlines.
2. A document circulation technology exploited to process mutual settlements for the sold ancillary non-aviation services, integrated into the general technology of settlements in ATSS-TCH, has been developed and implemented in the ATSS-TCH standards.

3. A new (previously unknown) model of the knapsack problem within the framework of Operation Research Theory, taking into account the synergetic effect from the objects jointly loaded into the knapsack, has been developed. The algorithm and the software for solving the problem, classified as an integer programming problem in the deterministic and stochastic setting, in the context of creating aviation and ancillary non-aviation services at an air transport enterprise (applied to ATSS-TCH), have been developed.
4. A new method for calculating the performance time distribution for a set of activities of a network diagram has been developed. The applied polynomial approximation of the performance time distribution functions for both individual activities and their combinations allows to describe different distributions in a uniform manner.
5. A mathematical model for mutual settlements, allowing to minimize the number of bank transactions when doing repayment of mutual liabilities by WSS participants, has been developed.
6. A model for the problem of travel agencies monitoring has been developed on the base of the multivariable forecast of their activity indexes to assess the risk danger level of an agency's financial insolvency (default).

7. THE WORK PRACTICAL VALUE AND IMPLEMENTATION OF THE RESULTS

The practical value of the thesis investigations consists in the following developed instruments:

- technological schemes of document circulation when processing the settlements for the sold ancillary non-aviation services, including: mainline railway passenger transportations by trains of «RZD» (including the route Riga – Moscow and Riga – St. Petersburg), transportations between a city and the airports by trains of «Aeroexpress», hotel services, insurance services in ATSS-TCH;
- the software allowing: to optimize the content of basic and ancillary aviation services in conjunction with ancillary non-aviation services at an air transport enterprise, to reduce financial risks, to minimize the period of processing the settlements and the number of bank transactions when doing repayment of participants' mutual liabilities;
- some materials of the thesis investigations were included into corresponding sections of the tutorials for TSI and Russian universities.

The methodological developments and practical recommendations on the base of the thesis investigations have been implemented in the six ATSS-TCH standards, which are used by all ATSS-TCH participants, including airlines and agencies of the Baltic States and some other countries of the European Union.

8. APPROBATION OF THE RESEARCH

The main results obtained in the thesis investigations were presented at 5 research conferences: scientific, research and practical conferences and workshops held in Italy, Latvia, Austria and Russia:

1. The 12-h International Conference "Reliability and Statistics in Transportation and Communication – 2012". Riga, Latvia: Transport and Telecommunication Institute, October 17-20, 2012.
2. The Seventh International Workshop on Simulation, Rimini, Italy: 21 – 25 May, 2013.
3. The International Conference «Transport Services – 2013». Moscow, Russia: Association of Air Transport Agencies, July 3 – 4, 2013.
4. The 13-h International Conference "Reliability and Statistics in Transportation and Communication – 2013". Riga, Latvia: Transport and Telecommunication Institute, October 16-19, 2013.
5. International Conference «The Eighth International Workshop on Simulation». Institute of Applied Statistics and Computing. University of Natural Resources and Life Sciences, Vienna, Austria, September 21-25, 2015.

9. THE THESIS STRUCTURE

The thesis consists of introduction, 5 chapters and a conclusion. It has 148 pages, 22 illustrations, 42 tables in the main body of the thesis, 3 appendices and 105 publication titles in the list of bibliography.

The introduction provides arguments for the research worthwhileness. Here the purpose and objectives of the research are formulated, the object and subject of the research are stated, and the scientific novelty and practical value of the obtained results are presented.

The first chapter of the thesis contains an analysis of the current situation and services offered on international air passenger transport, trends and problems regarding the enhancement of air passenger transportation and ancillary service sales. The distribution channels of these services are considered, a brief characteristic of the world settlement systems on air transport (WSS) is presented. Special attention is given to the functions of WSS and airlines back-offices systems.

The second chapter is devoted to the development of an optimization stochastic model and a method for selecting projects to create ancillary non-aviation services in conjunction with aviation services at an air transport enterprise. The model, unlike the well-known «knapsack» problem, takes into account the restrictions on total expenses for a planning period and the synergies of reducing expenses on jointly sold basic and ancillary services. Specific examples of forming packages of services, offered for sale in the AIR Transport Settlement System – Transport Clearing House (ATSS-TCH) and an airline, using the proposed model, are considered.

The third chapter is devoted to the development of a model and a method for calculating the performance time distribution on the network diagram activities, which are different from the classical ones due to the polynomial approximation of distribution functions of positive bounded random variables. The example of the considered model approbation is given in relation to the document processing, in accordance with the developed integrated scheme of logistics and document circulation, when making mutual payments for the sold ancillary non-aviation services in ATSS-TCH.

The forth chapter is devoted to the development of a model and a method for mutual settlements on the participants' liabilities when selling services, as exemplified by ATSS-TCH and certain airlines. The problem is formulated in the terms of the Graph Theory and linear programming. A description of the algorithm for solving the problem and the developed software are presented. An example of the considered model approbation is given in relation to ATSS-TCH.

The fifth chapter is devoted to the multivariable forecast of indexes of travel-agencies' activity, that allows to estimate the risk danger level of an agency's default. The chapter contains a description of the developed method for estimating the model parameters and the risk level. A specific example of estimating the default risk level of an agency accredited with ATSS-TCH is given.

