MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY

Air Transportation Management Department

PERMISSION TO DEFEND GRANTED
Head of the Department
__________________________G. M.Yun
“______”______________________2020

MASTER THESIS
(EXPLANATORY NOTES)

Theme: Implementation of innovations in airport passengers handling technology in the airport

Done by: Kateryna O. Holovchuk
Supervisor: Valentyna S. Konovaliuk, PhD Physico-mathematical Sciences, Associate professor
Standards Inspector: Yuliia V. Sevchenko, PhD in Economic, Associate professor

Kyiv 2020

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Кафедра організації авіаційних перевезень

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
___________________________Юн Г.М.
«______»_____________________2020 р.

ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ «МАГІСТР»

Тема: «Впровадження інновацій в технологію обслуговування пасажирів в аеропорту»

Виконавець: Головчук Катерина Олександрівна

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Київ 2020

NATIONALAVIATIONUNIVERSITY

Faculty of Management, Transport and Logistics

Air Transportation Management Department

Major (specialty): 6.070101 “Air Transportation Technology”

APPROVED BY
Head of the Department
________________________G. M. Yun
“______”____________________2020

TASK

of completion the master thesis

Kateryna O. Holovchuk

1. Theme of the master thesis entitled “Implementation of innovations in airport passengers handling technology in the airport” was approved by a decree of the Rector order № 2401/ст.. from 17.10.2019

2. Term performance of thesis: from 14.10.2019 to 29.12.2019 and 20.01.2020 to 09.02.2020.

3. Initial data required for writing the master thesis: production and financial results of Ukraine International Airlines, fleet size and type, types of services rendered by the airline.

4. Content of the explanatory notes: research of Ukrainian and international air transportation market, review of airline activity management, analysis of production and financial condition of the airline, review of the fleet of Ukraine International Airlines, review of existing boarding methods,, determination of critical paths of turnover activity, comparing of boarding methods, calculation saving cost as result of new boarding method implementation.

5. List of mandatory graphic matters: schemes of different boarding methods, passenger flow of UIA, financial result of company, turnaround process activities, critical paths.

6. Planning calendar

№	Assignment	Deadline for completion	Mark on completion
1.	Collection and processing of statistical data	14.10.19 - 01.11.19	done
2.	Writing of the theoretical part	01.11.19- 15.11.19	Done
3.	Writing of the analytical part	15.11.19- 01.12.19	Done
4.	Writing of the design part	01.12.19- 20.12.19	Done
5.	Writing of the introduction and summary	20.12.19- 29.12.19	Done
6.	Execution of the explanatory note, graphic matters and the presentation	20.01.20- 23.01.20	Done

7. Given date of the task: October 17, 2019.

Supervisor of the master thesis: Valentyna S. Konovaliuk

Task was accepted for completion: Kateryna O. Holovchuk

EXPLANATORY NOTE

The explanatory note for the master thesis entitled "Implementation of innovations in airport passengers handling technology in the airport" comprises of 107 pages, 24 figures, 11 tables and 34 references.

KEY WORDS: (5-15 слів) AIRLINE, AIRLINE BOARDING METHODS, AURCRAFT TURNAROUND, BOARDING STRATEGIES, TURNAROUND EFFICIENCY, TURNAROUND TIME.

Object of the master thesis is the company Ukraine International Airlines.

Subject of the master thesis is implementation of other boarding method as innovation in handling technology for airline's cost saving.

Main task of the master thesis is.

Methods of analysis include comparative analysis, SWOT-analysis, analysis of the financial parameters, graphical methods, statistical methods, analysis of relevant literature, mathematical methods.

During the completion of the master thesis it was established that implementation of other boarding method could improve all turnaround process time. Such an innovation will help improve the punctuality of the Ukraine International Airlines and also have a positive financial result.

The material base of this thesis is recommended to be used for the further researches, the educational process and for the professional practical implementation of the proposed improvements by Ukraine International Airlines.

CONTENT

LIST OF ABBREVIATION

AMOS — Asset Management Operating System

ASTC — Antonov - Aeronautical Scientific-Technical Complex named Antonov

ATO zone — Anti-Terrorist Operation Zone

BTF – Back-to-Front

CIS — Co-operative Insurance Society

CPLEX — optimization software package

GDP – Gross Domestic Product

GPA — Guinness Peat Aviation

IATA — International Aviation Transport Association

IOSA — International Operational Safety Audit

JAR — Joint Aviation Requirements

JSC — Joint-stock company

KLM — Royal Dutch Airlines, legally Koninklijke Luchtvaart Maatschappij

PERT — Program (Project) Evaluation and Review Technique

PrJSC — Private joint-stock company

PRM — Passengers with restricted mobility

SAS — Scandinavian Airlines

SOPM — Standard Operating Procedures Manual

SWOT (strengths, weaknesses, opportunities, and threats) — strategic planning technique

TAT — aircraft turnaround time

UIA — Ukraine International Airlines

x-RCPSP — extended resource-constrained project scheduling problem

INTRODUCTION

Air Transportation Management Department				*NAU.20.03.97 001EN*				
Done by:	*Kateryna O.Holovchuk*			*INTRODUCTION*	*Letter*		*Sheet*	*Sheets*
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INTRODUCTION

The aviation industry occupies an important place in the life of society, being involved in many spheres of life: transportation of passengers, mail, cargo and luggage, agricultural work, construction. The development of international relations and the globalization of economic processes stimulate the development of air transportation, the growth of demand for fast and convenient transportation. Ukraine is one of the few countries in the world to have a complete cycle of aviation engineering and is a world leader in the transport and regional passenger aviation sector.

Over the last 20 years, the activity of airlines in the market has changed a lot. Airlines have come to the need to develop direct selling, formed alliances, conducted studies of various processes of market relations aimed at ensuring a stable financial position. The development of the transport system of the country as a whole and the air transport system in particular becomes not only a prerequisite for the implementation of an innovative model of economic growth of the country, but also a factor for improving the quality of life of the population and the competitiveness of the national economy.

The relevance of the research topic is determined by the need to improve the efficiency of the enterprise through the introduction of an innovative approach, in which the focus is on the precession of boarding passengers on board the aircraft. This process can significantly improve and reduce the entire turnover process. Improving the efficiency of the process can significantly increase the punctuality of the company, respectively, customer loyalty will be increased. In addition, such changes can positively affect the financial condition of the company. Each extra minute of aircraft parking on the ground is substantially displayed at the expense.

It is well known that all successful airlines pay significant attention to the issues of continuous improvement of all processes in accordance with a previously developed strategy. In order to be effective, the airline's development strategy must be based on deep knowledge of the air transportation markets, and its implementation should be based on appropriate plans for market penetration with the wide use of marketing principles for creating a route network, sales policy, tariff policy, advertising, etc.

The organization of PJSC “Ukraine International Airlines”, the leading international company of Ukraine, which was founded in 1992 as a joint closed joint-stock company, was chosen as the object of study. The main activity of Ukraine International Airlines (UIA) is passenger and cargo transportation. A year later, from the day the company was founded, all the goals stated in the constituent documents were achieved: to create a high-quality, competitive international Ukrainian company; expand and integrate the activities of Ukrainian aviation around the world; introduce the best technologies and management methods; attract foreign investment and make a profit.

The aim of the work is to study the aircraft turnover process, identify critical paths among all activities performed, and also consider the possibility of introducing innovations in the form of changing the strategy for landing passengers on board the aircraft.

When studying this issue, it is necessary to solve the following problems: to study the theoretical foundations and consider all methods of boarding; to study the specifics of each of them, as well as to analyze what obstacles and restrictions for passengers each method provides; to calculate the time required for each passenger, taking into account the previously defined restrictions. In the final stage, it is necessary to determine the best strategy and make a financial miscalculation of the implementation of such a strategy.

The object of study is the Private Joint-Stock Company “Ukraine International Airlines”, the subject of study is improving the efficiency of the aircraft’s turnover process by introducing a new method of boarding passengers.

The theoretical and methodological basis of the study was the work of foreign and domestic authors on the study and application of the process approach and optimization of business processes. In the process, the works of modern researchers, such as M. van den Briel, J. R Villalobos, T. Lindemann, E. Bachmat, N. Stolyarov, S. Marelli, H. Landeghem, etc., were considered.

The thesis consists of three sections.

The first section summarizes the theoretical foundations for the development of the aviation industry, defining its role and place in the national economy. Different methods of boarding passengers, their characteristics, advantages and disadvantages have also been studied and considered.

The second section describes the organization of PJSC "International Airlines of Ukraine", provides financial and production analyzes of the airline's activities, describes the organizational structure.

The third section describes the miscalculations for the use of a radically different landing scheme to improve the efficiency of the turnaround process.

1. THEORETICAL PART

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1.1. Ukrainian and international market of air transportation

1.1.1. Role and place of aviation industry in the national economic system

Air transport is an important factor in influencing the development of the world economy, providing communication and communication between the most remote countries and regions of the world, it stimulates the growth of foreign economic cooperation, promotes international trade, creates jobs, encourages and facilitates international tourism. [1]

The economic impact of air transport on the development of the national and world economy can be roughly divided into direct, indirect, stimulating and accessory (additional) (see Fig. 1.1):

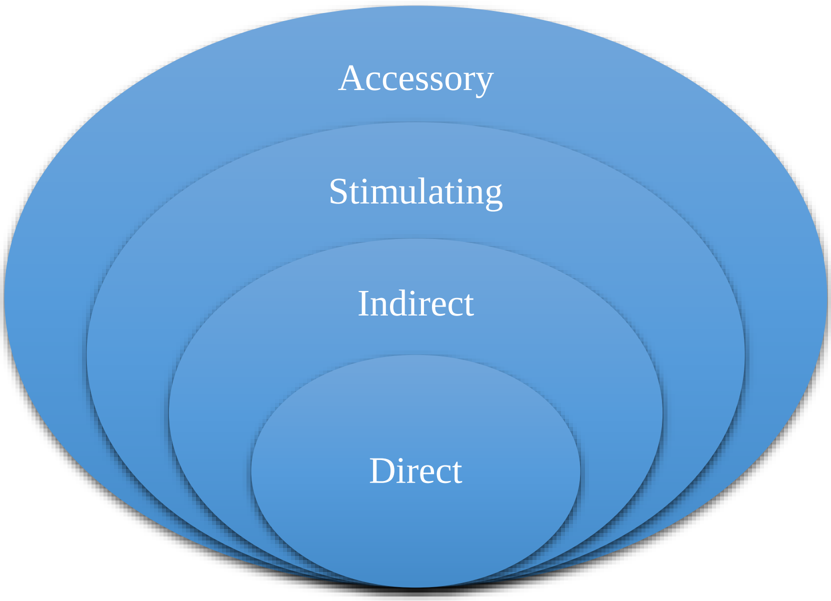

Fig. 1.1 The economic impact of air transport.

The direct economic impact is the creation of jobs and increasing of economic activity in the aviation industry. These include airline and airport operation activity, ground handling and aircraft refueling, air traffic control services, as well as aviation industry with headquarters and regional offices. [2]

According to a study conducted by Air Transport Action Group, the airline industry employs more than 8.7 million people worldwide, of which (see Fig. 1.2):

•2.3 million airline employees as aircraft crew, check-in agents at airports or ground-based technical staff;

•0.5 million are employed in the provision of airport operations (management, maintenance);

•4.6 million engaged in groundhandling (security services, state border services, duty free shops, and hotels and restaurants located at airports);

•0.2 million controllers provide air traffic control;

•1.2 million are employed in the production of aircraft, engines and other aviation systems [3].

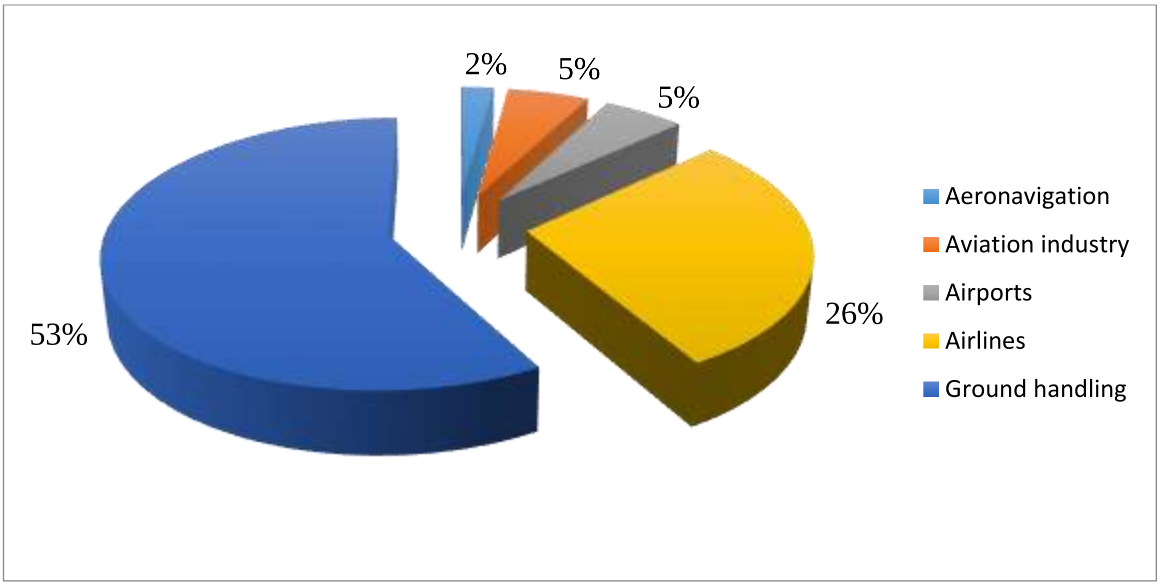

Fig. 1.2 Distribution of employment in aviation (by sectors)

In addition, due to the multiplier effect that occurs in the aviation industry, every 100 jobs created by aviation generate additional demand for 600 jobs in other industries.

Indirect economic impact is the creation of jobs and increased economic activity in related industries that provide the supply of goods and services to economic entities in the aviation industry. A striking example is catering companies supplying food and drink on board aircraft, air law audit and law firms, and aviation fuel suppliers. Thus, more than 9.8 million jobs are created by companies in related industries that are indirectly involved in air transportation. Thus, over $ 697 billion gross world product is generated. [2].

The individual costs of persons directly or indirectly employed in the aviation and related industries support the jobs and economic activity of retailers, consumer goods manufacturers, restaurants and banks. Thus the stimulating economic impact of air transport is revealed. For example, in 2018, aviation and related industries spent an estimated 4.6 million jobs worldwide on their individual revenues for the purchase of goods and services for their own consumption, and their contribution to the gross world product was estimated at $ 324 billion. [4]

Air transport has a positive impact not only on aviation and related industries, but also on the development of tourism business and international trade. Developed aviation infrastructure and a wide network of routes also contribute to the country's investment attractiveness. Thus, the accessory economic impact of air transport on other industries is revealed.

Undoubtedly, the role of air transport in the tourism industry is extremely important. Today, more than 52% of international travel is by air. The most striking example is the developing countries (such as Thailand, Egypt, Cuba). On the African continent, for example, about 2.5 million jobs are provided by the tourism industry [5]. As a rule, foreign tourists arrive in Africa by air. Having airline connections makes it easier for more tourists to arrive in a particular region or country. This applies to both leisure and business tourism. The money that tourists spend in the destination country on hotels, restaurants, theaters, transportation and communications supports the operation and profitability of a number of local industries.

The developed aviation industry also contributes to increasing the country's investment attractiveness and expanding its opportunities for international companies to operate in its territory. Transnational corporations' decisions on investment and production placement are largely influenced by the availability of convenient transportation, including air services. Countries and regions with high levels of development of aviation infrastructure and air routes are very attractive for both starting new businesses and developing and expanding existing businesses. An example is the American city of Atlanta, which in the late 1970s became extremely popular with a number of European airlines. Delta Airlines has begun direct flights from Hartsfield-Jackson (Atlanta) to European cities, as well as European airlines have begun offering direct flights to Atlanta. As a result, foreign direct investment in the state of Georgia has grown at a significant rate: If, in early 1978, 67 British companies operated in Atlanta, then in ten years their number had tripled to 201 companies [6].

The well-developed and accessible network of passenger routes is a key factor in effective communication between headquarters and regional and local representative offices of international companies, which is essential for effective operation and management. It is no accident that international organizations and large international companies seek to locate their headquarters and regional offices in cities with high transportation accessibility and developed infrastructure. [7]

1.1.2. Development trends of the aviation industry of Ukraine

The aviation industry belongs to strategically important sectors of the economy. Ukraine is one of nine countries in the world that have their own full-cycle production of aircraft. The Ukrainian civil air transport market is in the process of radical transformations, the essence of which is to increase the competitiveness of airlines in the context of the globalization of air transport. Strengthening the position of Ukraine in the international air transport system by increasing the competitiveness of domestic airlines is one of the priority areas of aviation activity and meets the requirements of the Concept of national transport strategy until 2030. [8]

An analysis of the main features of the modern air transportation market of Ukraine indicates that the main factor affecting the development of the air transportation market of Ukraine is the price, which is due, firstly, to the low solvency of the population, and secondly, the lack of a predetermined need for air transport within the country. Therefore, the main efforts of Ukrainian airlines should be aimed at solving the problems of achieving competitive advantages, which allow not only to operate efficiently in the air transportation market and increase their market share, but also to implement measures related to the development of the domestic air transportation market. The development of the domestic potential of the passenger air transportation market is as follows:

- updating the existing fleet of Ukrainian airlines and bringing it to international standards for technical, economic and environmental indicators;
- restoration and development of ground infrastructure facilities, characterized by significant depreciation of fixed assets;
- implementation of a tariff policy that promotes the development of the domestic air transportation market.

At present, the choice of pricing policy is determined by the conditions of the market environment and the preferences of passengers who dictate to the airline the size of the aircraft, the number of flights between cities. At the same time, such market factors as, for example, price changes and the threat of competition from foreign carriers, put many domestic airlines in the need to develop their development strategies.[9]

1.2. Factors influencing the passenger flow

In modern conditions, of particular importance is the solution to the problem of managing the economy (income and expenses) of the airline, taking into account the external and internal conditions in which it operates. The main and most effective tool is the regulation of airfares, an increase in the number of non-stop flights, and an analysis of the market for the aviation market.

Any expansion of the passenger air transport market is associated not only with an increase in economic activity, but also with an improvement in the social conditions of the population and the concomitant increase in its mobility, the development of the tourism industry, and the increased availability of air transport [10].

Various kinds of emergency events, both anthropogenic and non-anthropogenic in nature, can have a negative impact on transportation, however, civil aviation tends to quickly recover, after which there is a return to the growth trend. Over the past 20 years, the global traffic growth trend is an average of 5% annually.

Leaving outside the scope of consideration non-anthropogenic events, which include various kinds of natural phenomena (earthquakes, floods, tsunamis, volcanic eruptions), epidemics, as well as possible technological disasters (accident at nuclear power plants) and internal political factors (military operations, acts of terrorism, sanctions), which are capable of negatively affecting transportation in a certain region of the world for a certain time, the following main global external factors that influence the air transportation market can be distinguished [12]:

1) The economic situation has a direct impact on civilian air travel. The conducted studies indicate a linear relationship between the passenger flow of airports and the gross domestic product of the country. GDP takes into account both the level of business activity and the dynamics of population incomes. The Pearson correlation coefficient between the dynamics of GDP and passenger traffic for the period since 1998 is about 0.83.[13]

The dependence of traffic on GDP is observed in all developed countries. Boeing uses the dependence of changes in total passenger traffic on changes in GDP to forecast US domestic air traffic:

$$y = 0{,}78 \cdot x - 1{,}5\%$$

where x is the percentage change in GDP; y is the percentage change in the total passenger turnover [14].