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

10. POINTS SUBMITTED FOR THE DEFENSE

The highlights that are to be submitted for the defense:

1. Generalization and an analysis of statistical indexes of international air transport enterprises' activity, which allow to justify the conclusion, that ancillary non-aviation services significantly improve the efficiency of air transport activity.
2. The statement of the optimization problem of back-office functions for processing ancillary services as a set of interrelated tasks: service creation, scheduling of document processing, settlement handling and minimizing financial risks. The developed integrated scheme of logistics and document circulation, for the purposes of processing settlements for the sold ancillary services in ATSS-TCH, is used as the basis for the complex.
3. The model and method for formation and distribution of investments among various projects for providing ancillary non-aviation services at air transport enterprises, based on the stochastic variant of the classical «knapsack» problem. The proposed model generalizes the classical problem formulation: incomes from the items, loaded into knapsack, are dependent random variables.
4. The model and method for calculating the performance time distribution on the network diagram activities. The method allows to obtain the performance time distribution for all activities, and not only the average time, as it is customary in the classical approach. The method is used for processing sales documents.
5. A new problem of the Graph Theory about an optimal set of contours and a method for its solution. The method is used when doing settlements on ATSS-TCH participants' liabilities.
6. The model for producing a multivariable forecast of travel-agencies' activity indexes. The model and method are used in ATSS-TCH for monitoring and minimizing financial risks, in case of agencies' bankruptcy.

11. SUMMARY OF THE THESIS CHAPTERS

11.1. Analysis of the State, Trends and Development Problems of Servicing on the World Air Passenger Transport

The results of the conducted analysis of the current situation and services of international air passenger transport and distribution channels of these services, trends and problems of promoting the retail of air passenger transportation and ancillary services, functions of WSS and airlines' back-office systems, showed the following:

1) At present, the services provided on air passenger transport divide in basic, associated and ancillary ones.

Basic services on air passenger transport are passenger transportations.

Associated services on air passenger transport represent a set of services offered to passengers during transportation.

Associated air services are not chargeable and are provided by the air transport company in a mandatory manner.

In recent years, the main trend of the world civil aviation regarding a potential increase in profitability is offering of ancillary paid services. Hereby, a new market – the market of chargeable ancillary services - has been formed on air passenger transport**.**

Ancillary services, fees (payment), not specified on a ticket, are divided into two groups:

- ancillary aviation services – ancillary services, directly associated with the passenger transportation or with the airline company's activity;
- ancillary non-aviation services – intermediary services related to re-sale of goods and services from other providers.

Ancillary services of **the first group** are those previously included in the basic fare and singled out from the main service, that is transportation.

Ancillary services of **the second group** are those, which are not directly related to passenger transportation.

Retailing of an ever-expanding range of ancillary services allows airlines to provide passengers with more options, and hence to get additional profit more of the same.

2) Systematization of distribution channels for air passenger transport services and their delivery to customers (passengers) allowed to distinguish the most important channels for traditional airlines; they are the world billing and settlement systems (WSS).

Over 50% services of international air passenger transport are sold on the amount of more than $700 billion through the settlement systems' channels («accredited agency / GDS»).

The overview of ATSS-TCH activity indicators has shown that Russian ATSS takes a relatively modest place among such settlement systems as ARC and BSP IATA. But, ATSS - TCH effectively competes with BSP and satisfies the requirements to service delivery set by the Russian Federation and some other countries. But, ATSS-TCH has already launched the retail of services issued on STD forms (EMD), which is an important feature for the analysis and generalization. Other settlement systems do not possess such experience. Ancillary non-aviation services are not sold in the BSP neutral environment and such services are sold in ARC, but not in the neutral environment, i.e. they are not issued on EMD, and are issued on services providers' documents.

3) **The main task** of the nearest prospects for an air transport enterprise is to sell the air transportation service in a single package with ancillary services, taking into account each

customer's preferences, got from the sales prehistory and monitored with the help of social networks.

Solving such problem reveals the need of developing the existing products of e-commerce and launching new ones, as well as applying modern technologies for distribution, which would allow to «cut out» packages of air transport services for each individual customer, to give him an opportunity to compare prices not for individual basic and ancillary services, but for comparable packages of services, when purchasing them via the Internet.

IATA announced the launch of the new NDC project (New Distribution Capability) by the Resolution № 787 at the 69th general annual meeting in 2012. NDC is a new model for distributing airlines' basic and ancillary services. The introduction process of the NDC project and its impact on the sales market of basic and ancillary services on air transport are considered in the thesis.

4) Commercial air passenger transport continues to increase the volume of transportations (Table 1).

Table 1

Number of passengers transported by traditional airlines in the world

Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Number of passengers (billions)	1.75	1.85	2.0	2.15	2.35	2.35	2.25	2.40	2.50	2.95	3.10	3.20	3.50

5) Recently, despite the significantly increasing number of passenger transportations (more than 5%) traditional airlines' financial status has been unsatisfactory. The gained profit was only about 2.2% in 2014. At the same time, over the past period, there have been losses accumulated at a rate of about $200 billion, of which about $50 billion refer to the period from 2000 to 2009 (Table 2).

Table 2

Profit (losses) of international traditional airlines

Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
* $ billions	*(14)*	*(12)*	*(7.5)*	*(5.6)*	*(4.1)*	5	14.7	*(16)*	*(10)*	16	8.8	6.7	10.6	16.4	35.3

* The figures in brackets stand for losses.

6) A new market – the ancillary service market, that gave airlines more than $30 billion of additional profit in 2012, has begun to exercise a significant influence on airlines' on financial activity (Table 3).

Table 3

Earnings from ancillary services retailed by traditional airlines

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number of airlines	23	35	47	47	50	53	59	63	no data
Earnings from sales ($ billions)	2.45	10.25	13.47	21.46	22.6	27.1	31.5	38.1	59.2

7) The Russian airlines' financial status is also unsatisfactory: the statistics show an annual increase in the number of transported passengers (excluding 2009), but at the same time their activity has remained low efficient in whole (Table 4, Table 5).

Table 4

The number of passengers transported by the Russian airlines (millions of passengers)

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
The number of passengers, (millions of people)	35.09	38.03	45.11	49.8	45.11	56.95	64.12	74.03	84.56	93.18	92,1

Table 5

Profit (losses) of the Russian airlines

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
RUB billions*	*(0.3)*	5.2	2.8	*(12)*	*(3.3)*	9.9	*(14.4)*	*(7.8)*	*22.36*	*(10.97)*	*(33.55)*

*The figures in brackets stand for losses.

8) Cardinal measures are needed to achieve a considerable increase in the efficiency of the traditional airlines' commercial activity and their profitability. One of the most important is an expansion of the ancillary services range.

9) In the present conditions, the functions of air transport enterprises' back-office systems are clearly not modified enough to ensure efficient operation. The continuously expanding range of aviation and non-aviation ancillary services for retailing and, especially, an active implementation of the NDC project, cause an increase in investments, time commitment,

labour and other expenses of air transport enterprises, related to the management of service retailing, as well as collection, processing, analysis of information about sales, report preparation, mutual payments for the sold services and the measures aimed at reducing air transport enterprises' financial risks. While the gradual extension of the service list, enterprises' document circulation, agencies' non-payment risks, and the need for circulating assets inevitably increase as well. To guarantee an enterprise's effective operation in the present conditions, the introduction of new optimization mathematical models, which have not been used in air transport enterprises' back-office systems yet, are required.

The development and implementation of optimization mathematical models are needed. When applied, such models allow:

- to form a set of ancillary aviation and non-aviation services for retailing, taking into account the existing restrictions on the given air transport enterprise's investment opportunities;
- to optimize the settlement processing;
- to reduce the document flow, when processing the sold service data and making settlements;
- to make monitoring and forecasting the sales volume and agencies' activity in terms of the completeness and timeliness of the funds transfer for the sold services in order to minimize financial risks;
- to increase the efficiency of an air transport enterprise's activity as a whole.

11.2. Development of a Model for Attracting and Distributing Investments among Projects for Offering Ancillary Non-Aviation Services at Air Transport Enterprises

An optimal set of ancillary non-aviation services, packed for retailing in a certain time period, will allow the airline company to obtain additional incomes, due to the synergetic effect of the joint selling of such services. In this case the main task consists in finding variants of service combinations ensuring the maximum efficiency. The existing restrictions on the investment opportunities should also be taken into account.

The statement of this problem is based on the classical «knapsack problem». Each ancillary non-aviation service is represented as a separate item, put into a knapsack, with certain expenditures and incomes from the sale. In this case the following conditions are also specified:

- a number of project variants for each service;
- the synergetic indicator which increases the gained income from the items placed together in a knapsack (ancillary non-aviation services selected for selling);

- total expenditures.

We introduce the following notations:

k – project's number, $i = 1, 2, \ldots, k$,

n_i – a number of development variants for the *i-th* project,

$z_{j,i}$ – expenditures on the realization of the *j*-th variant for the *i*-th project,

$c_{j,i}$ – income from the realization of the *j-th* variant for the *i-th* project,

d_{j,i,j^*,j^*} - additional income, conditioned by the simultaneously realized *j-th* variant for the *i-th* project and *j**-th variant for the *i**-th project.

Additionally, we know a total amount of money *Z*, that must be distributed between different projects. More to that, each variant can develop according to one scheme only.

To give a mathematical setting of the problem, let us introduce Boolean variables $x_{i,j}$:

$$x_{i,j} = \begin{cases} 1, \text{if the } i-\text{th project is developed by the } j-\text{th variant}, \\ 0, \text{otherwise.} \end{cases}$$

Now it is possible to present the considered problem as a problem of integer optimization:

Maximize a total reward

$$f(x) = \sum_{i=1}^{k} \sum_{j}^{n_i} (c_{i,j} - z_{i,j}) x_{i,j} + \sum_{i=1}^{k} \sum_{j}^{n_i} \sum_{i^*=1}^{k} \sum_{j^*}^{n_i} d_{i,j,i^*,j^*} x_{i,j} x_{i^*,j^*} \tag{1}$$

Subject to restrictions:

$$\begin{gathered} \sum_{j=1}^{n_i} x_{i,j} = 1, \quad i = 1, \ldots, k, \\ \sum_{i=1}^{k} \sum_{j=1}^{n_i} x_{i,j} z_{i,j} \leq Z. \end{gathered} \tag{2}$$

The described problem is a generalization of the so-called *knapsack problem* and is a problem of integral-valued linear programming, which can be solved using numerical methods.

Initially it was assumed[1], that the additional income $d_{i,j,i*,j*}$, conditioned by the simultaneously realized *j- th* variant for the *i- th* project and *j*- th* variant for the *i*- th* project, is a constant.

However, the practical implementation of the model for ancillary service selection has shown that, with respect to airlines and ATSS-TCH, the given assumption is a significant disadvantage of such problem statement.

Firstly, the amount of the additional income $d_{i,j,i*,j*}$ for each combination of the *j-th* variant for the *i-th* project and of the *j*-th* variant for the *i*-th* project varies depending on the number of sold services within the given period of time. It is caused by the fact that joint retailing of different services allows to attract additional customers, who want to purchase the needed services not separately in different sales offices, but in one package, and in the same place.

Herewith, the number of such additional customers is not constant, and can vary from 0% to 100% of a total number of customers.

Secondly, the reduced back-offices expenditures on information and technical support of the bounded projects (minimizing the number of used CRS and GDS, the expenditures on cashiers training, expenditures on processing mutual payments, using the minimized number of IT in the projects to be bounded, as well as others) provide synergies from the jointly sold services to greater extent than incomes.

Taking into account the above circumstances, we suppose that not only incomes are normally distributed random variables $C_{j,i}$. Additional incomes can also be normally distributed random variables $D_{j,i,j*,i*}$. We also suppose that all random variables are mutually independent.

Then the above considered values $c_{j,i}$ and $d_{j,i,j*,i*}$ are expectations of the lasts:

$$E(C_{j,i}) = c_{j,i}$$

$$E(D_{i,j,i*,j*}) = d_{i,j,i*,j*}.$$

Considering the known variances, we have the following:

$Var(C_{j,i}) = \sigma^2_{j,i}$ is a variance of the random variable $C_{j,i}$.