The studies [15] show a clear statistical relationship between GDP indicators and individual indicators of sectors of the economy (for example, passenger flow and passenger turnover of both the country as a whole and its individual airports). In turn, a change in the state of the Ukraine economy affects not only the change in the dynamics of national indicators as a whole, but also the change in the performance indicators of individual regions.

One more indicator is inextricably linked to the value of GDP per capita, which objectively characterizes the degree of development of air transportation and population mobility - the number of flights per year per person. In countries with high per capita GDP, mobility is also great, and in economically underdeveloped countries with low incomes, the intensity of air transportation is also low.

2) The demographic situation affects civil aviation not only in terms of population growth or decline, but also in terms of urbanization, since urban residents have a higher income and therefore more often use the services of air transport. In addition, the growth of cities leads to the formation of aviation “hubs” in them, which stimulates the development of transportation.

3) Globalization and integration processes, which are closely related to political factors, create the prerequisites for the growth of international air travel. An example of how “opening borders" affects international traffic is the situation in Ukraine in the early 90s, when, against the background of a general reduction in traffic, a significant change in the ratio of passenger traffic on domestic and international lines began to take place.

4) The liberalization of the air transportation market is based on the principle that free enterprise and competition contribute to the development of any industry market and meet the interests of consumers. Market liberalization leads to an increase in air traffic and its availability.

5) Due to the fact that passengers are the main source of income for both airlines and airports, each of the parties should strive to influence factors depending on it, contributing to an increase in air traffic, and also eliminating or inhibiting phenomena that reduce air traffic growth (Table 1.1) [16].

Table 1.1

Factors affecting air traffic

Factors	Stimulating Growth	Restraining Growth
Depending on the general economic conditions in the country	- growth in production, GDP; - development of foreign trade relations; - growth of personal income; - population growth; - easing currency restrictions; - market liberalization.	- decline in production, GDP; - a fall in exports / imports; - devaluation of the national currency; - increase in the cost of travel; - high customs payments on - import of new aircraft.
Airline Dependent	- modernization of the aircraft fleet; - increase in fuel efficiency of aircraft; - cost reduction; - improvements in technology; - development of the route network; - high frequency of flights in the main directions; - a developed network of representative offices / sales agents.	- increase in operating costs; - low economic efficiency of the existing fleet of aircraft; - difficulties in updating the aircraft fleet; - difficulties in raising capital, high bank interest rates, large lease payments; - underdevelopment of the airline network.
Airport Dependent	- the presence of a network of airports (hubs and regional) in the country, region; - state support for the airport business; - development of non-aviation services at airports (hotels, restaurants, shops, etc.); - good transport links between the airport and nearby cities; - a large number of airlines served by the airport; - the ability to receive and service aircraft of various types.	- lack, insufficient number of airports in the country, region; - underdeveloped airport infrastructure (number of runways and their characteristics, outdated equipment, lack of new modern terminals, etc.); - the inability to receive and service long-range aircraft of a new generation; - the presence of an airline monopolist; - congestion of airports; - underdevelopment of non-aviation services.

In addition to external factors that influence the global passenger flow and the volume of traffic in the country as a whole, it can be distinguish regional factors that shape the demand for air travel within a specific territory (Figure 1.3.). [10]

Fig. 1.3 Factors determining the results of economic activities of airlines

Considering the whole complex of existing problems, as well as the significant role of air transport in ensuring the livelihoods of the country's regions, the most priority areas for the development of the regional passenger transportation market are the organization of feeder transportation (providing regional airlines with commercial loading of long-haul carriers) and the formation of a basic aerodrome network (creating hub airports hubs that will concentrate passenger traffic from domestic airlines.

1.3. Aircraft turnaround process

While the focus has been put on the improvement of airspace congestion, aircraft ground delays have not relatively received enough attention. An estimate from Austrian Airlines revealed that only 22% of the total costs of flight delays come from direct consequences, i.e. additional airline operational costs; 24% of the total costs come from passengers' permanent disloyalty. Research concerning the relationship between airline market shares and airline performance (in terms of schedule punctuality, service availability and safety records) showed the significance of passengers switching between airlines, once they experience unsatisfactory services from an airline. It has also been found that the significance of turnaround serviceability is not only essential to the improvement of schedule punctuality while turning around aircraft, but also essential to the maintenance of aircraft linkages and aircraft rotation stability. The turnaround time for a short-haul flight is defined as the time for an aircraft to complete full off-loading, loading and where required, catering and cabin cleaning procedures. For long-haul flights, the time including comprehensive technical and cabin services should be considered instead.

Generally, aircraft turnaround time (TAT) is defined as the time that elapses from landing an aircraft to taking off again for a new flight. During this period, the resources of the involved airline and the airport are mobilized to install the aircraft as soon as possible.

The ongoing process consists of scheduling and performing tasks to ensure the cleanliness, safety and efficiency of the next flight. Therefore, working time is one of the most important phases for airport operators, directly affecting whether passengers will enjoy the optimum experience. In short, this involves:

- Proper coordination of all resources involved to ensure punctuality of flight and to keep passengers at least waiting.
- Flawless maintenance to ensure that the journey is incident free and the plane lands on time at the next destination.

Several steps must be taken at the same time to complete the rotation phase effectively. The following steps must be completed before the aircraft can fly again:

1. Aircraft Parking. After landing, the aircraft must move to its designated parking space. Once there, operators responsible for ground handling will be blocked and marked with safe cones.

2. Disembarkation of passengers and crew. Then passengers will leave the aircraft through the doors (usually through one of them) to access the gateway or buses that will take them to the terminal.

3. Cabin cleaning. When passengers leave the aircraft through one of the doors, cabin cleaners will enter through another to remove garbage, clean toilets, and replace consumables.

4. Loading and ramp handling. At this point, operators responsible for loading and handling ramps come into operation. Luggage and goods will be unloaded and transported to the appropriate luggage carousel and warehouses.

5. Airline and aircraft inspection and SOPM. The Aircraft Manufacturer's Standard Operating Procedures Manual (SOPM) and the airline itself determine the technical safety check procedure to be followed when turning to ensure that the aircraft is in good condition. The Standard Operating Procedures Manual (SOPM) of the airplane manufacturer and the airline itself determines the technical safety check procedure to be followed when turning to ensure that the airplane is in good working order.

6. Aircraft refueling. Aircraft tanks should also be filled with the necessary fuel to ensure their safe arrival at their next destination.

7. Catering. Meanwhile, the catering service will provide beverages and food for passengers on the new route.

8. Loading of suitcases and goods. After the aircraft's hold is emptied, the handling agents re-fill it with luggage and cargo for the next flight.

9. Passenger boarding. One of the latest turnaround operations will be to board passengers. While handling all previous tasks, the crew and pilots had to concentrate on confirming the details of the route and the number of passengers, as well as conducting their own safety checks inside the aircraft.

10. Towing the aircraft to the start of the runway. At last and often assisted by a squeeze trailer, the aircraft leaves the parking lot and prepares to start a taxiing maneuver to gain access to the runway.

To keep airports profitable and efficient, ground handling operations are under more pressure than ever to speed up aircraft turnaround times. Turnaround times currently range from 25 minutes for short haul budget airlines, to 90 minutes for long haul premium airlines, during which many different activities must take place.

1.3.1. Passengers boarding

The process of boarding an airplane is of interest to a variety of groups. The public is interested both as a curiosity, as it is something that they may regularly experience, and as a consumer, as their experiences good or bad can affect their loyalties. Airline companies and their employees also have a stake in an efficient boarding procedure as time saved in the boarding process may result is monetary savings, in the quality of interactions with passengers, and in the application of human resources to the general process of preparing an airplane for departure.

A study which was conducted in 2008 by Nyquist and McFadden [11] indicates that the average cost to an airline company for each minute of time spent at the terminal is roughly $30. Thus, each minute saved in the turn-around time of a flight has the potential to generate over $16,000,000 in annual savings (assuming an average of 1500 flights per day). While the boarding process may not be the primary source of delay in returning an airplane to the skies, reducing the boarding time may effectively eliminate passenger boarding as a contributor in any meaningful measure. Consequently, subsequent efforts to streamline the other necessary tasks, such as refueling and maintenance, would be rewarded with a material reduction in time at the gate for each flight.

Several studies of the airplane boarding process exist and many of the conclusions are universal. The optimization is essentially a reduction of the number of times that passengers must either wait for or traverse each other, whether in the aisle (an aisle interference) or within a given row of seats (a seat interference). Some methods resulting from these studies are having the passengers seated at the windows boarding first, followed by the middle and aisle seats (hereafter called “Wilma”). Another method is the “Reverse Pyramid” method which adds an emphasis on boarding the rear of the cabin first. Both the Wilma method and the Reverse Pyramid method specifically eliminate seat interferences and, to differing degrees, aisle interferences.

Many of these previous studies concentrated on methods involving boarding groups rather than having passengers line up in a specified order. Thus, the authors could identify the best method of those that were tested, but it was not known if those methods represented the optimum boarding method overall. Some investigators identified the optimum boarding method under certain assumptions. Steffen method added to the reduction of aisle and seat interferences the idea of efficient, parallel use of the aisle. For example, if passengers are ordered such that the plane boards from the rear window seats, row-by-row to the front aisle seat there would be no seat interferences and no passenger would need to pass another in the aisle. However, in this scenario only the lead passenger or two would be able to stow their luggage — the rest of the passengers would simply be filling the aisle (rather than aisle interferences being eliminated, they are universal).

The Steffen method, on the other hand, orders the passengers in such a way that adjacent passengers in line are sitting in corresponding seats two rows apart from each other (e.g., 12A, 10A, 8A, 6A, etc.). This method trades a small number of aisle interferences at the front of the cabin, for the benefit of having multiple passengers stowing their luggage simultaneously. Other methods, such as Wilma and the Reverse Pyramid also realize parallel use of the aisle in a natural way as adjacent passengers are frequently sitting in widely separated rows.

Practical implementation aside, the Steffen method claims to be the fastest possible method, on average, to board passengers onto an airplane with a single door and a single aisle. Other claims made in Steffen that were tested in this experiment include: 1) random boarding (where passengers have assigned seats, but are allowed to board at any time) should perform as well as Wilma and 2) that boarding in blocks should perform worse than Wilma, random, and the Steffen method. Both of these secondary predictions are based upon efficiency considerations in the use of the aisle to stow luggage — random, Wilma, and the Steffen method spread passengers throughout the cabin while boarding in blocks tends to concentrate passengers in one part of the aircraft. Noted that Steffen does not fully treat seat interferences — which will be a likely source of discrepancy between the predictions in Steffen and reality. Another claim that it was not able to test, but which could be part of a future study, is that due to inefficiency in the use of the aisle, boarding from the back to the front of the cabin is nearly as bad as boarding from the front to the back.

1.3.2. Experimental Setup

In 2008 an experiment was conducted by Jason H. Staffen. The narrow-body mock airplane was used which had 12 rows of six seats with a single, central aisle. A small first-class section (two rows of seats) was used for camera and lighting equipment. The width of the fuselage is 11’ 7”. Each seat has the standard 17” width not including the 2” armrest. Rows of seats are spaced 32” and the aisle was

21” wide. The overhead bins were standard for older-model aircraft, but are slightly smaller than modern bins. In particular, the overhead bins did not accommodate standard size roll-aboard luggage when inserted wheels first.[17]

72 passengers were employed — volunteers and hollywood extras. The ages of the passengers ranged from young children age five through retired seniors with the bulk of passengers being employment-age adults. Passengers generally had a bag, roll-aboard carry-on, or both — though a small number of passengers had no luggage. When all passengers were on board with their luggage stowed there was very little remaining space in the overhead bins — essentially none of which was useful for additional storage. Thus, when the airplane was full, so were the overhead bins; though, there was never a time when a piece of luggage would not fit somewhere in the aircraft. Since excess luggage would likely affect each boarding method in a similar way the relative ranking of the different methods — in terms of the boarding time — should be well established by test.

Each passenger was given a set of five tickets with a seat assignment and either a passenger number or boarding group number (depending upon the method being tested). The methods were labeled numerically so that the passengers did not know which method was being tested. Seat assignments were chosen randomly such that passengers did not sit in the same seat with each method nor were they deliberately placed in the same location in the line or in the same boarding group. The only exceptions to these rules were three parent-child pairs who always had two adjacent seats and who were always at the front of the line, boarding first.

Finally, passengers used their individual luggage for each method (they did not swap luggage with other passengers). One could argue that swapping luggage would make the test of each method more robust. However, it is not clear that this is the case as fatigue with boarding the aircraft several times could mitigate the benefit of practice. Moreover, the adopted scenario is more representative of actual airplane boarding as passengers are likely to have the same or similar bags with them whenever they travel. Also, since passengers were generally not sitting in the same seats and did not board at the same time with each method, the luggage that was already stowed in the overhead bins would be different with each test — adding, to some extent, the desired randomness.

1.3.3. Boarding Methods

The five methods that were tested include: 1) boarding from the back to the front of the aircraft in a specified order, 2) boarding in four-row blocks, 3) the Wilma method, 4) the Steffen method, and 5) random boarding. Each of these methods is described below. Figures 1.4, 1.5, 1.6, 1.7 and 1.8 show the seating assignments or boarding groups:

Front						
						13
8	10	12		11	9	7
2	4	6		5	3	1

Fig. 1.4 Back to front seating order

Front						
2	2	2		2	2	2
2	2	2		2	2	2
2	2	2		2	2	2
2	2	2		2	2	2
3	3	3		3	3	3
3	3	3		3	3	3
3	3	3		3	3	3
3	3	3		3	3	3
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1

Fig. 1.5 Block boarding groups

Front						
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1

Fig. 1.6 Wilma boarding groups

Front						
24						18
12						6
23						17
11						5
22						16
10					28	4
21						15
9					27	3
20						14
8					26	2
19						13
7					25	1

Fig. 1.7 Steffen method seating order

Front						
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1

Fig. 1.8 Random method boarding group

The back-to-front method had passengers in a specific order starting with the back row window seats, then middle seats, then aisle seats. This pattern repeated itself for the rest of the rows moving toward the front of the plane. A naive guess regarding the most efficient method to board an airplane might suggest that this method is optimal as it is orderly, boarding passengers from the back of the plane to the front and from the windows to the aisle, and it avoids all seat interferences—excepting priority boarding.

The block method divided the 12 rows into three groups of four rows. The back four rows were the first group, followed by the front four rows, and finishing with the center four rows. The decision to use this method rather than boarding in blocks from the back to the front was admittedly arbitrary, but it is believed that the results should be representative of either method. Also it was elected to use three boarding groups rather than four so that each group would involve a larger number of rows — making it more similar to what one would expect with a full-size aircraft and capturing more the potential benefit of having more rows available to the passengers in each group.

The Wilma method used three boarding groups with the first group being all window seats, the second being all middle seats, and the third being all aisle seats. Within each group the passengers were essentially random. Thus, this method when followed would avoid passenger seat interferences but would have passenger aisle interferences.

The Steffen method has the passengers lining up in a prescribed order. This order incorporates in a specific way boarding from the back to the front and from the windows to the aisle. Adjacent passengers in line are sitting two rows apart from each other in corresponding seats (e.g. 12F, 10F, 8F, 6F, 4F, 2F). This method attempts to eliminate seat interferences and, as much as possible, aisle interferences while naturally allowing multiple passengers to stow their luggage simultaneously. The separation between adjacent passengers provides some space for each passenger to manipulate their luggage into the bins.

The final method was random boarding with a single boarding group. Since each passenger still had an assigned seat, this method is not equivalent to the free-for-all method where passengers select their seats at will. There is an important distinction between random boarding (where the passengers have assigned seats but not an assigned place in line) and free-for-all boarding. Free-for-all boarding is not random since passengers can make decisions about where to sit once they observe the state of the cabin—passengers can choose to avoid an aisle or seat interference where passengers in the random boarding method cannot.

1.3.4. Results of experiment

For each method there are two reported boarding times. The first “official” time is the elapsed time from when the first passenger set foot in the aircraft until the last passenger was seated. The second “extended” time is the elapsed time from when the passengers were told to proceed to board until the last passenger was seated. These times differ by only a few seconds and both times are reported here; the difference representing the time it took passengers to walk approximately six feet and to climb two stairs into the airplane. Table 1.2 shows the results of the different boarding methods.

Table 1.2

Elapsed time for each boarding method in minutes and seconds

Method	Official Time	Extended Time
Back-front	6:11	6:16
Blocks	6:54	6:56
Wilma	4:13	4:21
Steffen	3:36	3:40
Random	4:44	4:48

There are random fluctuations in the boarding process and that, in the absence of multiple realizations of the experiment boarding times are only estimates of the mean boarding time for each method. It was not feasible to re-run each boarding method several times.

It was noted that there may be some systematic biases at play in results (for example, the quantity and size of the luggage that passengers carried may be somewhat different than what a similar group might take while traveling). This difference, and other differences are more likely to affect the total length of time each method takes to board than they are to affect the ratios of those times. Thus, while times may be systematically low or high compared to what one would experience at a real airport with real travelers, the ratios of those times should be very similar in the different environments. Regardless, given the full capacity of both the airplane and the overhead storage areas, the wide range in passenger ages, and the random nature of the experiment, believed that these potential sources of bias will have a relatively small effect on the boarding times and that results for each method are sufficient for both qualitative discussion and for rigorous comparisons among them.

The boarding time for back-to-front boarding is an estimate of the effect of aisle interferences—which is, in turn, an estimate of the average luggage loading time for sample of passengers. This equivalency between luggage loading time and the time of an aisle interference is only applicable in this method because here the aisle interference happens at or near the row of the blocked passenger. Nominally, back-to-front boarding has no seat interferences, but it does have 71 aisle interferences. This method took just over 6 minutes (360 seconds — allowing the balance of the measured time to account for the time required to walk the length of the aircraft) which gives roughly 5 seconds per interference. Therefore, an estimate of the effective time for a passenger to stow luggage upon arriving at their seat is also 5 seconds — the actual time is likely slightly longer as there arise situations where multiple passengers stow their luggage simultaneously.

The difference in boarding time between random boarding and Wilma gives insight into the delay caused by seat interferences. Wilma nominally has no seat interferences while random boarding does have some. There are 3! = 6 different permutations of the order that passengers sit in their half-row (the three seats on their side of the aisle). The number of seat interferences caused by each permutation ranges from 0 to 3 with a mean of 1.5 (it is assumed for simplicity that the delays for seat interferences in a particular half-row add linearly rather than, say, in quadrature). Thus, a typical passenger in random boarding will be involved in 1.5 seat interferences. However, in relation to the time required to fill the aircraft, not all seat interferences are equivalent. Only seat interferences that cause an aisle interference will have a meaningful affect on the boarding time — a seat interference at the back of the airplane will not block a passenger who is stowing luggage at the front. Approximately half of the seat interferences will cause such an aisle interference (the probability that the subsequent passenger has a seat in a row number greater than or equal to the blocking passenger is actually 1/2 + 1/N, where N is the number of rows in the aircraft—this subtlety will be important later, but here it is simply trying to get a rough estimate of the cost of a seat interference).