$Var(D_{i,j,i*,j*}) = \sigma^2{}_{i,j,i*,j*}$ is a variance of the random variable $D_{j,i,j*,i*}$.

In this case in the formula (1) the constants $c_{j,i}$ and $d_{j,i,j*,i*}$ are changed by random variables $C_{j,i}$ and $D_{i,j,i*,j*}$. Therefore, a total reward (1) is a random variable. Next we will

[1] These data are provided in the thesis by R. Surinov, who is the co-author of the thesis, defended in Moscow State University of Management in 2014.

consider the so called *ruin probability* as an objective function: this is a probability that a total reward R is less than the prescribed value (*critical level*) R*. More precisely, our objective function can be presented as follows:

$$F(R^*) = P\{R \le R^*\}, \tag{3}$$

where R is determined by the formula (1) changing $c_{j,i}$ by $C_{j,i}$ and d_{j,i,j^*,i^*} by D_{i,j,i^*,j^*}.

The random variable R has normal distribution with the following mean value and the variance:

$$E(R) = \sum_{i=1}^{k}\sum_{j}^{n_i}(E(C_{j,i}) - z_{i,j})x_{i,j} + \sum_{i=1}^{k}\sum_{j}^{n_i}\sum_{i^*=1}^{k}\sum_{j^*}^{n_i} E(D_{i,j,i^*,j^*})x_{i,j}x_{i^*,j^*} =$$
$$= \sum_{i=1}^{k}\sum_{j}^{n_i}(c_{i,j} - z_{i,j})x_{i,j} + \sum_{i=1}^{k}\sum_{j}^{n_i}\sum_{i^*=1}^{k}\sum_{j^*}^{n_i} d_{i,j,i^*,j^*}x_{i,j}x_{i^*,j^*} \tag{4}$$

$$D(R) = d_{i,j,i^*,j^*}\sum_{i=1}^{k}\sum_{j=1}^{n_i}(x_{i,j})^2 Var(C_{j,i}) + \sum_{i}\sum_{j}\sum_{i^*}\sum_{j^*}(x_{i,j}x_{i^*,j^*})^2 \sigma^2{}_{i,j,i^*,j^*}.$$

Therefore, the distribution function F can be written as follows:

$$F(R^*) = \Phi\left(\frac{R^* - E(R)}{\sqrt{D(R)}}\right), \tag{5}$$

where $\Phi(.)$ is a distribution function for the standard normal distribution.

Below we will introduce *F(R*, Z),* if a total amount of money Z is a variable value.

Further, we must find the optimal decision, that satisfies the restrictions (2) and minimize the ruin probability (5). We can use the procedure of simple enumeration of all possible solutions, replacing the objective function (1) by (5).

The described procedure is illustrated in the thesis, when providing solutions to the problem of the investment optimal distribution among the projects for modifying the ancillary service packages in WSS and an airline.

On the basis of the proposed method, the «Methodological Recommendations for Formation of Services of Air Transport Settlement System (ATSS-TCH) and Accredited Agencies based on Optimization of Distribution of Given Investments» (approved by TCH

President of 11.12.2013) have been developed and implemented into the ATSS-TCH performance. It is confirmed by the relevant act ratifying the introduction of the thesis research results.

The methodological recommendations are used for picking up an optimal set of ancillary non-aviation services for their implementation in ATSS during a specified time period. Based on the calculation results obtained, the decisions about the viability of investments in projects for service creation or development in ATSS-TCH are taken by TCH management.

11.3. Development of the Network Planning Model for Document Processing when Selling Services at Air Transport Enterprises

Document processing for the sold services in settlement systems is connected with performing various procedures of accounting, reporting, challenging claims, reconciliation, monitoring and revision work, etc. Thus, practically, there are no specific regulations governing the document processing for the sold ancillary non-aviation services, unlike the document processing for the sold aviation services. The documentation procedure regarding the sold ancillary non-aviation services further complicates the overall document management in the settlement systems. The operating procedures of settlement systems are limited by time frames, so it is of crucial importance to carry out an analysis and evaluation of time distribution for both individual activities and the total amount of work.

A numerical method for obtaining the activity time distribution for a network diagram is presented in this chapter. The method is unified, it allows to describe the activity time distribution on both individual activities and their various combinations (such as the sum, maximum and minimum) in a uniform manner. The method is based on the polynomial approximation of the distribution functions of positive, finite, and continuous random variables. A unified and simple description of distribution functions simplifies the usage of various distribution schemes. The necessity to control and ensure the approximation accuracy through the selection of an interval (b, c) for the considered random variables and the polynomial order are the method's disadvantages. On the other hand, in many cases, there are only sample data available, with the data of the distribution type applied to the corresponding random variables being missing. Due to that, the proposed approach is highly acceptable, since the empirical moments are sufficient for its application

The problem of obtaining the activity time distribution for all the activities of a network diagram is commonly solved using simulation modeling. Analytical solutions are typically based on normal approximations, while it is assumed that the lengths of subcritical paths are mutually independent random variables. A unified approach, which makes it possible to obtain the approximating distribution without the mentioned assumptions, is presented in the thesis.

The activities in the network diagram have arbitrary durations. We denote the duration of the *i*–th activity as X_i. We assume that this duration is a positive and finite random variable with its moments, available up to the *m*–th order:

$$P\{X_i < c_i\} = 1, \quad c_i < \infty; \quad \mu_{i,r} = E\left(X_i^r\right), \quad r = 1,...,m,$$

in the way, that $\mu_i = E(X_i) = \mu_{i,1}$ is the average duration of the *i*-th work. It is assumed throughout the thesis that various activities durations are mutually independent random variables $X_1, X_2, ..., X_k$.

It is common assumption in the network scheduling, that the initial moment corresponds to the start of the first activity. Depending on the type of the successive activity, it starts under two different conditions:

1) Immediately after completing the last activity from a set of activities, which has edges leading to the activity in question.
2) Immediately after the first of the mentioned activities is finished.

The corresponding vertices of the diagram will be called $\vee$– vertices and $\wedge$- vertices. These symbols are not used if there is only one predecessor activity for the given activity. The moment of the completion of all the activities of the set *T** corresponds to the moment of the completion of the final *κ*–th activity.

Our goal is to calculate the activity time distribution function for all the activities *T**: $F(x) = P\{T^* \le x\}$. This makes it possible to calculate such numerical characteristics of *T**, as the expected value *E*(*T**) and the variance *D*(*T**), as well as the upper bound probability *p** of the completion of the whole set of activities before the predetermined moment $t > 0$:

$$P\{T^* > x\} = 1 - F(x) \le p^*. \tag{6}$$

The present statement of the problem, as well as the approach used for solving it, is different from the previous ones. Specifically, we suggested approximating the distribution functions of both individual activities and their combinations by polynomials. The order of the polynomial is selected in compliance with the requirement of ensuring the prescribed accuracy, and the coefficients are assigned in a most efficient way to ensure the equality of moments for the initial distribution and the approximation.

The chapter focuses on the approximation of the activity time distribution for individual activities. In this chapter the approximation of distribution function for a positive random variable X_i, for which the moments $\mu_{i,r} = E\left(X_i^r\right)$, $r = 1,...,m$: $F_i(x) = P\{X_i \le x\}$, $x \ge 0$ are available, is performed. At the same time, it is assumed that the considered random variable does not exceed the known value c_i : $P\{X_i > c_i\} = 1 - F_i(c_i) = \overline{F}_i(c_i) = 0$.

A simple polynomial approximation having an order of q is used:

$$F(x) = z_1 x + z_2 x^2 + ... + z_q x^q, \; 0 \le x \le c, \tag{7}$$

where $\{z_i\}$ – are constant coefficients, which are to be determined.

The corresponding distribution density is denoted as $f(x)$:

$$f(x) = z_1 + 2z_2 x + ... + qz_q x^{q-1}, \; 0 \le x \le c \tag{8}$$

The variables $\{z_i\}$ should be determined to satisfy the following conditions:

$$F(c) = z_1 c + z_2 c^2 + ... + z_q c^q = 1, \tag{9}$$

$$\int_0^c x^r f(x) dx = \mu_r, \;\; r = 1,...,m, \tag{10}$$

The substitution of the expression for the density $f(x)$ into the latter formula results in

$$\mu_r = \int_0^c x^r \left(z_1 + 2z_2 x + ... + qz_q x^{q-1}\right) dx = \sum_{j=1}^{q} z_j \frac{j}{r+j} c^{r+j}, \;\; r = 1,...,m. \tag{11}$$

Thus, the following system of linear algebraic equations, with respect to the variables $z_j \ge 0, \;\; j = 1,...,q$, is derived:

$$\begin{aligned} &\sum_{j=1}^{q} c^j z_j = 1, \\ &\sum_{j=1}^{q} \frac{j}{r+j} c^{r+j} z_j = \mu_r, \;\; r = 1,...,m. \end{aligned} \tag{12}$$

The derived system shows that polynomials having orders $m + 1$ should be used for the approximation, i.e. $q = m + 1$.

The solution of the system of linear algebraic equations (12), with respect to the variables $\{z_j\}$, presents no problem, since the restriction matrix in place is invertible and well-conditioned.

Further on, the approximation of a distribution function for a sum of two mutually independent, positive, variables X_1 and X_2, for the minimum and for the maximum, is performed.

Thus, the standard unified procedures for the iterative calculations of the studied distributions and their moments are developed.

In general, the approximation procedure of the activity duration of the network diagram is as follows:

As it was noted above, the activities of the network diagram are numbered in a way that the edges lead from the activities with smaller numbers to those with higher numbers. Therefore, the activity time distribution may be approximated successfully from the first activity, which starts at the zero instant. Then, the approximating distributions for the starting time and the completion time of the successive activities are calculated. If the given activity has a single preceding activity, then its starting time coincides with the completion time of the given preceding activity. In this case, the addition of two independent random variables takes place, and the approximating completion time distribution is determined in compliance with the moments of the sum. If there are several preceding activities, then the maximum or the minimum scheme takes place. First of all, the corresponding approximating distribution for the starting time of the successive activity is determined in this case. Then, the moments of the obtained distribution are calculated. They are used to obtain the moments of the completion time of the successive activity through the summation with the duration moments of the successive activity.

At the end, the approximating distribution for the final activity is calculated, which, in fact, is the sought completion time distribution for all activities in the network diagram.

The approbation of the considered model in relation to ATSS-TCH has been completed, and the results are presented in the thesis.

The method is proposed to minimize the execution time of document processing (and the whole process of mutual settlements) for the sold package of basic and ancillary services on air transport, in conjunction with non-aviation ancillary services in ATSS-TCH. Based on the obtained calculation results, decisions for optimizing the TCH departments' activity are made, in order to establish the terms for reporting and transferring the proceeds to the participants, in compliance with the ATSS-TCH regulatory and technological.

11.4. Development of the Model for Financial Settlements on Participants' Liabilities when Selling Services on Air Transport

The mutual payment liabilities occur between subjects in different practical areas. Mutual repayment can be done to reduce real money transfers between the subjects. The proposed method for solving such a problem is characterized by small computation time consuming and high economic effectiveness.

The problem consists in finding the corresponding chain of subjects involved in mutual settlements. The problem is formulated in terms of the graph theory. For solving this problem, both the Graph theory and the linear programming theory are used.