Between Wilma and random boarding it is expected to have 1/2×1.5×72 = 54 meaningful seat interferences. The observed difference in boarding times was roughly 30 seconds such that the effective delay for seat interference, in this case, is just under 1 second. The true delay is actually twice this quantity since only about half of the interferences affect the boarding time. At first glance this would seem an underestimate for the time it takes for a seated passenger to stand and switch places with a second passenger. However, much of this maneuvering is done in parallel with the luggage stowing — a passenger typically informs their neighbor, before their luggage is completely stowed, that they will need to move past one another. Thus, the two-second delay is primarily for passengers to file back into their half-row — a reasonable estimate.

Taking these effects into consideration, one may wonder why block boarding fared so poorly. Block boarding allows for some passengers to stow their luggage simultaneously — eliminating some aisle interferences. The particular method which was employed also eliminates some aisle interferences by having the first and second groups sit in different portions of the aircraft. Here is where the subtle difference between random boarding and block boarding might provide an explanation. In random boarding the length of the airplane was 12 rows. In block boarding you are essentially boarding three smaller airplanes of only four rows. Thus, the probability for a particular seat interference to cause aisle interference grows from $1/2 + 1/12 = 0.58$ to $1/2 + 1/4 = 0.75$ which is nearly 30% higher. The number of passengers who can simultaneously stow their luggage is at most two, if one assumes that a passenger needs two rows of space to do so. In random boarding this number grows to six simultaneous passengers — again at most (typically these numbers will be somewhat less).

Thus, if the number of rows in a boarding block is too small, the result is little different than boarding back to front. But, now there are a considerable number of seat interferences, roughly 30% more for airplane geometry. The extreme case is block boarding by single rows where the aisle interferences are exactly what one would get from back to front, but no one expects three seat interferences at the full ~ 2 second cost of a seat interference (all seat interferences affect all passengers). While there is likely some random element to the nearly 45 second increase in boarding time from back to front compared with block boarding, the effect of seat interferences alone would account for nearly 40 of those seconds (30% more than the 30 second difference observed between random and Wilma). Clearly, boarding in blocks of four rows does not help the enplaning process. Blocki of 12 rows, on the other hand, clearly do — the difference between back to front and random boarding (almost 90 seconds) shows this. Said another way, boarding blocks of 12 rows (entire airplane) instead of blocks of four rows eliminates the equivalent of 18 passengers stowing their luggage (due to a combination of reducing the number of aisle interferences and adding a number of seat interferences). Still, in terms of fast boarding times, block boarding will likely never be superior to random boarding — only other considerations would serve to justify its use.

In this test, Steffen method was considerably better than all other methods. By design it has no seat interferences and 11 aisle interferences—passengers enter in 12 sets, but the first set has no interference preceding it. Yet, even in the controlled environment of experiment, this design was not fully implemented. Six passengers (those with small children) boarded first, some passengers will sit in the wrong seat. In short, there is still randomness to the process. This randomness alone cannot explain why the Steffen method did not board in a single minute as one might estimate from eleven aisle interferences of five seconds each.

The primary answer lies in a remaining, characteristic timescale in the boarding process—the time it takes to walk the length of the airplane. This last part is manifest in the nature of the aisle interferences. For back-to-front boarding, the aisle interference corresponds to a 5 second wait for the preceding passenger, after which the blocked passenger can immediately begin stowing their luggage. For random boarding typical aisle interference corresponds to the same 5 second wait, but now it is, on average, in the middle of the aircraft. This wait is followed by a walk of roughly half of the remaining distance to the rear of the cabin to the average location of the passenger's row. The aisle interferences in the back to front method are less severe as there is no subsequent walk. In the Steffen method the aisle interferences are of the worst sort. They occur at the front of the airplane with the entire length of the airplane to traverse once the interference has passed.

If one assumes that it takes roughly one second to walk past each row, then the Steffen method has nearly 2.5 minutes of built-in delays just from walking.

Add the luggage loading time of five seconds at the start of each delay and you are beyond three minutes. Add the seat interferences from the parent/child pairs and an estimate consistent with the observed boarding time of roughly 3.5 minutes takes shape.

From the Steffen method to the Wilma method one trades an increase in the number of aisle interferences for aisle interferences that are less severe (the result of this trade, however, still increases the boarding time). Then, from Wilma to random boarding one adds seat interferences (for the benefit of simplicity and perhaps some unknown amount of customer satisfaction). Block boarding, finally, adds cost to the seat interferences, making them relatively worse in terms of the time they consume as a larger fraction of the seat interferences will cause aisle interferences.

Noted that the estimates which have derived for the time consumed by walking the aisle, seat and aisle interferences, and luggage stowing are all estimates based upon the observed boarding times of the methods. They were made in an effort to properly interpret the results in terms of known factors in the boarding process. A more rigorous study of each of these quantities is beyond the scope of this work, but would serve to provide more understanding the interplay between all of the factors, including some not discussed here, that contribute to the boarding time.

1.3.5. Conclusions of experiment

Experimentally it is proved that there is a marked difference in the time required to board an aircraft depending upon the boarding method used. The evidence strongly supports the heuristic argument from Steffen that methods that parallelize the boarding process by more efficiently utilizing the aisle (having more passengers stow their luggage simultaneously) will board more quickly than those that do not. The relative benefit of the application of this theory will grow with the length of the aircraft. Here, a 12-row mock airplane is used, but a more typical airplane with twice that number of rows will gain more by the implementation of parallelized boarding methods.

How this improvement scales with the cabin length is different for each method. For the Steffen method, the benefit will scale almost linearly. If the airplane is twice as long, the time savings will be nearly twice as much since the density of luggage-stowing passengers will remain the same and the boarding will still be maximally parallel. For Wilma and random boarding the benefit will not be as strong since the benefits of parallel boarding are randomly distributed along the length of the cabin instead of being regularly distributed. For block boarding the benefit will come almost exclusively through an increased size of the boarding group (more rows per group).

Given the observed boarding times, the Wilma method boards faster than block boarding (with four-row blocks) by a factor of almost 1.7 while the Steffen method boards faster by almost a factor of 2. An accurate estimate of the time it would take to board an airplane two or three times as long would take a more detailed study of the relative interplay of the relevant timescales of the problem—the time to stow luggage (i.e., the time consumed by an aisle interference), the time consumed by seat interferences, and the time required to walk the length of the airplane. Nevertheless, even if one simply doubles the boarding times observed here the savings of the Steffen method over the block method would be nearly seven minutes. This savings could be as much as $110,000,000 annually per carrier well over a billion dollars for the industry and likely could be more given the parallel nature of the boarding process. Indeed, a test with a longer aircraft may show surprising results in this regard.

Some practical impediments arise when implementing the Steffen method. However, it was fairly easy to do in experiment, and some carriers already have the customers line up in a specified order (e.g., Southwest Airlines and, more recently, a trial by American) showing that the challenge is surmountable. Other considerations such as companion travelers are also fairly simple to accommodate in the context of the Steffen method and, if done well, would have a marginal, if not negligible, effect on the boarding time. (Specifically, as long as paired passengers are not seated near the front of the aircraft where the primary aisle interferences materialize, they will have a few additional seconds—on average half of the time required to walk the length of the cabin—to stow their luggage and be seated.) While the cost savings of the Steffen, or other optimized boarding method, may not be completely realizable due to maintenance and outfitting time, the motivation to reduce the time required for these other, necessary activities would be increased if passenger boarding was removed as an effective limitation.

2. ANALYTICAL PART

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2.1. Analysis of the activities of PrJSC UIA

2.1.1. General characteristics of PrJSC UIA

Ukraine International Airlines is the flagship airline and the largest Ukrainian air carrier. The head office of the company is in Kyiv, the hub is in the international airport "Boryspil". The company provides passenger and cargo air transportation in the main directions of Ukraine - Europe, USA, Middle East, CIS countries, Asia.

The first flight was operated on the route Kyiv-London-Kyiv on November 25, 1992. This date is considered the birthday of UIA. From the very beginning, UIA operated its flights on Boeing 737 family aircraft, thus becoming the first operator of this type of airliners in the CIS.

The founders of the UIA were the Civil Aviation Association of Ukraine and the largest Irish leasing company Guinness Peat Aviation (GPA). An interesting fact is that one of the founders of the GPA in 1975 was Tony Ryan, at that time Aer Lingus Airlines, who later co-founded the Ryanair low-cost carrier, which was named Ryan.

Following the cessation of Air Ukraine flights in 2002, Ukraine International Airlines became essentially Ukraine's national carrier. Since 2004, UIA has been headed by Yuri Miroshnikov. Miroshnikov's term of office as UIA President has been terminated since September 12, 2019 due to the expiration of the contract. However, he was left a member of the Supervisory Board. It is specified that Miroshnikov is a representative of the shareholder Ontobet Promotions Limited.

Currently, the ex-first deputy director general of the Boryspil Airport, Eugene Dyhne, has been appointed President of the International Airlines of Ukraine.

The corporate governance and control of UIA is carried out by the following bodies:

- General Meeting of Shareholders;

- Supervisory Board;

- The president;

- Revision Commission.

UIA mission: Ukraine's International Airlines is a safe, reliable and profitable airline, whose professional team is proud to provide all clients with consistently high-quality, profitable and competitive services.

The main tasks of UIA are:

- Flight safety;

- Providing a high level of service;

- Introduction of the latest technologies;

- Promotion of the development of the Ukrainian airline industry at the international level;

- Creation of an organization - a reliable employer, uniting professionals in a close-knit team and creating all conditions for their development and self-realization.

UIA's absolute priority is safety, the standards of which comply with the highest international requirements. Ukraine International Airlines was the first in the CIS to receive the IOSA Certificate (International Operational Safety Audit) and was registered in the international quality register IATA (International Aviation Transport Association). At the beginning of 2019, UIA successfully passed the check for compliance with modern operational safety requirements and received its seventh IOSA Operator Certificate. This was another confirmation of the high level of aviation security, operating standards and reliability of the airline fleet.[18]

The IATA Safety Audit Program (IOSA) is a world-renowned and recognized certification system designed to evaluate airline operations management and control systems. The IOSA program is guided by internationally recognized audit principles for quality and is designed to allow audits to be conducted in a standardized and consistent manner. Ukraine International Airlines is the first airline officially registered with IOSA in the CIS to successfully pass the IATA Security Audit (IOSA). UIA has become the 51th registered IOSA carrier of 230

IATA members, joining companies such as KLM, Lufthansa, Austrian Airlines, TAP and SAS, which are in the IOSA registry.

UIA's position in the Ukrainian air transportation market has changed dramatically since 2012. Moreover, the main change was due to the bankruptcy of a competitor - JSC Aerosvit. While UIA's share was about 28% in 2010-2011, it rose to 54% in 2013 (after the bankruptcy of Aerosvit). In the following years, the share of the airline continued to grow amid the departure of other airlines from Ukraine. In 2014, UIA's share reached 56.9%, in 2015 - 76%, in 2016 - about 73%.[19]

According to the results of 2018, Ukraine International Airlines of Ukraine (UIA) carried over 8 million passengers, which is 15% higher than in 2017.

Dynamics of changes in passenger flow of airline is shown on Figure 2.1.

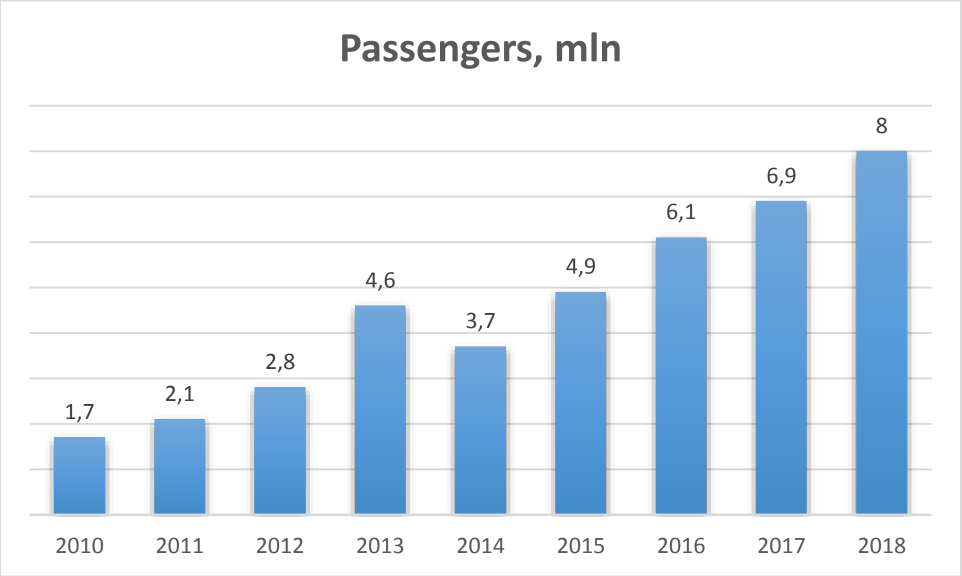

Fig. 2.1 Volume of transported passengers

At the same time, the share of transfer passengers on UIA regular flights amounted to 53%.

The carrier performed 9% more flights compared to 2017. The passenger seat occupancy rate was 81%. The volume of transportation of goods and mail increased by 12%, the report said.[20]

On November 16, 2018, the airline carried its 50 millionth passenger.[20]

UIA has a JAR-145 certificate, which gives the right to a full cycle of maintenance of Boeing equipment, including the implementation of complex forms of maintenance C-Check and D-Check. Certified by IOSA and IATA, as well as by the European Air Traffic Safety Agency (EASA).[19]

Currently, the airline operates about 1100 international and domestic flights per week, connecting Ukraine (Kyiv, Lviv, Zaporozhye, Dnipro, Odessa, Kharkov, Ivano-Frankivsk, Vinnitsa, Kherson, Chernivtsi) and 40 capitals and major cities in Europe, the CIS, and Northern America, Asia, the Middle East and Africa. UIA also provides connections with the routes of its international partners in more than 3,000 destinations around the world.

As of November 2019, UIA has entered into code-sharing agreements with the following airlines:

- airBaltic
- Air france
- Air Moldova
- Austrian airlines
- Azerbaijan Airlines
- Belavia
- Brussels airlines
- Egypt air
- Iberia
- KLM
- Swiss International Air Lines
- TAP Portugal
- Turkish Airlines

Ukraine International Airlines' fleet consists of 35 modern airliners: 3 wide-body long-haul Boeing 777-200ER aircraft, 2 long-haul Boeing 767-300ER, 23 medium-haul New Generation Boeing 737, 5 medium-haul Embraer-190 and 2 medium-haul Embraer-195.[21]

Tables 2.1 and 2.2 illustrate fleet composition of Ukraine International Airlines. There is highlighted quantity of each aircraft type, its capacity and maximal range.

Table 2.1

UIA Fleet

Aicraft	Current quantity	Ordered	Passenger capacity		
			C	Y	Total
Boeing 737-800	24	0	-	186	186
Boeing 737-900	4	0	-	215	189/215
Boeing 767-300ER	4	0	12	249	261
Boeing 777-200ER	3	1	21	340	361
Embraer E190	5	0	12	92	104
Embraer E195	2	0	12	96	108
Boeing 737 MAX 8	0	3	-	-	-

Table 2.2

Technical features of UIA aircraft[21]

BOEING 777-200ER	
Max. cruising speed	905 km/h
Seating capacity	361
Max. range approx.	14 260 km
Number of aircraft	3

Table 2.2 Continuation

BOEING 767-300ER	
Max. cruising speed	850 km/h
Seating capacity	261
Max. range approx.	11 070 km
Number of aircraft	2
BOEING 737-800	
Max. cruising speed	940 km/h
Seating capacity	186
Max. range approx.	6000 km
Number of aircraft	19
BOEING 737-900	
Max. cruising speed	970 km/h
Seating capacity	189/215
Max. range approx.	6000 km
Number of aircraft	4
EMBRAER-190	
Max. cruising speed	890 km/h
Seating capacity	104
Max. range approx.	3300 km
Number of aircraft	5
EMBRAER-195	
Max. cruising speed	890 km/h
Seating capacity	116
Max. range approx.	3990 km
Number of aircraft	2

Compared to 2018, UIA reduced its fleet from 45 to 41 aircraft, discontinuing the operation of the age-old Boeing 737 Classic aircraft. The average age of the fleet increased from 11 to 11.7 years. The airline has the youngest regional fleet, consisting of five Embraer 190 and one Embraer 195 (average age 8 years). The oldest is a long-haul, including four Boeing 767-300ER and three Boeing 777-200ER with an average age of 22.6 years.

The fleet now consists of 28 Boeing 737 Next Generation airliners with an average age of 9.7 years.

The youngest aircraft in the airline's fleet are three Boeing 737-800s received in 2018 directly from the factory. The oldest are the four Boeing 767-300ERs from 1991-1993.

UIA average age by aircraft family:

- Boeing 737 Next Generation - 9.7 years
- Embraer 190 - 8 years
- Boeing 767-300ER - 27 years old
- Boeing 777-200ER - 16.7 years[22]

Table 2.3 shows the rating of Ukrainian airlines by the average age of the fleet. Based on this table, it can be seen that UIA takes second place after SkyUp.

Table 2.3

Rating of Ukrainian airlines by fleet age

Airline	Fleet average age 2019 year	Fleet average age 2018 year	Dynamics
SkyUp	11,5	8,7	2,8
UIA	11,7	11	0,7
Wind Rose	18	17	1
Atlasjet Ukraine	18,5	17,5	1
Azur Air Ukraine	21,2	17,7	3,5
Jonika	23,3	—	—
Anda Air	27	26,8	0,2
Yanair	27,1	26,1	1
Bravo Airways	28	25,4	2,6
Dream Wind	28,5	—	—
Bukovyna Airlines	29	24,3	4,7

Table 2.3 Continuation

UM Air	30	29	1
Motor Sich	38,9	37,1	1,8

UIA called the year 2019 the year of stabilization - the company did not plan to increase the fleet, but only to update it, replacing older aircraft with new ones. There were also no plans to expand the geography of flights. The plans were to achieve net profit [**Ошибка! Источник ссылки не найден.**].

At the end of October 2019, Ukraine International Airlines announced the launch of large-scale optimization of flights in the eastern and western directions in order to return the business to the breakeven zone. In 2020, airline flights from Kyiv to Krakow and Bangkok will disappear.

In 2020-2022, earlier, the opening of new directions was planned: 2020 - Uzhgorod, Dublin, Manchester, Bologna, Gdansk, Bishkek, Kuwait, Miami, Guangzhou; 2021 - Zagreb, Varna, Tallinn, Erbil, Seoul; 2022 - Belgrade, Bratislava, Beirut, Shiraz, Addis Ababa, Chicago.

By 2021, the number of UIA employees will increase to 5 thousand people. At the same time, personnel per one aircraft, on the contrary, will decrease from 80 to 68 people / aircraft, which indicate greater efficiency [**Ошибка! Источник ссылки не найден.**].

2.1.2. SWOT-analysis of UIA

- **S - Strengths**

1) Security is an absolute priority. UIA was the first in the CIS to be registered in the international quality register IATA;

2) Convenient flight schedule for all categories of passengers;

3) Wide route network. The airline connects Ukraine with key cities in Europe, Asia, the USA, the CIS countries and the Middle East. Together with partners, UIA offers more than 3,000 destinations around the world;

4) Implementation of both passenger and freight traffic;

5) Loyalty program for frequent flyers “Panorama Club”;

6) Extensive experience in group transportation;

7) Extensive infrastructure (branches and representative offices in Ukraine and abroad);

8) The presence of international certificates of quality and safety.

- **T - threats**

1) Low purchasing power of the population of Ukraine;

2) Unstable political situation in the country;

3) Increased competition from foreign airlines;

4) High prices for jet fuel;

5) Falling demand for passenger transportation;

6) Seasonality of demand.

- **O- opportunities**

1) Continuous development and implementation of new types of services and tariff plans for both regular customers and in order to attract new;

2) Increase in own scheduled flights;

3) Opening of new directions, routes;

4) Fleet increase;

5) Possibility of joining international airline alliances;

6) Getting the potential benefits of using a marketing approach, including the use of foreign experience in this area;

7) Regular staff development.

- **W - weaknesses**

1) Weak image of airlines in the global market;

2) Poor knowledge of spoken English by airline staff;

3) High dependence on the solvency of the population.

SWOT is analysis, a tool for understanding and making decisions for any type of situation in an organization. Existing companies like Ukraine International Airlines can use SWOT analysis at any time to evaluate environmental change and proactive response. In fact, it is recommended that the strategy meetings be held at least once a year, beginning with a SWOT analysis. SWOT analysis headers provide a good basis for reviewing the strategy, position, and direction of a company proposal or any other idea. SWOT analysis is used for planning, strategic development, competitor appraisal, marketing, business development and research reports. The SWOT pattern allows you to think more actively than to rely on habitual or instinctive reactions.

Analyzing the main indicators of the airline, it will taken into account such aspects as financial and production indicators.

Directions and types of foreign economic activity of UIA:

• Expansion of the route network by increasing the number of own flights from Ukraine to Western Europe and Asia;

• Extension of the route network by increasing the number of charter flights;

• Expanding the network of its routes by increasing freight traffic;

• Collaboration with foreign partner airlines;

• Education and training of specialists on a commercial basis.

UIA now has agreements on mutual settlements with 126 airlines, including all the world's leading carriers. In order to strengthen its global presence, UIA has established close partnerships with many of these airlines. Through partnerships and agreements with more than 680 airlines in the world, UIA can deliver to more than 3,000 destinations worldwide.

UIA is actually the No. 1 carrier between Ukraine and Western Europe. UIA connects Ukraine to the world with convenient and durable air connections, providing the best connections with Western Europe to all airlines operating in Ukraine.

2.1.3. Cost analysis

Airline costs are growing in line with its revenue, increase in passenger flow and the number of flights. This is due to the high costs of aircraft. They absorb most of the money while passenger services and implementation costs are low.

The cost of one UIA flight includes the following items: fuel price, salary for flight crew and cabin crew, flight crew and cabin crew meals, aircraft maintenance, navigation fees, airport take-off and landing fees, passenger fees, on-board meals for passengers, expenses for booking and ticket sales by agencies (commissions), aircraft leasing, spare parts leasing, insurance, administrative expenses. All items of expenses listed above are conditionally subdivided into operating expenses, expenses relative to other organizations and firms, salary expenses and administrative expenses.

The first group includes fuel for takeoff and landing, navigation, maintenance. The second group includes those related to aircraft leasing, spare parts leasing, and insurance. The third group consists of the salaries of pilots and flight attendants, salaries of a different composition, travel expenses, studies of flight personnel and flight attendants, consultations of foreign specialists, on management and marketing, advertising, and other administrative expenses.

Fuel and navigation charges are, on average, 10 and 8.8% of the cost of a flight, and airport charges are 12.8%. Charges for navigation (span of the state) are set by Eurocontrol. One of the most significant and important expense items is airport taxes. Services at airports that are members of IATA are based on the IATA Standard Ground Handling Agreement.

The cost structure of the airline is presented on Fig. 2.5.

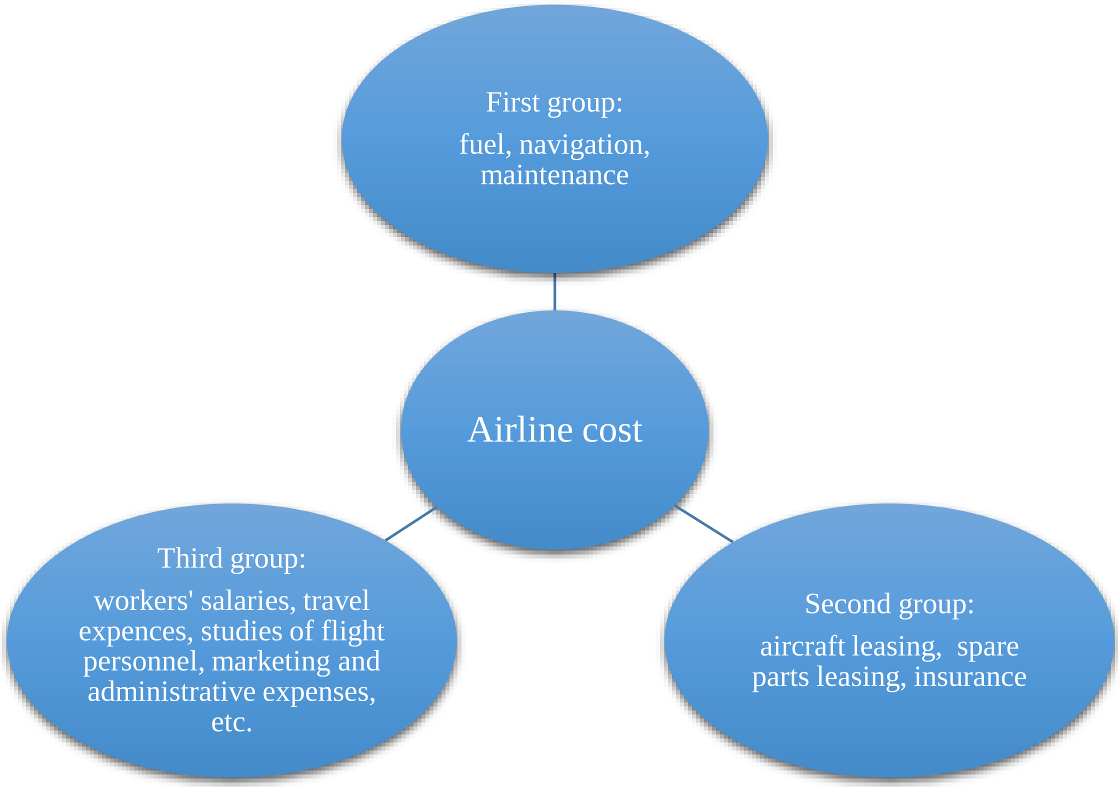

Fig.2.4 Structure of airline's cost

The main source of cost savings in current conditions in the aviation industry is the use of advanced technologies. Technological changes aimed at improving the efficiency of the aviation transport system must be constantly supported by continuous investments in aviation research and development of new equipment and new technologies. However, at the present stage of development of the enterprises of aviation industry, own funds obtained from profit and depreciation are not enough for technical updating, and attraction of borrowed funds, in conditions of high inflation, unstable market situation, is quite problematic.

In such circumstances, it is difficult for Ukrainian airlines to achieve the level of profitability and efficiency inherent to foreign airlines. The difference in performance can be seen by analyzing the cost structure. In foreign airlines depreciation is 6%, they have more opportunities for updating the air fleet. Much more money is spent on maintenance than Ukrainian airlines. This makes it possible to maintain the equipment in good condition, reduce the cost of major repairs, and update the equipment as needed. In addition, new aircraft have higher fuel efficiency, which significantly saves fuel in the face of ever-increasing prices.

Reducing the amount of resources consumed leads to productivity gains, that is, lower unit costs. This reduction in airline costs is used to reduce actual fares paid by passengers and shippers, or to improve financial results.

Another factor that affects the competitiveness of an airline, its efficiency, is intellectual capital. The components of the intellectual capital of the airline are: human capital embodied in the employees of the company in the form of their experience, knowledge, skills; intellectual property, infrastructure and market assets.

In the typical structure of the personnel of the airline, which has developed in the world practice of air transport, the following components are distinguished by the number of personnel: flight - 10%, technical - 25%, commercial - 50%, administration - 15%. The organizational structure of the personnel of the Ukrainian airline is somewhat different in size from the foreign one. In the national airline, most of the personnel are in the flight and aviation warehouse, that is, personnel directly involved in the transportation process. Foreign airlines receive most of their profits from non-aviation activities. This is confirmed by the data: commercial staff accounts for half of the workforce. In the Ukrainian airline, such a structure is due to the use of outdated equipment, which requires high labor costs for maintenance and repair; the country's legislation does not facilitate the development of non-aviation activities.

Also important factor is the quality of staff, his level of training, professionalism. Due to the low level of wages, there is a problem with updating the intellectual resources of the aviation complex (the young designer receives 10,000-12,000 UAH per month). Low wages cause an outflow of staff. A similar picture is with test pilots, whose salary is in the Antonov ASTC is at best 1,000 USD per month. Airlines from Southeast Asia and the Middle East offer a salary of 5,000-10,000 USD for much easier work for pilots on commercial flights

Therefore, the main task of the airline in today's conditions is to ensure the efficiency of its activities by introducing innovations in conditions of scarce resources.

UIA celebrates the year 2019 with a stable growth in passenger traffic, a huge route network, a built-up business structure and a fleet ready to provide it.

The reverse side of the coin is a loss of UAH 2.7 billion against UAH 304.51 million in 2017 and an increase in the debt portfolio (Fig. 2.6) [26]

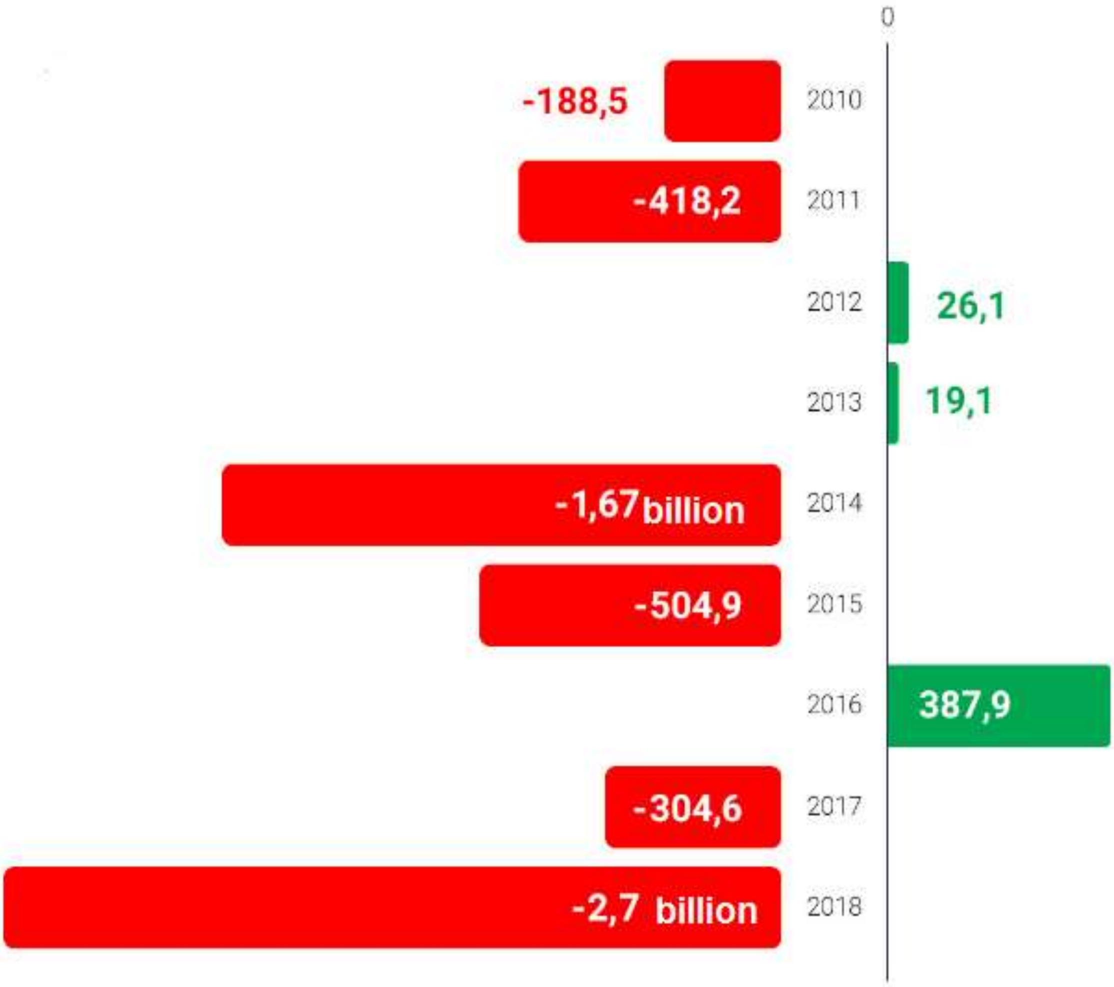

Fig.2.5 UIA financial result, mln. UAH

.The management of the company faces a non-trivial task - to stay afloat in the increasing competitive field. An alternative is to leave the market. A similar story was already in Ukrainian aviation. In 2013, AeroSvit Airlines, among which Igor Kolomoisky was also a shareholder, was unable to pay its debts and went bankrupt.

The state also has a difficult choice - to leave it as it is or to save the country's main airline. The first option is fraught with the bankruptcy of the system carrier and the collapse in the aviation market, the second with billions in costs to save it.

Regardless of who holds the post of president of the company, he will face the need to solve the UIA problem. This may be nationalization following the example of PrivatBank, or targeted financial assistance.

Financial statements alone are not enough to draw conclusions about the state of the carrier. But the situation is alarming. "It can be seen that the company was operating at a loss, and was making ends meet solely because it was increasing accounts payable (that is, it did not fully pay for goods and services) in the amount of UAH 1.4 billion.

According to the president of the company, the sharp increase in the cost of fuel (at this point takes 30% of the UIA cost structure), the cost of updating the fleet and the high rates for navigation at Ukrainian airports are to blame. In addition, the airline lost money on flying around the closed airspace of the Russian Federation, Crimea and the ATO zone when flying east.

A six-month delay in the delivery of three Boeing 777s cost the company $ 20 million. UIA sold tickets for the declared routes for operation based on the capacity of Boeing 777, but in fact flights had to be operated on a Boeing 767, accommodating 100 passengers less. Within six months they were sent by flights of other airlines at the expense of UIA.

Another $ 7-8 million airline annually overpays on fuel due to excise taxes, which are not in Europe. It turns out extra $ 50- $ 60 per ton.

The airline was not able to develop a viable model of work in the conditions of constant turbulence of the Ukrainian market.

After UIA took over most of the profitable AeroSvit routes and part of its fleet in 2013, the company faced a growing pain.

The problem was exacerbated with the war in the Donbass, a stagnant economy and the devaluation of the hryvnia.

In 2013-2014, UIA almost doubled, while domestic passenger traffic in Ukraine fell whiter than 40%. As a result, foreign airlines began to close flights, and UIA declared a 1.67 billion UAH loss.

Solving the problem of low domestic demand, the company took the path of lowering prices by impoverishing the product. The actions are essentially correct, but in 2014-2015 it did not work out to explain this to passengers correctly.

The carrier completely lost the information field. Previously, a ticket conditionally cost $ 200 (1600 UAH), but it began to cost $ 150 (4000 UAH). Passenger incomes did not increase. As a result, UIA was faced with rejection of the new policy by the client.

The situation was aggravated by the closure of the Russian sky in 2014. Previously, flights to Russia for UIA were one of the most profitable. The fleet involved in the Russian directions had to be transferred to unprofitable routes - just so that the planes would not stand.

The company was forced to fly anywhere, even to Tehran, if only the plane would somehow pay off. Because every month it is need to pay $ 100,000 for leasing a plane, and sometimes up to $ 500,000. The more hours in the sky, the more you can "fall" on the fare and compete.

The network model also did not work as it should. The share of transit passengers in the passenger traffic structure of UIA is only 53%. They bring little money.

As the ex-president of the company Yuri Miroshnikov explains, the transit flow is attracted by a low price, which convinces the passenger to fly from east to west not through Istanbul, Sheremetyevo, Warsaw, or Frankfurt, but through Boryspil.

In the best case, half the plane flies "to zero." The rest is at the expense of UIA. Indeed, how can you attract a passenger to fly longer (by flying around the territory of the Russian Federation), with a smaller step of seats, without food - only at a price. As a result, when the cost of a chair is $ 100, there is a choice: nothing to get by sending an empty board or at least $ 20 to get from a chair - the loss is already less.

Another problem of the company is a large number of customers flying at "no baggage" tariffs. As a rule, they choose a carrier not for service, but for a low price. As soon as it increases, this passenger will leave to competitors.

As a result, in 2018, UIA was in a situation where the growth in passenger traffic did not lead to an increase in profitability.[27]

At the end of October 2019, Ukraine International Airlines announced the introduction of a break-even flight program. UIA has decided to optimize the hub system at Boryspil International Airport, taking into account fluctuations in demand, transit flows, forecasts of the Ukrainian economy and the situation with the need to fly around the Russian Federation. The reduction of the flight program is due to the need to optimize the costs of the airline and return it to the break-even zone. The new schedule was introduced from November 16, 2019 for the entire winter and summer seasons of IATA 2019/2020 navigation.

According to the program, all UIA scheduled flights to Western Europe will be operated during the day with departure from Kyiv in the period 9:30 - 10:30 and arriving in Kyiv between 17:30 - 18:30 local time. The frequency of flights between Kyiv and Brussels, Copenhagen, Stockholm and Madrid will increase to daily. Twice a day flights will be operated on the routes Kyiv - London - Kyiv and Kyiv - Vilnius - Kyiv.

All UIA scheduled flights to Cairo, Dubai, Ankara, Izmir, Yerevan, Baku and Tehran will be operated at night with departure from Kyiv and arriving in Kyiv in the morning. Flights to Tel Aviv, Istanbul and Tbilisi will operate several times a day.[28]

Due to the negative profitability, UIA will suspend flights to Amman, Minsk and Riga.

At the same time, UIA will continue to provide regular air services between the cities of Ukraine, connecting the capital with Odessa, Kharkiv and Lviv with two flights a day, and with Dnipro, Kherson, Chernivtsi, Zaporizhzhia and Ivano-Frankivsk daily.

During winter navigation, UIA flights between Kyiv and Toronto will increase from two to three a week. Also, from November 17 there will be changes in the schedule of flights from New York to Kyiv. The flight schedule from Kyiv to New York remains unchanged. Flights to the US and Canada will be performed on Boeing-777 aircraft.

The number of weekly flights between Kyiv and Delhi will increase to five in the winter 2019/2020 season and then to seven in the summer 2020 season. UIA will operate Boeing-767 aircraft on this route.