Mathematically, the problem can be formulated in terms of the graph theory in the following way. Given a directed finite graph $G = (V, E)$ whose set of vertex V relates to the subjects of settlements and the set of arcs E relates to payment liabilities. An arc from vertex $v_i \in V$ to the vertex $v_j \in V$ is denoted as $e_{i,j} \in E$. Its length $d(e_{i,j}) > 0$ equals to an amount of money from subject i to subject j. Mutual payments can be done to reduce the real money transfers. It can be possible if there exists such a closed chain c between the subjects (vertices) and if the same amount of money is passed along the chain in such a way that the first subject receives amount of money he sent. Herewith, the maximal possible amount of money equals the minimum payment (the length of an arc) in this chain: $\min\{d(e) : e \in c\}$. It corresponds to a simple contour (without repeating vertices) on a graph and the indicated amount transferred must not exceed the minimum length of the arcs, included in the contour. We call this amount the weight $x(c)$ of the contour c or a transaction.

The problem consists in finding the set of such contours, where:

1. For any graph arc $e \in E$ the sum of weights of contours, which an arc reaches, must not exceed the weight of the arc $d(e)$.
2. The sum of all contours weights (transactions) is ultimate.

Let us formulate the problem more exactly. Let C is some set of simple contours; $k = |C|$ is the number of contours. The weights of contours $\{c\}$ included in the set C must satisfy the condition

$$\begin{aligned} & x(c) > 0, \quad \forall c \in C, \\ & \sum_{c \in C, e \in c} x(c) \le d(e), \quad \forall e \in E, \end{aligned} \tag{13}$$

and maximize the objective function

$$f(C) = \sum_{c \in C} x(c). \qquad (14)$$

Thus, the problem consists in forming a set of simple contours C satisfying the restrictions (13) and maximizing the criterion (14).

The solution of the formulated problem involves two components. Firstly, we must determine the set of simple contours C. Secondly we must assign weights for contours satisfying the condition (27).

The stated method is an approximate one, since it does not work with the whole set of simple contours, but only with a subset thereof. Thereby, the method computational laboriousness decreases. We construct the contours, taking into account their possible maximum weight. It is done to neutralize the efficiency loss, caused by the latter circumstance. The method is based on «the maximin path tree» a concept proposed by the theory of directed graphs, analogous to the concept «the shortest path tree».

To form a tree of maximin paths we introduce an algorithm. This algorithm is a certain modification of Dijkstra's algorithm. As a result, a set of contours C is formed. Further, the Graph problem (13), (14) is restated in terms of the linear programming problem as follows.

Let $\boldsymbol{M}$ is a Boolean matrix, rows of which correspond to contours, and the columns correspond to arcs $e \in E$ of the graph $G = (V, E)$. 1 is at an intersection of a row and a column, if an arc is included in a contour, and 0 - otherwise. Let us consider the vector-lines $x = (x(1), x(2), \ldots, x(|C|))$, $d = (d(1), d(2), \ldots, d(|E|))$ and the vector-line $\delta = (1, 1, \ldots, 1)$ of size units $k = |C|$. Then we have the following problem of linear programming:

Maximize the objective function

$$f(x) = \delta \, x^T$$

Under restrictions

$$x(c) > 0, \;\; \forall c \in C,$$
$$xM \leq d.$$

The model is used in ATSS-TCH in order to reduce the ATSS-TCH participants' needs for circulating funds and to minimize the non-payment risks regarding the revenue from the sold air transportations and ancillary services. The obtained calculation results allow to modify the group of subjects involved in the settlement of mutual counter liabilities of the ATSS-TCH participants through mutual payments.

To set an example, the thesis considers the instances of settling mutual liabilities on the sold and refunded air transportations, rail transportations and hotel services between the relevant ATSS participants.

11.5. Monitoring of Travel Agencies on the Base of the Multivariate Forecast of their Activity Indicators

Agencies sell air transportation and ancillary services during a specified period of time. When the sale period is completed, agencies prepare sales reports and transfer the money gained from the sold transportation and ancillary services. As a rule, the process of drawing up reports and further transfer of funds takes a few working days. Thus, service providers receive revenues for the sold services to their accounts by an average on the 10^{th} day after the end of the sales period.

With such settlement procedure, service providers inevitably face financial risks: on the 10^{th} day after the end of the sales period an agency already gets the revenue for the next sales period. Thus, the amount at risk includes the funds by an average of two sales periods.

In order to minimize the financial risks, service providers should exercise permanent control of agencies' activity concerning the sales volume dynamics and in compliance with payments deadlines for the sold services, as well as retaliate against agencies. To completely eliminate the financial risks, the proper measures must be applied preventively, before the agency accumulates arrears on the revenue.

To take preventive measures, not only statistical data about the sales volume and systematic delays of revenue transfers are needed, but also a forecast of the agency's activity indexes, compiled on the statistical basis with taking into account both the internal and external factors affecting the agency's activity.

Agencies are required to submit reports on their activity in equally spaced times, denoted as t, t = 1, 2, … (i.e. 24-hour periods, ten-day periods, etc.). These reports are differentiated according to sales offices, as well as types of delivered services, which will be indexed as k, (k = 1, 2,…, K). Hereafter, the data related to these types will be referred to as "*indexes"*.

Let us take an agency accredited with ATSS and indicate $Y(t) = (Y_1(t), Y_2(t),.., Y_K(t))^T$ as the reported indexes submitted at moment t. By the given moment– T, we will have the data $Y(1), Y(2),..., Y(T)$ to be used as the evaluation basis of *risk danger level* regarding this agency's possible default. Moreover, we know certain *exogenous variables* (or *external factors*), operating at the moment of time t, t = 1, 2, …: $x(t) = (x_1(t), x_2(t),.., x_M(t))$. The period statistics are also available for these values - $x(1), x(2),..., x(T)$.

The proposed statistical models to assess the risk danger level are considered below. All of them are based on the values of K–dimension index $Y(t)$ and exogenous variables $x(t)$ as per certain previous time instances.