The air service between Kyiv and Beijing will be suspended and the frequency of flights on the Kyiv - Bangkok - Kyiv route will be reduced to 3 weekly flights. Such changes came into force on November 16 and will continue to be effective until the Government of Ukraine develops an effective decision to create a level playing field for Ukrainian and foreign carriers when operating flights with the territory of the Russian Federation.

Due to changes to the long-haul flight plan, the operation of duplicate overnight flights and duplicate UIA day flights in the east will be reduced.

From 2015 to the present, top management and shareholders of PrJSC have focused on implementing and expanding the Modern Business Process Reengineering program, the essence of which is to save costs and generate additional revenue. This program has been successfully running for the fourth consecutive year and saves significant financial resources that are redirected to the development of the most promising areas in the future. The main projects and perspective directions of development of the airline, which the top management of PrJSC "International Airlines of Ukraine" has been working on for the last years:

- One of the first projects launched at the end of 2014 to save financial resources at PrJSC was the Electronic Onboard Crew Portfolio. This program made it possible to replace paper directories and programs for the calculation of runways with a total weight of almost 50 kg on electronic tablets, which were agreed by the authorized body. This made it possible to reduce fuel consumption per year by more than 120,000 kg, i.e. to optimize and facilitate the operating conditions of the airline’s flight crew;

- Switch to its own AMOS maintenance organization, which allows to plan, optimize and control the maintenance of the UIA fleet in such a way as to minimize airplane downtime, taking into account the flight load of the aircraft and the entire history of technical support for each vessel;

- Implement a project for centralized aircraft centering calculation to reduce costs and ensure flight safety. This project had a positive impact on the planning and analysis of commercial traffic congestion, as well as on improving the efficiency of mail and cargo transportation, which in turn led to fuel savings;

- Ground handling time of the “rotating” flight was reduced to 40 min due to optimization of the ground services interaction and due to the timely completion of tasks during the preparation of the aircraft for the flight, which led to an increase in the total flight hours of the aircraft;

- Improving the accuracy of fuel refueling calculations and reducing the level of additional “spare” fuel makes it possible to save on the transportation of excess weight by airplane in both directions. This project was carried out in two stages, namely: the analysis of fuel costs in all directions and on different types of aircraft, as well as an individual calculation of fuel costs for each type of aircraft. Through the implementation of this project, the company has minimized fuel costs for each flight by up to 1.5%;

- Reduction: Airplane weights, fuel consumption and CO_2 emissions by upgrading the interior of the aircraft, namely the replacement of passenger seats with more modern and lighter ones. Thus, after replacing 8 rows of seats, the aircraft became 130 kg lighter;

- A staff mobility enhancement program has been launched at the airline's maintenance department, which reduced flight delays for technical reasons and reduced the cost of an aircraft parking at an airport, which averages $ 1,500 per day;

- An international roaming cost optimization program is in place, as the airline must keep in touch with partners and employees who are performing their business abroad. UIA's top management has been able to sign lucrative corporate agreements with cellular operators to help the airline reduce operating costs by up to 40% in one minute;
- The transition to carbon brakes for modern types of Boeing 737 NG (New Generation) aircraft makes it possible to increase the number of cycles of their operation as opposed to steel ones, while reducing the aircraft's weight by 300 kg and thus reducing fuel consumption and CO2 emissions;
- International Airlines of Ukraine is constantly working to increase the number of discounts for airport services and hotel stay. Due to the acquisition of new destinations and increasing their frequency in existing destinations, the airline gives guarantees for the continued use of airport services, handling companies and hotels, using high reputation capital, in response to which the company receives significant discounts;
- Having worked in various directions, the top management of the airline analyzes the activities of PrJSCs outside the base airports, which makes it possible to replace the service provider through tendering (in the absence of monopolized services at any of the airports).

It should be noted that the problem of obtaining forecast information about the external environment of the airline, which is a feature of modern development, which is a high degree of uncertainty, is much more complicated. When forecasting the future state of the internal environment, businesses that operate in the international market, deal with both managed (objects, events and phenomena) and unmanaged factors. Forecasting difficulties in this case are due, first of all, to the increase in the number of uncontrolled (compared to domestic companies only) factors affecting the airline's domestic business and expansion of the geography of doing international business, as well as being accounted for in the process of forecasting its future characteristics. The problem is exacerbated by the fact that the development of a strategy for the development of international competitiveness of the company should take into account the medium and long-term prospects, which are not always inherently high accuracy and reliability. At the same time, the short-term prospects for the development of international competitiveness of the enterprise should not remain outside the attention of top management of the airline.

3. DESIGN PART

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3.1 The aircraft turnaround time

Aircraft turnaround is the orderly process of all the activities carried out on the aircraft since it arrives to its assigned gate until it is ready for departure. Some of these activities can be developed in parallel, while others have to be completed following a sequential path. Thus, for example, disembarking, cabin cleaning, and boarding of passengers are sequential activities, while baggage loading and passengers boarding can be done in parallel. Turnaround times are not the same for all flights, since they depend upon several factors. Thus, for instance, the length of the flight is essential when planning the turnaround time. If the flight is a long distance one, the turnaround time will typically be greater, since it usually affects a large-size aircraft. The type of flight is also relevant when planning the turnaround: often, an international flight where customs and immigration controls are requested might require longer turnaround times than domestic flights. The type of airline must also be taken into account: low-cost airlines tend to perform just the strictly necessary tasks, since its main objective is to minimize costs – including turnaround times. For example, on certain low-cost flights it is possible that catering operations are not required. On the other hand, traditional companies – who are looking for a greater customer's satisfaction – might perform longer turnaround processes with complementary activities.

The main activities related to the turnaround process are represented in Fig.3.1:

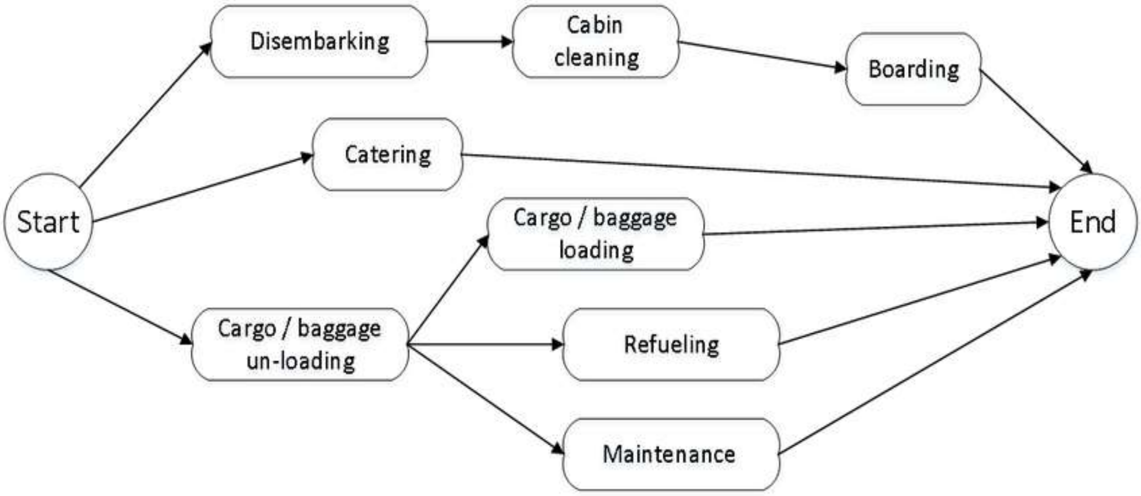


Fig. 3.1 Graph representation of a turnaround process

1) passengers' boarding/disembarking, either if the aircraft is located in a remote stand or adjacent to a finger;

2) luggage loading / unloading, either if bulk containers are used or not;

3) refueling, which is only allowed if certain security conditions are satisfied;

4) routine maintenance, i.e., tasks related to a basic verification of the aircraft conditions to start a new flight;

5) catering loading / unloading, if any;

6) cabin cleaning, which is carried out in the time period between passengers' de-boarding and the subsequent boarding;

7) security procedures, which refer to certain checks that must be carried out to ensure the proper functioning of the aircraft systems – e.g., checking of the evacuation ramps, oxygen masks, fire-prevention systems, etc.;

8) preflight checklist, which refers to verify the proper functioning of all the basic flight systems in the aircraft – this task is carried out once the boarding has finished and before starting the takeoff operations.

Ukraine International Airlines use a traditional turnaround structure, which includes all main stages of process. Cleaning is performed after all performed flights, catering is always provided at least for business class passengers and for sale. Also, company has license for cargo transportation. Being a major national carrier, all aircraft usually carry not only passenger baggage, but also tons of cargo. Thus, unloading/loading of cargo compartments takes more time than only luggage unloading/loading. The increased load of the aircraft requires more fuel. Thus, refueling takes longer. And for safety, boarding passengers is only done after refueling, even if all the other necessary cabin procedures are long over.

3.1.1 Related work

In the scientific literature, there are two main approaches for analyzing aircraft turnaround processes. In the 'task-based' approach each activity is individually analyzed considering its completion time and how it contributes to the completion time of the entire stage. By analyzing these individual activities, critical paths can be identified and policies to reduce potential bottlenecks will be proposed. On the contrary, in the 'aggregated' approach no details on the activities are provided. Instead, the main goal is to decide about the size of a buffer time that can be allocated in order to optimize the trade-off between delay costs –generated by unexpected delays in the turnaround stage – and the cost of keeping the aircraft at the airport during more time than necessary.

In this paper focus is on the task-based approach, where turnaround activities are typically analyzed using the classical project evaluation and review technique (PERT). The use of this technique has two correlated objectives: firstly, to assess and improve the efficiency of the operational processes carried out by the airline; secondly, to assess and improve the efficiency of the allocation of human resources. Fig. 3.1 shows a representation of a classical turnaround process, in which up to five paths can be distinguished. One of the goals of approach is to determine which of them has more probabilities to be the critical one (i.e., the one requiring more time to be completed) as well as how random delays in any of them will affect the random completion time of the entire stage.

In most of the studies carried out in the literature, completion times associated to each activity are considered to be a single deterministic value (i.e., the expected time). In order to introduce a more realistic version, some authors propose to consider three possible (yet still deterministic) times for each activity:

- an optimistic completion time;
- an 'average' completion time;
- a pessimistic completion time.

In addition, some authors propose the use of Markov Chains to simulate the dynamic and stochastic behavior of the different turnaround activities. The corresponding model is applied to two sequential streams of critical activities: 'cargo and baggage handling' and 'cabin cleaning and passenger processing'. For each of the streams their main states and potential disturbances are defined. Probability distributions, such as the Exponential, Beta, and Normal are used for modeling of the completion times of each activity – this is a conceptual mistake probably imposed by the method employed, since it would be much convenient to use Weibull or lognormal probability distributions for modeling non-negative random times. In addition, four independent events causing frequently delays in the turnaround process are added to the model: a fueling delay, a delay while switching aircrafts, a delay due to a damaged aircraft, and a delay in maintenance checks. The model is offered to airlines as a tool to explore their turnaround processes and their potential bottlenecks.

Yet, other authors propose to model the problem as an extended resource-constrained project scheduling problem (x-RCPSP). The x-RCPSP is based on the definition of alternative activities, i.e., different ways to perform the same activity in a faster way by allocating additional resources to it. Thus, for example, an alternative activity for the disembarking of passengers using only one door would be to do it using two doors (although the cost would be higher, the completion time would be significantly reduced in most cases). The idea behind the x-RCPSP is to offer managers the possibility of dynamically adapting their decisions in response to unexpected events, e.g., if an aircraft arrives late at the boarding gate, the manager can decide to use alternative activities that will reduce the effect of accumulated delays.

3.1.2 Combining simulation with survival analysis concepts

Several authors have studied in detail different ways of combining Monte Carlo as well as discrete-event simulation with survival analysis. As suggested in some of these previous works, it will be assumed that the completion time associated with each task can be modeled as a random variable. These random variables will follow a series of given probability distributions – most likely, a Weibull or a lognormal probability distribution. Then, in order to analyze the probabilistic behavior of the turnaround process we are interested in estimating its associated survival function, i.e., the function that determines the probability that the process is still 'alive' (not finished) at any target time in the future. Given fixed target time $t_i \geq 0$, the goal is to estimate the probability that the turnaround process will still be 'alive' (not completed) at t_i. In this case, the process will still be alive as far as any of the different paths of activities is not completed yet. In other words, the turnaround process will be completed as soon as all the mandatory paths are terminated. The status of the process at any given time can be then considered as a Bernoulli random variable (either finished or not), and the previously described probability can be estimated by using Monte Carlo simulation and computing the ratio between the number of times that the process is still operative at t_i and the number of simulation runs. Of course, confidence intervals for these estimates can also be obtained.

Being able to compute the survival function associated to a turnaround design might provide interesting insights for the decision maker. For instance, it might be the case that alternative feasible designs (i.e., different combinations of paths satisfying the order constraints) might generate different survival functions with varying probabilistic behavior – even if they have similar expected completion times. Thus, Fig. 3.2 shows the survival functions associated with two different turnaround designs. [31]

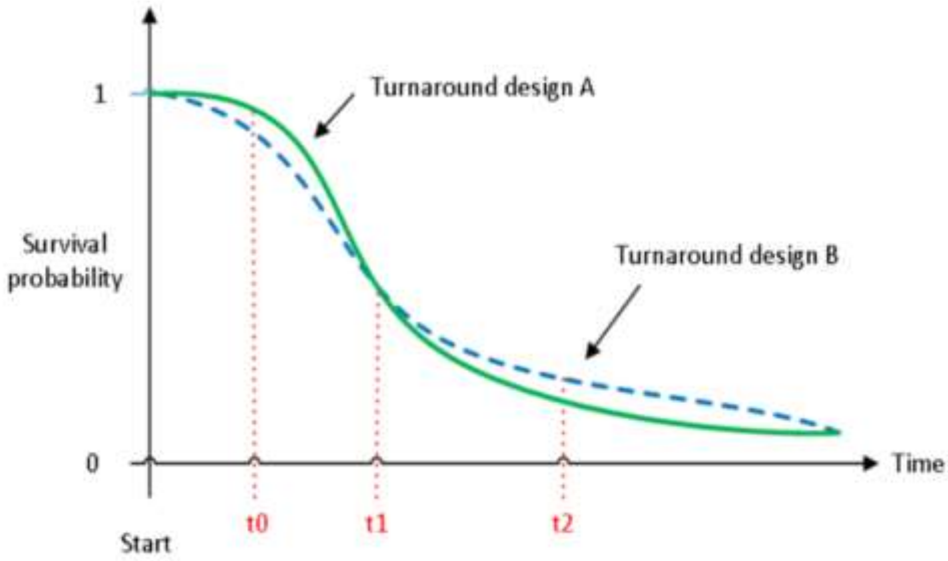


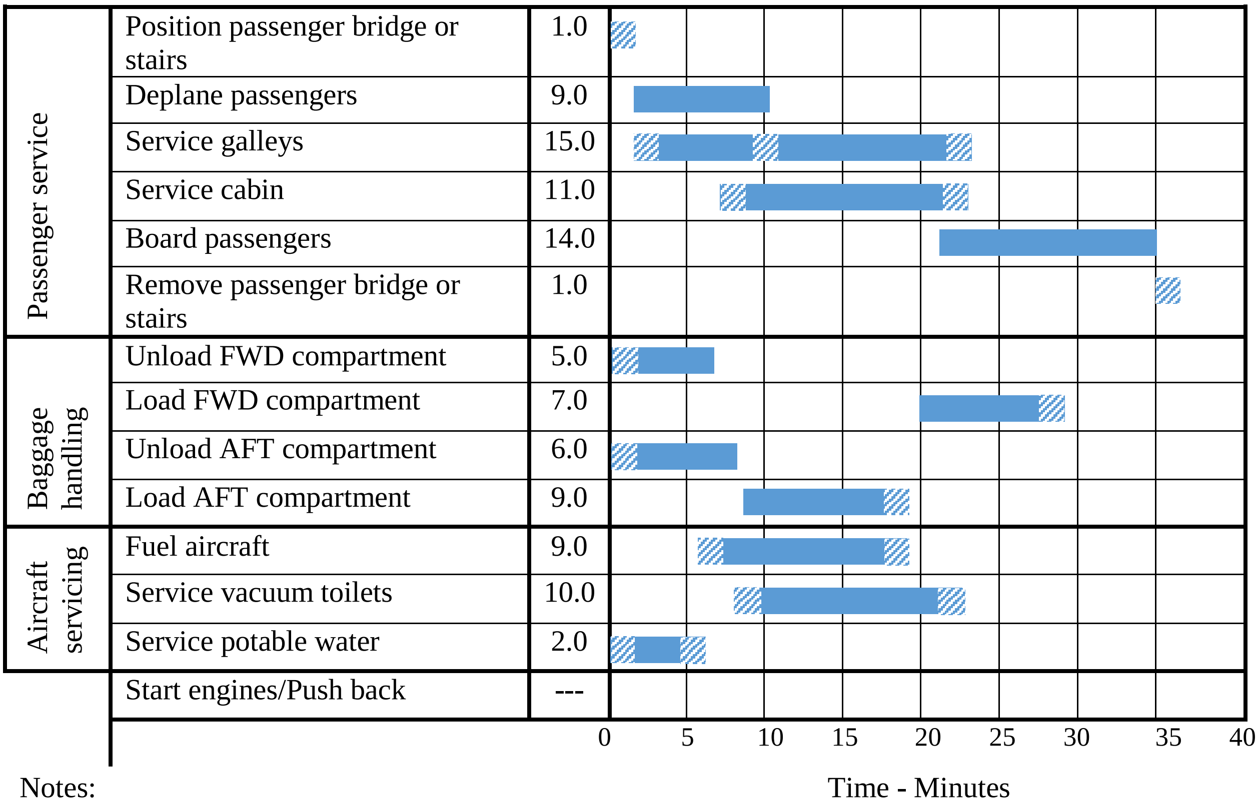
Fig. 3.2 Comparison of two crossing survival functions of different designs.

Notice that for target times lower than t_1 (e.g., t_0), design B seems to outperform design A, i.e., the probability of the turnaround being completed by t_0 is higher with design B. On the contrary, for target times higher than t_1 (e.g., t_2), design B shows a higher probability that the turnaround process is still not terminated yet – and, therefore, design A should be preferred instead. This analysis might be specially interesting when the manager has to face a predefined deadline for the turnaround stage that must be satisfied.

Notice that simulation can not only provide estimates of the survival function at each target time, but it can also provide detailed information on the process, such as: observations on the random completion times associated with each path, percentage of times each of the paths has been acting as a bottleneck, and observations on the random completion times associated with the entire turnaround process, from which useful statistics – such as average times, variance, and quartiles – can be easily computed.

3.1.3. Analysis of duration of turnaround activities

A series of observations have been carried out to test simulation-survival approach. These experiments refer to turnaround processes associated with a Boeing 737-800. The turnaround activities are the ones proposed by the aircraft manufacturer. As fleet of UIA consists mainly of Boeing 737 and airline follows traditional scheme of turnaround process, proposed list of activities can be used. Assumed deterministic times for each activity are illustrated on the Fig 3.3 as a Gant Chart. The graph representation of this example is the previous one given in Fig. 3.1.



Notes:

- Position/remove equipment
- 100% exchange of passengers and cargo
- 160 pax board and deplane via fwd lh entry door
- passenger loading rates: unloading – 18 pax per minute loading – 12 max per minute
- baggage loading rates: unloading – 15 bags per minute loading 10 bags per minute
- 1 bag per pax
- 69 bags fwd /91 bags aft 83% stacking efficiency
- 1 galley truck used
- 100% load factor

Fig. 3.3 Gant Chart: Standard turnaround activities for the Boeing 737-800

In order to provide more realism to analysis, Weibull probability distributions (considering the aforementioned deterministic values as expected values) is employed to model the completion times of each activity. Finally, the performance of the turnaround process has been analyzed under three different levels of passengers' occupation (75%, 90%, and 100%), since working under different levels of occupation could generate variations in the critical path and the associated survival functions.

According to the activities proposed by Boeing, three main types of activities can be observed: the activities carried out in the cabin, the handling activities, and the ones associated with servicing the aircraft.

Table 3.1 shows the estimated average times for each turnaround activity for the B737-800. It also shows times taking into account the different passenger-occupancy levels.

Table 3.1

Estimated average times for activities in the B737-800 aircraft

		Occupancy levels:	**100%**	**90%**	**75%**
Type of activity	**Number**	**Activities**	**Time (min)**		
Passenger Services	1	Deplane passengers	9	8	7
	2	Board passengers	14	12	10
	3	Catering (Service Galleys)	15	15	15
	4	Cleaning (Service Cabin)	11	11	11
Cargo handling	5	Unload cargo/baggage	6	6	6
	6	Load cargo/baggage	16	16	16
Aircraft service	7	Fuel	9	9	9
	8	Maintenance	10	10	10

The results obtained by approach are shown in Table 3.2. Fig. 3.4 presents the corresponding density plots for the different paths considering different levels of occupancy. Notice that the total time of the turnaround stage is reduced as the passengers' occupation level is decreased. In this case, the path related to disembarking, cleaning, and boarding the plane is the most frequent critical path, which is true regardless of the occupancy level: even with a 75% occupancy level, this path continues to be the critical one 95% of the time.

Table 3.2

Estimated expected times for the turnaround stage

Occupancy 100% Average time: 34 min			Occupancy 90% Average time: 31 min			Occupancy 75% Average time: 28 min		
Paths	**Longest**	**Shortest**	**Paths**	**Longest**	**Shortest**	**Paths**	**Longest**	**Shortest**
1	99.91%	0.00%	1	99.08%	0.00%	1	94.66%	0.00%
2	0.00%	41.70%	2	0.00%	41.82%	2	0.00%	41.65%
3	0.09%	0.06%	3	0.92%	0.08%	3	5.34%	0.05%
4	0.00%	40.12%	4	0.00%	40.03%	4	0.00%	40.38%
5	0.00%	18.12%	5	0.00%	18.07%	5	0.00%	17.92%

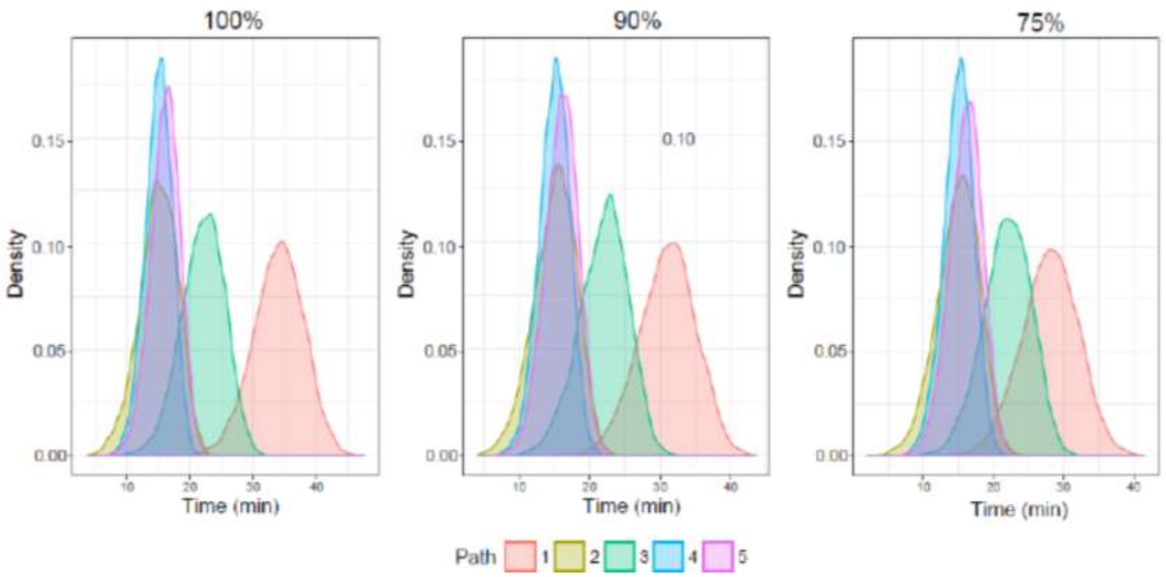


Fig. 3.4 Density plot of activity paths for the Boeing 737-800

The results show that the disembarking-cleaning-boarding path was the most frequent critical one in all the considered scenarios. Therefore, any reduction in the duration of that path will have a positive impact on the turnaround time. The results also show that the less critical paths are those associated with catering, refueling, and maintenance processes. This indicates that the human teams dedicated to these paths are able to complete their assigned tasks before the end of the turnaround.

3.2. Development of the mathematical model

3.2.1. Data collection

In the data collection phase, the non-participant observation technique is selected. According to the non-participant observation type of data collection, the observer does not intervene with the participants. The data is mainly collected by observing the system from a distance while taking notes.

3.2.2 Process mapping

In order to model the turnaround operations and to identify constraints, a process-mapping technique is used. For each turnaround operation inputs, outputs, constraints and resources are identified. The parent process-map diagram of the turnaround operations is shown in Fig. 3.5

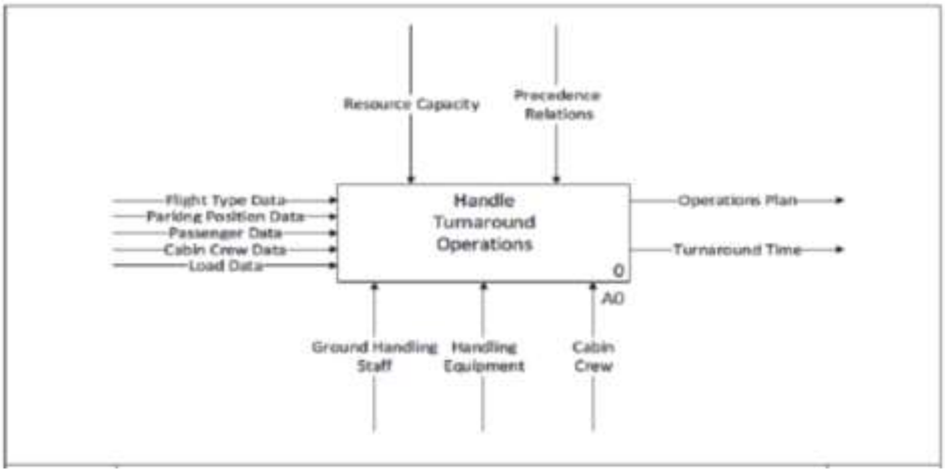


Fig. 3.5 Process Map Level 1 (Parent Diagram)

The process map presented in Fig. 3.5 is called ‘Parent Box’.

In this diagram, the inputs to the handling activity of the turnaround are flight type data, parking position information, passenger data, cabin crew data and load data, which contains the information about the amount of fuel, clean water and baggage, is needed for or expected at that flight type. The outputs of this process are schedule(s) of turnaround operations and the optimal turnaround time. Some constraints would control / restrict the turnaround activity including precedence relationship of operations and resource capacities. Resources, which are used during this process, are ground handling/turnaround operations staff, handling equipment and cabin crew.

The turnaround operations module presented in Fig. 3.5 is then decomposed into a child diagram that involves a number of detailed turnaround operations. A detailed process map is presented in Fig. 3.6.

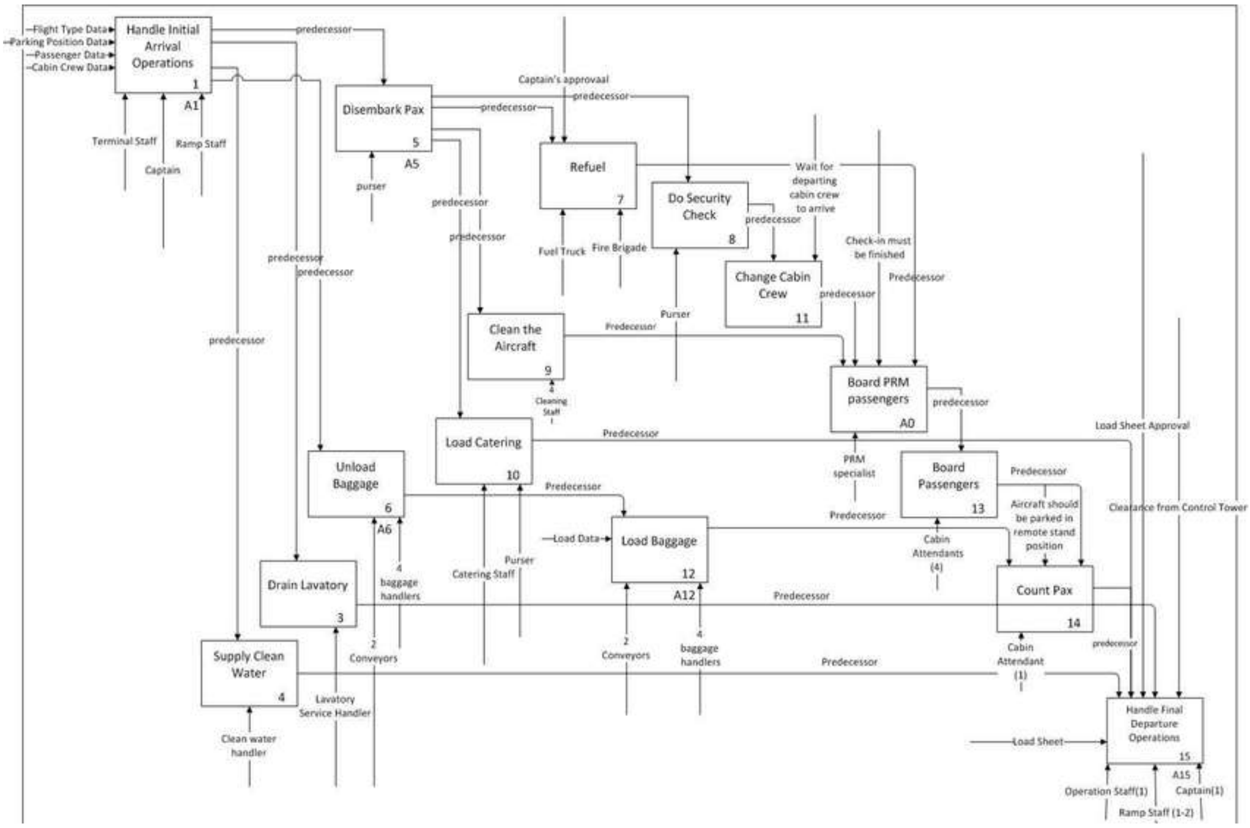


Fig. 3.6 Turnaround Processes (Child Diagram)

In Fig. 3.6, the process map begins with the initial arrival operations with inputs of flight type data, parking position, passenger and cabin crew information. Terminal staff, captain and ramp staff are involved as resources in this process. After disembarking of all passengers, baggage unloading, lavatory, and potable water services operations begin.

The process of passengers disembarking is a predecessor of many other processes such as refueling, security checks, aircraft cleaning and catering. In order to start the refueling process another constraint has to be satisfied, the captain's approval on the amount of fuel to be lifted. Catering loading is handled by catering staff often with participation by the flight pursuer. Another output of passenger disembarking is considered as a constraint that would restrict security checks where the cabin crew checks inside the aircraft in case someone left their stuff. The output of aircraft cleaning is a predecessor to boarding of PRM passengers. Waiting for the departing crew to arrive is another constraint that would restrict the “change cabin crew” process. The output of this process is a constraint to the passengers boarding process because passengers cannot be boarded unless the new crew are onboard the aircraft. The baggage unloading process is the constraint for baggage loading process. After boarding PRM passengers by a PRM specialist, passenger boarding starts. Cabin attendants handle passenger boarding process as well. The output of this process is constraint of counting the passengers. Another constraint of this process is baggage loading and aircraft should be parked in remote stand position. As a final step, operation staff, ramp staff and captain handle the final departure operation. Input of this process is the load sheet approval. The constraints of this process are predecessors from the drain lavatory, supply clean water, load-catering operations beside other constraints including load sheet approval and clearance from the control tower.

3.2.3 Methodology

The first step of developing a mathematical optimization model involves setting a number of assumptions. The next sub-sections will reflect the step-by-step stages of the model development starting from the modelling assumptions.

3.2.3.1. Modeling assumptions

Managing turnaround operations is a complex process with many variables. For this reason, a number of assumptions are set in order to make the problem solvable in a polynomial time.

These assumptions are:

- The following operations are considered necessary in every flight:
    - Cabin Crew change;
    - Fueling;
    - Lavatory Service;
    - Water Service;
    - Boarding and disembarking PRM passengers;
- All equipment and other vehicles are ready in the parking area before aircraft arrives;
- There is no restriction on the number of resources required for each operation.

3.2.3.2. Model indices and decision variables

- Model Indices

Here, j and k are the turnaround operations and they belong to a set where j or k starts from 1 to total number of operations in the system.

The parameters used in this model are:

- P_j which is the processing time of job j;
- $M = \sum_{j=1}^{n} p_j$ is the upper bound on the total duration of operations.

- Decision Variables

The decision variables used in the developed mathematical model are:

C_{max} = Completion time of the last job,

S_j = Start time of job j,

$$y_{jk} = \begin{Bmatrix} 1, if\ job\ j\ is\ processed\ before\ job\ k \\ 0,\ otherwise \end{Bmatrix}$$

3.2.3.3 Development of the linear programming model

The developed mathematical model ‘TurnOper_LP’ based on the aforementioned assumptions is as below:

$$Minimize\ C_{max} \tag{3.1}$$

subject to

$$S_k \geq S_j + p_j \qquad \forall_{j \to k} \in A \tag{3.2}$$

$$C_{max} \geq S_j + p_j \qquad \forall_j \in J \tag{3.3}$$

$$S_k \geq S_j + p_j - M(1 - y_{jk}) \qquad \forall_{j,k} \in B | j \neq k \tag{3.4}$$

$$S_k \geq S_j + p_j - My_{jk} \qquad \forall_{j,k} \in B | j \neq k \tag{3.5}$$

$$S_j, C_{max} \geq 0, \quad y_{jk} \in \{0,1\} \qquad \forall_{j,k} \in J \tag{3.6}$$

The objective function (1) will find the minimum completion time of the final job taking into account the following constraints:

Constraint (2) ensures that the turnaround operations must be scheduled taking into account the precedence relationships of these operations. For example, refueling needs to be finished before the passenger boarding can start. This constraint does not allow the model to schedule these two operations in parallel. It forces to assign the boarding to start after the finish time of the refueling.

Constraint (3) makes sure that the completion time of any operation is the sum of start time and processing time of that operation. For example, if the start time of operation j=1 is at time 0, and if the processing time of that operation is 5 minutes, then the completion time of the operation will be at time 5.

Constraint (4) and (5) are the disjunctive constraints which do not allow these operations to be handled simultaneously (either j will precede k or k will precede j). An example to these two operations can be given as loading the PRM passengers while the aircraft is on the remote parking stand cannot be handled at the same time while loading the catering from the front door. Both uses the same door (space) hence with this constraint, it is not allowed for both operations to be handled simultaneously. The final constraint (6) ensures that Non-negativity is achieved and y_{jk} is binary.

After running this model, the start time of each operation will be generated and all the turnaround operations will be scheduled taking into consideration constraints (2-6). Hence, the critical path can be identified after the start time of the operation is provided by the model, so that turnaround operations that will increase/ decrease the turnaround time will be identified if the time of these operations is increased/decreased (such as passenger boarding).

In order to run the developed model 'TurnOper_LP', data on the processing times of each operation should be collected. After the data collection, durations of each operation should be gathered and an average duration for each operation calculated. Four different sets of inputs each representing a different flight type can then be individually fed into the developed model (referred as "coefficients" such as the processing time (p) of every operation (j)) to generate the required flight type schedule.

The developed mathematical optimization model could be translated to CPLEX software format.

3.2.4. Determination of critical moments

The aircraft turnaround process is a critical one for both airlines and airports. For airports, efficient turnaround process constitutes an opportunity to increase their overall capacity; for airlines, dealing with these processes in an optimal way can significantly reduce their associated cost.

This work proposes the combined use of simulation with survival analysis in order to analyze the different paths of activities that compose a typical turnaround process. As illustrated in the part 3.1.3, hybrid approach can be used not only to identify critical actions and paths in the process, but also to study potential benefits of different turnaround designs. Also, by introducing random times instead of assuming a deterministic behavior, the analysis of the process is more realistic, and survival functions can be obtained for each of the proposed designs. The idea here is to find the optimal design for the turnaround process, i.e., to find the feasible design that maximizes the probability that the turnaround process can be completed before a given deadline while respecting all the activity-precedence constraints.

All operations which influence the duration of turnaround time are determined as critical. Therefore, passenger boarding is one the most, so called, critical path of a turnaround since it significantly influences the course of other operations. Even though the boarding is only one of the operations in a turnaround event set, it is much easily adaptive and modifiable than some other operations. In the last 20 years numerous boarding strategies were proposed to optimize airplane utilization and shorten turnaround time. Next the most effective boarding method will be identifid for Ukraine International Airlines.

3.3. Optimal boarding method determination

The boarding of passengers is only one single step of the whole process, it is yet the most critical one that determines the total ground handling time: Fig. 3.3 shows the generic time consumption of the ground service. On this illustration can be schematically seen which procedures are running simultaneously and which ones are starting as soon as another process is finished. It should additionally be said that on this image there is no information that illustrates which process requires another one to be finished. But it can generally be understood, that in order to speed up one process while another independent one is not finished, would not decrease the total turnaround time of an aircraft. The boarding of passengers requires all activities in the cabin to be finished, so that the boarding process starts as one of the last element. Thus, an improvement in boarding time can shorten the total ground service time. It is the critical procedure of the ground handling process that ends last before the plane is being prepared for taxiing by removing passenger bridges, closing doors and starting engines. There are no parallel activities running anymore at that time (see Fig. 3.3).

On the following figure 3.7, the turnaround time of an aircraft is illustrated on a split up flowchart. On this chart can be seen the dependence of different services as well as the approximated durations. This chart furthermore confirms the enplane time to be the most time consuming part of the process.