The considered autoregression model can be presented in the following way for i = 1, 2, 3; $t > S$, 0; $c_{i,i} = 0$;

$$Y_i(t) = b_i + \sum_{j=1}^{3} c_{i,j} Y_j(t) + \sum_{j=1}^{3} \beta_{i,j} Y_j(t-1) + \sum_{s=2}^{S} \beta_i^{(s)} Y_i(t-s) + \sum_{j=1}^{M} \alpha_{i,j} x_j(t) + Z_i(t). \tag{15}$$

We introduce the following designations:

$$b = (b_1 \quad b_2 \quad b_3)^T, \ C = (c_{i,j})_{3\times3}, \ \mathrm{B} = (\beta_{i,j})_{3\times3}, \ ,$$
$$\beta^{\langle s\rangle} = \left(\beta_1^{\langle s\rangle}, \beta_2^{\langle s\rangle}, \beta_3^{\langle s\rangle}\right)^T, \ \mathrm{A} = (\alpha_{i,j})_{3\times M}, x(t) = (x_1 \quad \ldots \quad x_M)^T.$$

Now, the model (15) can be recorded in a matrix form:

$$Y(t) = (Y_1(t), Y_2(t), Y_3(t))^T = b + CY(t) + \mathrm{B}Y(t-1) + \sum_{s=2}^{S} diag\left(\beta^{\langle s\rangle}\right) Y(T-s) + \mathrm{A}x(t) + Z(t), \tag{16}$$

Where $Z(t) = (Z_1(t), Z_2(t), Z_3(t))^T$ is a three-dimensional random vector with independent components and unknown variances $\sigma_1^2, \sigma_2^2, \sigma_3^2$.

Hence, the linear dependence set below will be postulated in this model:

1) the components of $Y(t)$ vector between each other;
2) $Y(t)$ vector against the previous value $Y(t - 1)$; 2) the component of $Y(t)$ vector against the previous values of the relevant components;
3) $Y(t)$ vector against exogenous variables $x(t)$ and the random component of $Z(t)$ for time instance t.

Values b, C, B, $\beta^{\langle s\rangle}$ ($s = 1,\ldots,S$), A and $\sigma_1^2, \sigma_2^2, \sigma_3^2$ stand for unknown model parameters. Since $c_{i,i} = 0$, unknown parameters total to 3(7+ M +S). This number is rather large, which strongly complicates the evaluation of unknown parameters.

The model (15) can be simplified taking into account the values of $Y(t\text{-}s)$ per previous years by means of discounting, i.e. with factor d^{t-s}, assumed to be known. Therefore, the model will be presented as follows:

$$Y(t) = (Y_1(t), Y_2(t), Y_3(t))^T = $$
$$= b + CY(t) + \mathrm{B}Y(t-1) + diag\left(\beta^{\langle 1\rangle}\right) \sum_{s=2}^{S} d^{t-s} Y(t-s) + \mathrm{A}x(t) + Z(t), \tag{17}$$

The number of the model's unknown parameters now equals 24+3M.

The shown models are quite common. By omitting some components therein, we can arrive at simpler models.

The evaluation of the model parameters (16) and (17) is performed by methods of a multivariate statistical analysis.

Let us express the model (17) as a multivariate regression. If N denotes the number of observations, used for evaluation, $N > 4 + M$; Θ serves as the matrix for unknown parameters of dimension 3x $(4+M)$, while $\Psi(t,N)$ is the matrix of accompanying variables of dimension $(4+M)\times N$, then

$$
\begin{aligned}
\tilde{Y}(t,N) &= \big(\big(Y(t-N+1), Y(t-N+2), \ldots, Y(t)\big)\big)^T = \Theta\Psi(t,N) + \tilde{Z}(t,N), \\
\tilde{Z}(t,N) &= \big(\big(Z(t-N+1), Z(t-N+1), \ldots, Z(t)\big)\big).
\end{aligned} \tag{18}
$$

Hence, we need to arrange matrixes Θ and $\Psi(t,N)$. So we get:

$$
\Theta = (b \quad \mathrm{B} \quad \mathrm{A}) = \begin{pmatrix} b_1 & \beta_{1,1} & \beta_{1,2} & \beta_{1,3} & \alpha_{1,1} & \ldots & \alpha_{1,M} \\ b_2 & \beta_{2,1} & \beta_{2,2} & \beta_{2,3} & \alpha_{2,1} & \ldots & \alpha_{2,M} \\ b_3 & \beta_{3,1} & \beta_{3,2} & \beta_{3,3} & \alpha_{3,1} & \ldots & \alpha_{3,M} \end{pmatrix}_{3\times(4+M)} . \tag{19}
$$

$$
\Psi(t,N) = \begin{pmatrix} 1 & 1 & \ldots & 1 \\ \sum_{s=1}^{S} d^{t-s} Y(t-(N-1)-s) & \sum_{s=1}^{S} d^{t-s} Y(t-(N-2)-s)) & \ldots & \sum_{s=1}^{S} d^{t-s} Y(t-s) \\ \ldots & \ldots & \ldots & \ldots \\ x(t-(N-1)) & x(t-N+2) & \ldots & x(t) \end{pmatrix}_{(4+M)\times N} . \tag{20}
$$

When estimating the parameters, it is feasible to lay considerable emphasis on more recent observations. This can be achieved by introducing *«weights»*, applied to various observations. Let ω be a positive number, less than 1. Weight 1 is applied to the last observation, ω - to next to last, then - ω^{2}, etc. For the time instance $t - n$, the weight will be ω^{t-n}, $n = 1, 2, \ldots, t$. Let W be a diagonal matrix with elements $\{\omega^{t-n}\}$ on the main diagonal. This matrix is called a «*weight*» matrix.