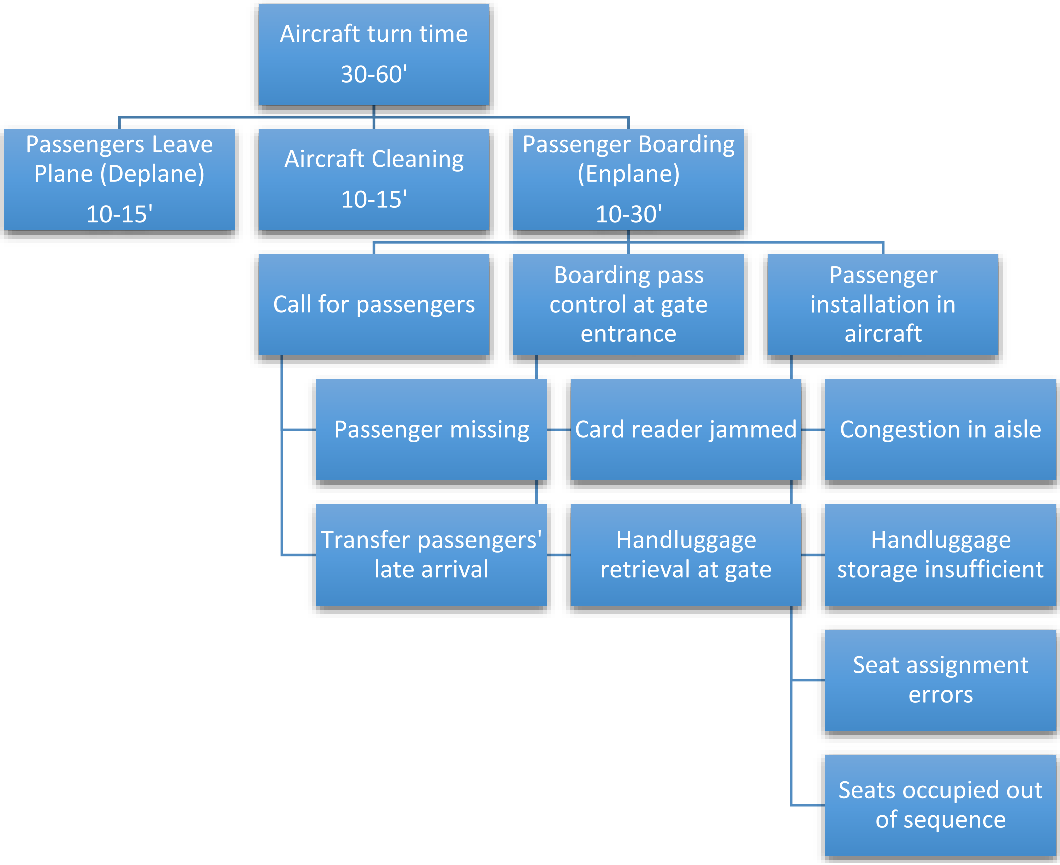


Fig. 3.7 Elements and disturbances of aircraft turnaround time

In order to do a simulation of the boarding process, its characteristics need to be analyzed and fragmented. The process as it happens in real can be written down by observations. Solely sorting out the negligible elements reveals as the significant part of this procedure. Concerning simplifications, different authors of boarding studies apply likewise different conditions on their simulations. Finally, a simulation is based on a certain amount of assumptions that model the real world process. There can be added an optional amount of parameters to the simulation that refine the model. In so doing, the model gets closer to reality. The main characteristics of a boarding process are determined by human behavior, as human beings are the actors in this model.

In order to investigate the consequences of human activities, the system must be analyzed where great care must be taken to ensure that all relevant aspects of the real system are preserved. System analysis is important to increase the understanding, where science has made good use of a range of techniques for abstraction and aggregation. Models are always abstractions (simplifications) of reality.

3.3.1. Model system identification

As passengers will interact with each other (for example lining up in the queue), the boarding process is a Cybernetic system.

As the process takes places within a certain amount of time, where various parameters are time-depending, the boarding process is also a Dynamic system.

The system boundary of the actual boarding process is the aircraft cabin. Nevertheless, some authors mention the ticket counter as part of the system as well. This is rather a question of definition – the ticket counter can also be seen as a generator for the system input.

Since passengers are boarding the airplane from outside the system boundary process breakdown, the boarding of an airplane is an open system.

3.3.2 Process breakdown

Beyond, an overview of single steps that a passenger experiences when boarding an aircraft are listed. These steps are determined according to as well as by confirmation and addition based on personal experience:

1) Ticket counter: queuing and wait for ticket to be scanned;
2) Passenger boarding bridge: proceeding to airplane door;
3) Airplane aisle: entering boarding door and proceeding to assigned row;

4) Stowing bags: stowing luggage into the bins – will be also denoted as clearing time;

5) Sit down: sitting down at the assigned seat.

In principle, steps 1) and 2) do not have any effect on boarding time, as long as people are passing the ticket counter faster than actually boarding the airplane. Yet, not all studies are only taking the steps into consideration starting at point 3). The virtual breezeway is rather being used to put the passengers into the specific order - given by the simulation rules. Now, it is a matter of opinion if this can be seen as a simulated breezeway or just a simulation constraint. The airplane door is nevertheless the system border, from where “objects” (passengers) are being sent into the system.

When considering the application of gathered simulation result later on, the boarding request of passengers with particularly assigned seats would be the equivalent part of this.

The time to sit down is negligible as the aisle is immediately being cleared after step 4). Solely in case of seat interference, the time to get up and sit down again needs to be considered.

3.3.3. Assumptions for modelling

For the essential boarding process reaching from step 3) to 5), basic assumptions need to be made. These assumptions will be e.g. parameters and constraints on a simulation. The basic parameters are the walking speed of a passenger and the time that one passenger needs to sit down respectively to stow his luggage. Another essential parameter is the pax flow rate (number of passengers that enter the airplane in a certain amount of time, see more details further down in this chapter). When there is a work focusing on the comparison of different policies rather than finding a reality related time, the association of a time to this parameters can be left out. The parameters must therefore have a factor relation or a unit that fits the simulation clock (e.g.: Clearing time = 3 times the Sit down time, Walking speed = 0.3 grid units/simulation step and so on). The Table 3.3 lists the range of these parameter assumptions. As these parameters can depend on others, the range can occasionally underlie high factors:

Table 3.3

Parameter assumption

Parameter	Range	Unit
Walking speed	0,27 - 0,44	[m/s]
Clearing time	6,00 - 30,00	[s]
Get up out of seat	3,00 - 4,20	[s]
Pax flow rate	0,20 - 1,00	[pax/s]

These assumptions can possibly only be found empirically.

Other assumptions that are necessarily to be made (especially for simulations) are edge constraints. The basic edge constraints are the system boarders and the behaviour of passengers. The system boarder is basically the aircraft cabin, limited to the boarding door as the system entrance and the seats on the other hand as the final position of passengers. The assumptions that need to be made for the human behaviour are a bit more complex, since one cannot consider the passengers to be robots that follow a strict statement: “go and sit down!”. Nevertheless, they need to be done by entirely the developer of the model. Due to this fact, the simplification can be a sensitive element of modelling. The simplification process could be described by occasionally following steps:

- Removing elements and actions of no importance to model goals;
- Aggregating elements and actions of little importance to model goals;
- Restricting the number of values state variables may take;
- Replacing detailed causal scenarios by mathematical functions.

Below, essential assumptions for the behaviour of passengers respectively the boarding process model itself are listed. This can be treated as the realization of the points mentioned above. The assumptions are sorted by the steps that were determined above.

Step 3

- The aisle is only wide enough for one person;

- On airplanes with more than one aisle, passengers choose the one which is the closest to their seat. In the event of a tie, the aisle is being chosen at random.

Step 4 and 5

- People always choose the correct seat. When a passenger has taken a wrong seat, he will be bumped when the right passenger arrives. When the mistaken passenger has to take his seat more towards the front of the aiplane, he/she will have to wait for (part of the) the aisle to clear;

- When passengers arrive at their assigned seats, they must stow their carry-on luggage;

- The time for already seated passengers to get up in order to let someone pass is negligible;

- Until a passenger has taken seat, the aisle will be occupied by: the space in front of his seat + an additional specific space value;

- Passengers stow their bags always in the bins in front of their seats (bins never fill up);

- Passengers stow their bags always in the bins in front of their seats, but the loading time increases as the bins fill up;

- If there is already someone present between him/her and the assigned seat, the seated passenger needs a specific time to gets up and sit down again;

- This movement time only affects the prolonging time of the incoming passenger.

3.3.4. Passenger flow rate

The passenger flow rate is determined to be the number of passengers that pass a system boarder per time ($\frac{pax}{sec}$). In some cases of boarding policies, the flow needs to be interrupted in order ensure the logic constraints. For example: when passengers board in groups, the following set of passengers will not directly pass the ticket counter until the first group has finished or nearly finished seating. In other words: passengers are not necessarily constantly passing the ticket counter.

As it can be of interest which value to consider for a computational or analytical model, Marelli discovered the average passenger flow rate on the deplane and enplane process over a number of decades from the 1960's until to the late 1990's (Fig.3.8)[29]:

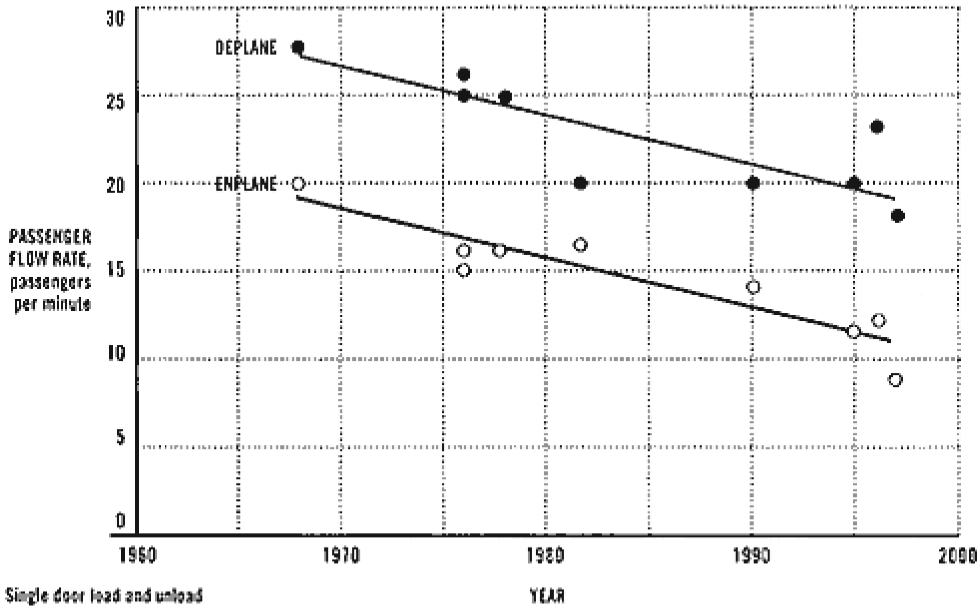


Fig. 3.8 Passenger flow rate over time

From the linearization line on this graph can be read out a value of around $11 \left[\frac{pax}{min}\right] \approx 0.18 \left[\frac{pax}{sec}\right]$ for the latest results. This value could be assumed for an actual approach of a boarding process model.

3.3.5. Passenger flow rate influence

As passenger interference in the cabin only occurs when passengers block each other because they are boarding at the same time, it is manifest that by a lower passenger flow rate, the applied policy will less influence the boarding time.

Van Den Briel plotted two boarding method times over the passenger flow rate and showed exactly this very clearly: at a passenger flow rate greater than 10, the two methods result in approximately equal times (Fig. 3.9) [31]:

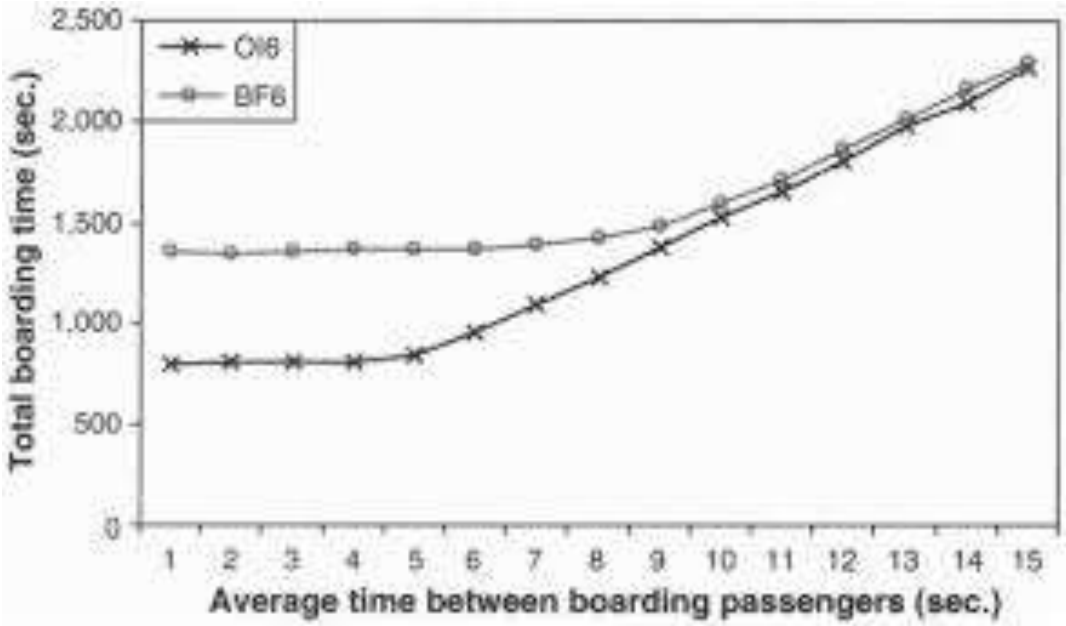


Fig. 3.9 Passenger flow rate influence on boarding time

One can now assume that other boarding methods than the two exampled ones show similar behaviour. It is furthermore interesting to see that between a passenger flow rate of 1 and 5 in one case and between 1 and 7 in the second case, there is no difference in boarding time over increasing pax/flow rate at all.

The curve that indicates lower boarding times shows that its quality decreases earlier.

3.3.6. Impediments of Boarding Process

There are two basic elements that interfere the boarding process:

1) Aisle interference

One passenger loads his luggage and blocks the aisle for other passengers that are lining up behind him.

2) Seat interference

An already seated passenger blocks another one because his assigned seat is located in the same row and in front of his follower. Either the passenger needs to get up or be over climbed.

In both cases the aisle will stay blocked for a certain amount of time. Since the passenger that gets up in order to enable the incoming passenger to sit down needs to escape into the aisle, seat interference always causes aisle interference by logical constraint (unless it is being assumed that the interfering person is being over climbed with the same speed than normal sitting down process). In the following figure, the two kinds of interferences are visualized on Fig. 3.10:

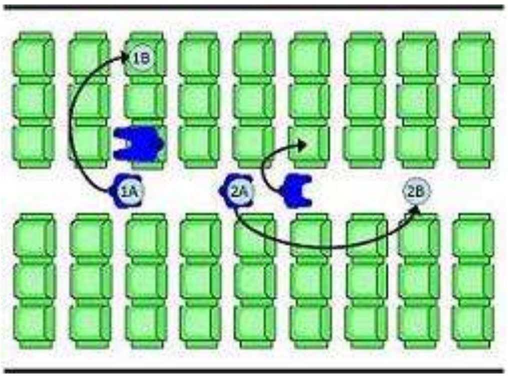


Fig. 3.6 Seat interference

In case of seat interference passenger (1A) tries to get to a seat near the window (1B) but is obstructed by another passenger already seated near the aisle.

Aisle interference: A passenger (2A) tries to reach his seat further down the aisle (2B) but is obstructed by other passengers trying to find their seats or stow their luggage.

It needs to be mentioned here, that due to JAR 25.817 [32] the seat interference does not force more than two passengers to get up in order to let an incoming one sit down.

Following JAR 25.817:

$n_{SA} \leq 6$ – for single aisle aircraft;

$n_{SA} \geq 6$ – for wide-body aircraft.

The assumption of having these two factors as boarding obstructers requires assuming constant parameters. Loitering passengers could definitely slow down the process as well, but this does not play a role when comparing different policies which are determined by the order of assigned seats to be filled. When changing the policy, only the resulting difference in number of aisle and seat interferences is significant for the quality.

Mathematical Approach Seat Interference

In order to calculate the seat interference time, the following approach can be used:

$$T = t_{p1} + \cdots + t_{pk} + t_p \tag{3.7}$$

where $t_{p1}...t_{pk}$ are being passing times for the k seated passengers and t_p is the time to get up and sit down again.

Mathematical Approach Aisle Interference

The time a passenger needs to wait in the aisle is not determined by a constant time, rather than by the constraint that he can only continue when the passenger in front continues to walk or clears the aisle. The same can be applied for the next passenger, and so on. Within a simulation, this could be realized by a do-while loop. In any event, the origin of the aisle interference is always a passenger that has not yet cleared the aisle. The following approach for the clearing time:

$$clearing\ time = t_B \cdot \left(\frac{num\_seated}{10}\right) \tag{3.8}$$

While t_B is a determined time factor [*sec*] and *num_seated* the number of passengers that have already sit down. This causes the clearing time to be a function of the occupancy of the airplane, representing the time increase to stow the hand luggage as the bins start to fill up. This assumption is not essential for the boarding process simulation and has therefore not been made previosly (see assumptions chapter 3.3.2).

3.3.7. Implementation in reality

So how realistic it would be to implement a result that has been discovered by-seat assignments as the optimum. A problem in reality would be in fact to ask every single passenger to board the airplane. The result of a group, where within this group passengers enplanes randomly, is much easier to realize. To influence the boarding sequence of passengers, call-off systems are currently often used. With this method, the particular zone that is next entering the plane is called by the ground staff.

"By-group" call of systems are being used by airlines applying all policies where the cabin is separated into certain zones determined by the according policy. Passengers always must be requested when it is their turn to enter the airplane. One way to realize this, is giving announcements via a loudspeaker or visual cards.

A solution, where not only groups but even single passengers can be guided to a specific seat would be to distribute the seat assignments dynamically. In this case, the seats could be as signed not till the passenger passes the ticket counter. The next to be occupied seat could be printed on the ticket when the passenger or the ramp agent pulls the ticket into the counter. The disadvantage is clearly that passengers do not have an opportunity to choose their favourite seat. Furthermore, people travelling together (families, business travellers etc) will probably hardly accept to be placed certain rows apart from each other. A resulting re-arrange chaos by passengers is likely and could potentially delay the boarding even more.

3.4. Models for Boarding Process

Models help to understand the behaviour of a system and the effects of interactions among its components. In the scope of boarding process modelling, the understanding of the effects of the boarding policy needs to be understood and investigated.

There are several ways to model natural processes. The main methods that come into question for the boarding process are simulations or analytical models.

3.4.1. Analytical Models

Analytical models are practically very limited in terms of complexity. At least since the implementation of non-linear processes, analytical models need to be split up into steps or solved by a differential equation. This easily becomes too complex as it would be still worth avoiding a simulation. Only a few boarding policies can be realized by the analytical method, requiring however a strongly simplified system model.

Optimization models for maximizing or minimizing an objective function under constraints:

$$g_i(\bar{x}) \begin{cases} \geq \\ = \\ \leq \end{cases} 0 \quad \text{for } i = 1, 2, \dots \text{m},$$

where x here is a vector of variables with n components.

Simple Approach for Analytical Models of Boarding Process

Stolyarov in 2007 [30] designed models which allow expressing boarding times linearly. Every boarding policy requires its own formulation. Their models require four variables:

t_w := the time it takes 1 passenger to walk 1 row;

t_B := the time it takes 1 passenger to load a bag and vacate the aisle;

n := the number of rows on the airplane;

s := number of seats abreast;

T := total boarding time;

Due to the few variables, the analytical models require some major assumptions that enable their validity. The following declarations can be used in order to define the model:

- t_w is constant for all passengers;
- t_B is constant (bins do not fill up);
- All people enter the plane in a pre-set order;
- The seating floor plan has one central aisle with k seats in each row;
- All passengers stow equivalent carry-on bags;
- All passengers at a time can stow a bag above a given row;
- Only one passenger at a time can stow a bag above a given row;
- There cannot be more passengers in the aisle than there are rows;

Now, this model can be used to analytically calculate boarding times of various logics. The simplest boarding method to be reflected within the model is the Wilma method. As many people here can board the plane as there are rows *(n)* at one go, these people need the time to enter the cabin.

$$n \cdot t_w \tag{3.9}$$

The next step is stowing the carry-on luggage. This requires an additional time t_B (Due to assumption at point 3.), the process of stowing can be done by all of them at the same time. This needs to be repeated *s* times for each seat abreast: in case of a 6-abreast seat plan, two times for window seats, two times for middle seats and two time for aisle seats. The total boarding time for the Wilma method now reads as:

$$T = s(nt_w + t_B) \tag{3.10}$$

Within the same way of simple analyzing of the boarding methods, other policies can be described within this model as follows:

Back to Front (by row):

$$T = snt_w + (sn - n + 1)t_B \tag{3.11}$$

s^{th} row parallel boarding:

$$T = s(nt_w + kt_B) \tag{3.12}$$

In the s^{th} row parallel boarding calculation, for simplicity reasons the number of rows is a multiple of s. A brief explanation to this logic reads as follows: the first *s* people that enter the plane are all sitting in the back row. The next *s* people all sit in the s^{th} row up from the back, and so on. The logic behind this policy is that the passengers are loading their luggage at the same time with a maximum distance. This is possibly only meaningful in airplanes with relatively short cabins.

3.5. Analytical approach for investigation of different cabin diameters

In this chapter, an analytical method is being derived and applied to the Wilma and Back-to-Front policy in order to show the impact on the number of seats abreast.

The general idea of the Wilma method is to eliminate seat interferences. Thus for this method, only aisle interference is notionally significant. But with decreasing number of seats abreast, the other important factor of seat interferences will accordingly decrease (for methods containing seat interference). Hence, one can suppose that for a deceasing number of seats the Wilma efficiency gets weaker in comparison to for example the Back-to-Front policy, as its main advantage will be eliminated. As the Back-to-Front method is often considered as the worst and the Wilma as the best method, this shall be an attempt to show that under given circumstances the result can possibly be flipped between these two methods.

It was assumed so far that all passengers enter the airplane in a pre-set order within a boarding group. This is in fact generally far from reality; but only when considering smaller groups to board at once, this assumption gets less important for the result. In other words: the probability of aisle interference in reality to occur at Wilma is unlike greater than at BTF.

3.5.1. Mathematical Assumptions

When wanting to investigate the impact of aisle interference within the analytical method, a few assumptions need to be made. This considers the probability of aisle interference depending on the size of a boarding group, as well as its impact on boarding time. The probability depends on the number of seat rows that are a possibility for the boarding group to be occupied.

Let i people belong to a group g and to a boarding zone z of n rows that belong to the zone:

In case of Wilma:

$$g_{wilma} = \frac{x}{s} \tag{3.13}$$

or

$$g_{wilma} = n \tag{3.14}$$

in case of BTF:

$$g_{btf} = \frac{x}{z} \tag{3.15}$$

Let P_i be the probability of a passenger to experience aisle interference; where i is the position within the group:

$$i \in g \in N$$

and

$$1 < i < g$$

The further behind a group, the greater the probability of experiencing aisle interference. For the leader of the group, the probability is 0. Where k is the number of rows where seats will be getting occupied, for any follower i in this group, the probability reads as:

$$P_i = 1 - \frac{k-1}{ki} \tag{3.16}$$

When plotting P over i, it can be seen that the probability shows up an asymptotic behaviour (Fig. 3.11). The further behind in the group, the probability to be blocked approaches 100%.

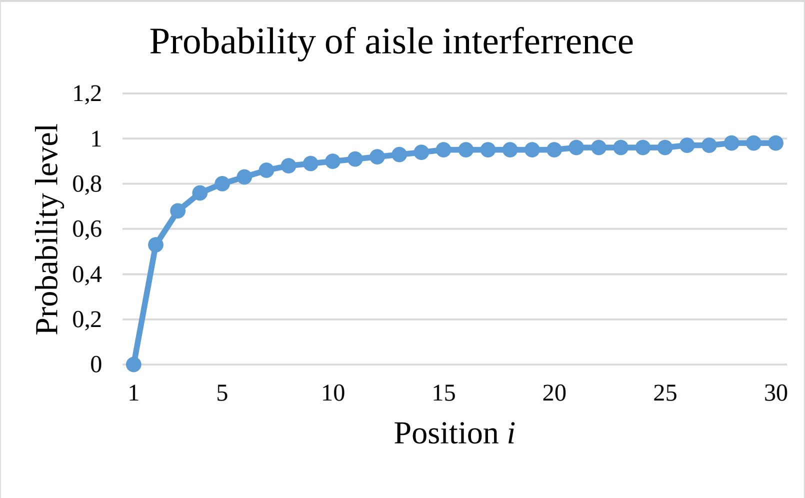


Fig. 3.11 P over i with the example of k = 30

With a given number of rows n, k stays constant over s for both Wilma and BTF:

$$k_{wilma} = \frac{x}{s} \tag{3.17}$$

$$k_{btf} = \frac{x}{sz} \tag{3.18}$$

When plugging (3.17) respectively (3.18) in (3.16), P_i now reads as:

$$P_{i\_wilma} = 1 - \frac{\frac{x}{s} - 1}{\frac{x}{s} i} \tag{3.19}$$

and

$$P_{i\_btf} = 1 - \frac{\frac{x}{sz} - 1}{\frac{x}{sz} i} \tag{3.20}$$

Since the interference time will not only affect the passenger directly behind, but also the whole queue, the total delay time D for a group g can now be found by numerical integration:

$$D_g = p \sum_{i=1}^{g} p_i \tag{3.21}$$

where p is a single penalty time that it takes a passenger to load his luggage. The total extra delay time D_{total} for the particular policy is the number of groups that is necessary to fill the cabin multiplied by D_g. The number of groups is $\frac{x}{g}$. D_{total} then reads as:

$$D_{total\_wilma} = D_{g\_wilma} \cdot \frac{x}{g_{wilma}} = D_{g\_wilma} \cdot \frac{x}{n} = D_{g\_wilma} \cdot s \tag{3.22}$$

and

$$D_{total\_btf} = D_{g\_btf} \cdot \frac{x}{g_{btf}} = D_{g\_btf} \cdot \frac{xz}{x} = D_{g\_btf} \cdot z \tag{3.23}$$

3.5.2. Sample study

A defined seat layout with n = *30* rows will now be taken as a reference where the calculation of D_{g_Wilma} and D_{g_btf} will be repeated for $2 < s < 6 \in N$. The number of zones will be determinder to be z=5.

The resulting numbers of seats for this layout is = x = (60,90,120,150,180). This represents the same fuselage length over a changing number of seats abeast (see Fig.3.12):

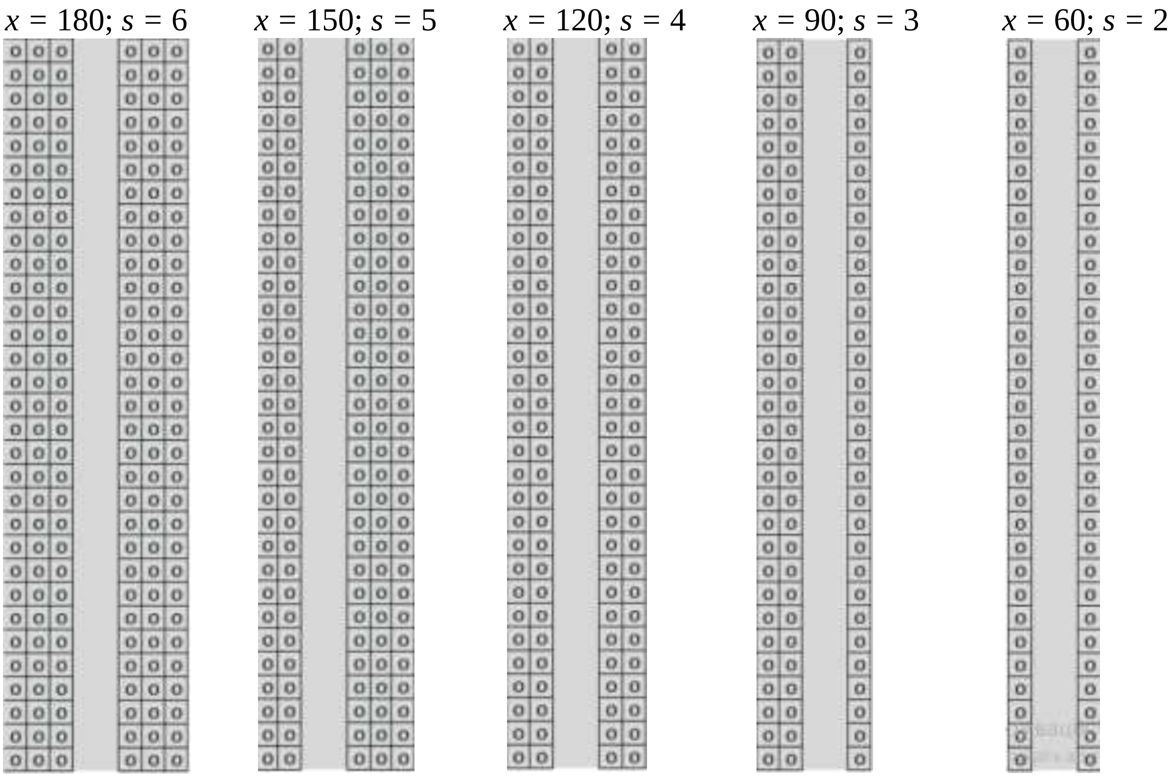


Fig. 3.7 Sample seat layouts

3.5.3. Results

The results for the sample layouts in chapter 3.5.1 are listed in the Table3.4:

Table 3.4

Results of P_g and P_{total}

			Wilma			BTF		
Seats abreast	Pax	Penalty [s]	$P_{g\_wilma}[s]$	# of groups	P_{total} [s]	$P_{g\_btf}[s]$	# of groups	P_{total} [s]
2	60	5	130,5	2	261,0	46,2	2	231,2
3	90	5	130,5	3	391,6	74,6	3	373,0
4	120	5	130,5	4	522,1	103,4	4	517,15
5	150	5	130,5	5	652,6	132,5	5	662,6
6	180	5	130,5	6	783,1	161,8	6	808,85

With this method, now the extra penalty when considering aisle interference for each method has been discovered. The analytical methods can now be used to calculate walking times. The two results could be super positioned afterwards. But since the delta total boarding times between the two do not change over s, it is sufficient for the purpose of comparison to only consider the interference times. Plotting the total boarding times over s now reve the following Fig. 3.13:

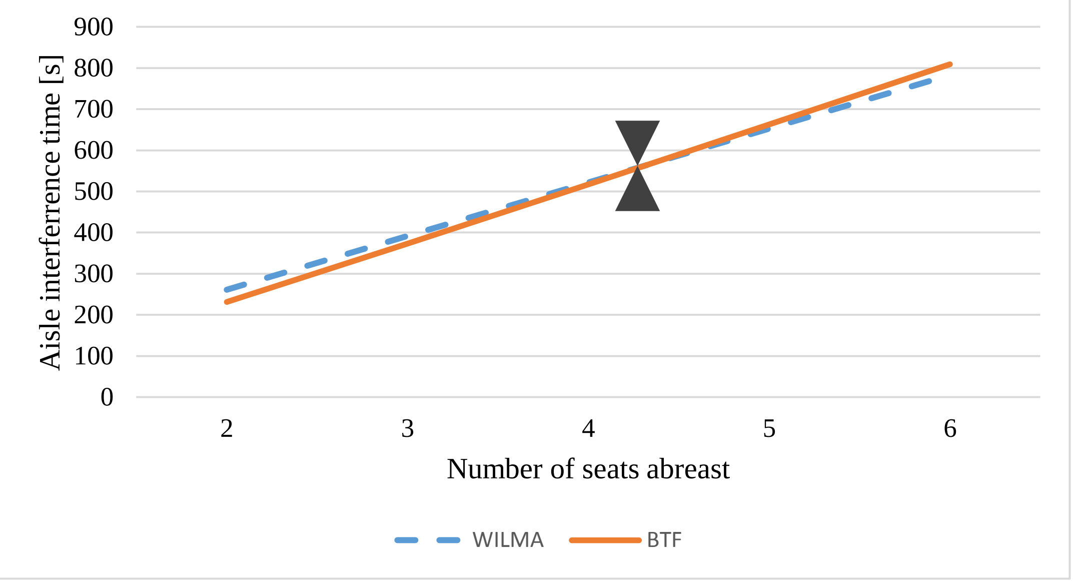


Fig. 3.8 P_{total} of Wilma and BTF over s

As it can be seen from Table 3.4 and Fig.3.13, the Back-to-Front method featur less aisle need interference on layouts with $s < 5$. Certainly, all assumptions explained above need to be rerespected. For example, seat interference is not respected. The assumption of leaving seat interference out could comprise that people can reach their window/middle seat s without the interfering person getting up.

3.6. Outcome effect

3.6.1. Best Strategy

There are two main different classes of results for an optimal boarding strategy. It can be ei-her by seat, or by seat group. By seat group is more practically. By seat-strategies provide more flexibility and optimized results.

But on the other hand it is less feasible in reality (see problem of implementation in reality chapter 3.3.7).

In fact, a ‘by group result’ compromises a ‘by seat result’, but only by additionally respecting that there is no big difference in which order the boarding takes place within the group. In other words: the order within the group is always random. Now, the results that were discovered in the different studies are either by-seat or by-group.

By-group results follow strategies like Wilma, Rotating Zones, etc. While by-seat results can possibly be matched with a named strategy.

The following Table 3.5 summarizes the best practical results that were found in research studies:

Table 3.5

Results f best strategy

Author	Best strategy
Landeghem, 2000 [33]	WILMA
Van den Briel, 2005 [31]	WILMA/Reverse pyramid
Ferrari, 2005 [34]	WILMA
Marelli, 1998 [29]	WILMA
Steffen, 2008 [17]	WILMA
Stolyarov, 2007 [30]	WILMA

It can clearly be seen that for the class of group boarding, the Wilma method is the most efficient one.

3.6.2. Worst Strategy

It is obvious to understand that a Front-to-Back system and possibly also "Aisle-Middle-Window" strategy would slow the whole process most significantly down while people keep blocking each when while loading their luggage or sitting down. There has been done no investigation considering the question of "what is the worst strategy". Interestingly, this strategy is known as to be the traditional one and most commonly used by many airlines. Against expectations, random boarding, which one would associate with chaos, is significantly faster than Back-to-Front (Steffen 2008)[17].

3.6.3. Influence of Aircraft Size

The more seats an aircraft layout has, the longer the boarding will obviously take. The rather interesting question is, if there is a boarding policy that outperforms another one when increasing the number of seats (respectively having two aisles instead of one). The results of Stolyarov 2007 [30] provide the following answer to this:

For very small planes (< 75 pax), all algorithms performed within 1.2 minutes of each other. The relative efficiency of the algorithms remains all sizes of planes and all types of seating layouts

One can conclude from this, that on a layout of an airplane with less than 75 seats, it is not worth applying a certain boarding policy. For airplanes with more than 75 seats it useful to apply an efficient boarding policy.

3.6.4. Financial Impact

The essential question for airline in terms of boarding time improvement is how they can potentially benefit from it. As described in chapter 3.2.3, the less time an active aircraft is on the ground, the less money will be needed be accrued for it.

When considering an average boarding time, the cost savings for an airline over a year can be approximated. By this, different policies can be compared in terms of their rentability.

Following McFadden 2008 [1131], the annual ground costs for an airline can be approximated by the following formula:

$$C = B \cdot M \cdot D \cdot 365\ days \tag{3.24}$$

where:

C - annual cost;

B - average boarding time;

M - Cost per 1[min] on ground;

D - average number of daily flights.

It is being assumed that the average number of flights over the year is approximately 65 000. Following chapter 2.3, the cost per minute on ground can be approximated to be $30. The cost savings for an airline applying an innovative boarding policy can be now read out of Table 3.6.

Table 3.6

Potential Financial Impact

Boarding method	**Average boarding time *B* [min]**	**Annual cost *C* [s]**	**Cost savings over traditional methods**
Traditional	30,33	$63 693 000	-
Non-traditional (2 carry-on)	19,78	$41 538 000	35%

Table 3.6 Continuation

Non-traditional (1 carry-on)	15,18	$31 878 000	50%
Non-traditional (no carry-on)	8,18	$17 178 000	73%

As can be seen from the table above, regardless of the presence of carry-on luggage in the passenger, the implementation of boarding by the Wilma method, has better efficiency, both in terms of time and financial savings.

SUMMARY

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SUMMARY

In the master's thesis the theoretical generalization, substantiation of the importance of the role of aviation industry, as one of the key branches of the national economy system of the world, and Ukraine in particular, is made.

The aviation industry of today is a large branch of the national economy of the country. At its core, the air transport industry is a global network of aircraft, airports, air navigation providers of aviation service providers. It is responsible for connecting to the global economy, providing millions of jobs and improving the current state of quality of life.

By analyzing the cost structure of an airline, it can be determined the impact factors that the airline can change and those that affect regardless of company policy. The process of aircraft turnover includes such processes as are required to be performed, as well as those that may be modified, excluded or optimized by the airline. By analyzing turnaround activities times, the most critical paths were identified.

One of these is the process of boarding passengers. Having examined all the boarding strategies in detail, identifying their disadvantages and advantages, as well as the possibility of realistic implementation, two types of passenger boarding were chosen: Wilma and Back-to-Front.

As a next step, it was necessary to investigate what obstacles may appear in the passenger's way as he passes to his place.

It was also important to keep in mind that, in addition to obstructions in the form of other passengers, there could be obstacles to placing cabin luggage on shelves.

After calculating and analyzing previous research, it was determined that the Wilma method is the most effective and convenient. On this basis, an approximate financial result of such an innovation was calculated using a simple formula. To make an approximate annual estimate, it has been determined that the annual number of flights with Ukraine International Airlines is approximately 65,000.

Based on the number of flights, it was calculated that the Wilma method, with 1 hand luggage per passenger, was 50% more efficient than the traditional landing method. In financial terms, efficiency is about $ 31,878,000.

The development and practical application of modern technologies in the field of air transportation are closely interconnected with the solution of important economic problems, one of which is to reduce costs and increase the efficiency of the airline. There is no single recipe for cost reduction. But there are several ways airlines can take advantage of efficiency and cost savings.

Therefore, the main task of the airline in today's conditions is to ensure the efficiency of its activities by introducing innovations in conditions of scarce resources.

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