The evaluation of the *weight* method for the least squares will look as follows:

$$
\tilde{\Theta} = ((\tilde{b} \quad \tilde{\mathrm{B}} \quad \tilde{\mathrm{A}})) = \tilde{Y}(t,N) W \Psi(t,N)^T \left(\Psi(t,N) W \Psi(t,N)^T\right)^{-1}. \tag{21}
$$

After evaluating the model parameters, we proceed to the default risk evaluation, and to perform this, we use the composite (weighted average) criterion:

$$R(t) = r^T Y(t) = \begin{pmatrix} r_1 & r_2 & r_3 \end{pmatrix} \begin{pmatrix} Y_1(t) \\ Y_2(t) \\ Y_3(t) \end{pmatrix} = \sum_{i=1}^{3} r_i Y_i(t), \qquad (22)$$

Where the weights $\begin{pmatrix} r_1 & r_2 & r_3 \end{pmatrix}$ are assumed to be preset.

For the sake of a clear picture, let us assume that higher risks correspond to the criterion higher values. Moreover, the critical risk ceiling *R** is set and once it is broken, we will face a risk. Hence, the rules for risk evaluation are formulated below:

Rule 1. When t is the instance of the last reported data, and $R(t) > R^*$, we face a risk.

Rule 2. Let us assume that t is the instance of the last reported data, and we need to evaluate the risk for a future instance $t+\tau$ ($\tau > 0$). Next, we forecast the criterion under the formula:

$$\tilde{R}(t+\tau) = r^T \tilde{Y}(t+\tau) = \begin{pmatrix} r_1 & r_2 & r_3 \end{pmatrix} \begin{pmatrix} \tilde{Y}_1(t+\tau) \\ \tilde{Y}_2(t+\tau) \\ \tilde{Y}_3(t+\tau) \end{pmatrix} = \sum_{i=1}^{3} r_i \tilde{Y}_i(t+\tau). \qquad (23)$$

The random component has a dispersion:

$$D = D\left(r^T Z(t+\tau)\right) = D\left(\sum_{i=1}^{3} r_i Z_i(t+\tau)\right) = \sum_{i=1}^{3} r_i^{\,2} D\left(Z_i(t+\tau)\right) = \sum_{i=1}^{3} r_i \sigma_i^{\,2}. \qquad (24)$$

Computing the risk probability:

$$P\left\{\tilde{R}(t+\tau) + r^T Z(t+\tau) \ge R^*\right\} =$$
$$P\left\{\sum_{i=1}^{3} r_i \tilde{Y}_i(t+\tau) + r^T Z(t+\tau) \ge R^*\right\} = 1 - \Phi\left(\frac{1}{\sqrt{\tilde{D}}}\left(R^* - \sum_{i=1}^{3} r_i \tilde{Y}_i(t+\tau)\right)\right), \qquad (25)$$

where in dispersion calculations under the formula (24), instead of unknown component dispersions $\sigma_1^2, \sigma_2^2, \sigma_3^2$, their evaluations are used.

The risk level is determined by the value of this probability.

The thesis contains a numerical example illustrating the proposed approach. The developed model approbation was conducted on a specified example of estimating the default risk level of an agency accredited with ATSS-TCH.

The developed model is put forward to be implemented into the TCH Information System to provide the basis of an IT toolkit used to assess the default risk level of an agency accredited with ATSS-TCH.

12. CONCLUSION

1. The conducted analysis of development trends in the sphere of international air passenger transport services has shown, that against the background of unsatisfactory financial results, traditional airlines are forced to take cardinal measures to achieve a qualitative increase of their profitability. And the most important one is the development of ancillary service retailing on airlines' corporate websites.

2. In order to increase competition with airlines' websites, international settlement systems should expand the range of ancillary non-aviation services provided for sale. Development of infrastructure, logistics and IT, offering such services for sale, turns out to be the main way to improve the settlement systems' efficiency and competitiveness. The given measure will contribute to transforming the international air transport settlement systems into general transport settlement systems, increasing incomes of all participants of settlement systems with minimal additional expenditures, combining the sale of a wide range of aviation and non-aviation services as one package in the same sales office.

3. A comprehensive analysis conducted to study the processes of organizing retailing of ancillary non-aviation services and mutual settlements for them in the ATSS-TCH neutral environment has shown that the AS retail has already provided ATSS-TCH participants with significant advantages.

4. The model for forming a range of ancillary non-aviation services and distributing investments for projects aimed at retailing such services in relation to the settlement systems and airlines has been designed in the deterministic and stochastic statement, which, unlike the classical «knapsack problem», takes into account the synergistic effect from the items jointly «loaded into knapsack». The solving method of the posed problem and the software have also been developed.

5. Taking into account the developed model for forming a range of ancillary non-aviation services and distributing investments for retail projects, methodological recommendations for handling financial settlements and distribution of investments on AS retail development projects have been laid down.

6. A numerical method for ensuring the time distribution for the tasks of the network diagram, based on the polynomial approximation of the distribution functions of positive, finite, and continuous random variables, has been developed. The method facilitates the work with various distributions, providing a uniform and simple description of distribution functions. The method has been applied not only in ATSS, but has also been offered to guarantee the automation of managing aircraft departures, should a failure situation at the airport arise.

7. A method for solving the problem regarding the settlement of mutual liabilities has been developed. The method is based on forming a set of contours in the correspondingly structured graph. The coverage of mutual liabilities between the participants relate to certain contours and are estimated in compliance with the amounts of money, transferred by them. The maximum amount of settlements is achieved by solving the formulated problem of linear programming.

8. A model for monitoring the agencies accredited with ATSS – TCH has been developed on the base of the multivariate forecast of their activity indicators, in order to assess the risk level of an agency's default.

9. The results of the thesis investigations are presented in two management training tutorials bearing the Training and Methodological Association (EMA) stamp for Russian universities and in a tutorial for TSI (Latvia). This is confirmed by the authors in the prefaces to these tutorials, as well as by the authorship of the EMA tutorial in air navigation for Russian universities.

10. The developed models are used in ATSS-TCH practice, as confirmed by the prepared ATSS-TCH normative documents, approved by TCH President, the methodological recommendations, as well as by the fact of their implementation.

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[1] Mentioned in the introductions and prefaces to the tutorials.