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PhD THESIS

SUMMARY

MANAGEMENT OF AERONAUTICAL LOGISTICS ACTIVITIES. STUDY ON HANDLING PROCESSES

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CAPITOLUL V

OPTIMIZATION OF THE DEICING PROCESS

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Introduction

In an area with a growing dynamic of activity, with an annual growth rate of 4.6% per year of global traffic, it is quite difficult to ignore the challenges of this sector of activity.

Concerns over the past 20 years have shifted to new models and means of simulating aeronautical activities in the airport area, where a number of characteristic activities involving many aeronautical agents are concentrated.

Due to the complexity of the specific activities, but also due to the need for cohesion between different aeronautical agents, a lots of institutions or logistics specialists have focused on identifying new models and means to improve the performance of the ground support activity.

It is surprising that in an area where the activities are strictly procedural, there are still many problems that lead to a series of syncopes, in the processes of cooperation between partners. For this reason, in this paper aims to present a series of conclusive aspects, in relation to the ground support activity, as a continuous concern and focused on different directions of the specific activities of the airports.

In this sense, it is necessary to establish a main objective of the work that will lead, step by step, to obtaining remarkable results in the field:

„Increasing the management capacity of the handling activity and especially of the ground deicing activity of the aircraft″

In order to be able to solve this main objective, it is necessary to set some secondary objectives that will lead step by step to its achievement. For this reason, the development of the paper was based on the following secondary objectives:

- **Objective 1**: *"Identify the main research topics in airport support activity in the last 20 years";*
- **Objective 2**: "*Defining the main elements characteristic of airport logistics processes*";
- **Objective 3**: "*Define the main ground support processes at an airport*"
- **Objective 4**: "*Establishing the main entry and exit parameters for each process, as well as how they can be correlated, so that it grows the activity at an airport*";
- **Objective 5**: "*Identify the characteristic operating times on the ground and in flight in order to increase the accuracy of the programming of ground support activities*";
- **Objective 6**: "*Establish a mathematical model to identify the amount of ADF / AAF used, depending on the identified influencing factors*";
- **Objective 7**: "*Optimize the deicing process through a function with multiple constraints*".

Careful study of specific handling activities is required as a result of the growing number of airport movements and the need to provide competitive services to the specific needs of ground air operations. In this sense, the handling activity has become more and more important lately, as a result of the requirements formulated by the low-cost companies and not only, to reduce the duration of the stopover and to concentrate a series of services in a short time interval. This is only possible through good organization and cooperation between all parties involved.

An important role in the development of global handling has been played by IATA by establishing standards and means of cooperation between the parties involved in ground support processes, being over time a real catalyst for the development of the air transport industry.

The role of the paper is to point out those elements that enhance the handling activity, outlining well the elements characteristic of this activity and the way in which different elements of this activity and other ground support activities, on an airport. An even greater motivation in the development of this subject comes from the fact that, for the most part, during the aircraft turnaround, the handling occupies a large part of the time allocated to the turaround, after maintenance time. However, it is an area of work with a lot of interest, both from the airlines and from the airports or handling companies.

This paper focuses on several key directions in defining ground support activities, such as:

- state of the art of research in the airport field;
- logistics of airport services;
- the role of ACDM in the development of the ground services activity;
- study on deicing processes;
- optimization of the deicing process.

All these are directions that will be developed in this paper in order to show the importance of handling activities and how they contribute to the achievement of outstanding results in favor of airlines and other aeronautical agents involved.

Understanding the current concerns of researchers in this field, is a necessary to the first step in training and defining any specialist, and at the same time they help to identify opportunities for the future research and that could contribute to the development of this domain.

From the studies made and presented briefly in Chapter 1, it is identified that in the area of deicing of aircraft on the ground there are few concerns and it would be an opportunity to develop studies that would contribute to a better management of these activities. Deicing is an essential component of the operation in the cold season, where there are conditions for the formation of ice deposits on the surfaces of the aircraft. Without this activity, the safety of air operations would be much reduced and would lead to high risks.

The presentation of airport-specific logistics activities aims to identify all the specific processes and activities, the particular or defining elements encountered in this activity and which could lead to a better integration of them in an IT system. The development of this chapter aims to highlight the sequence of activities and constraints we have on certain activities and how we can model them so as to obtain the best results with a minimum of resources involved. In order to highlight the specificity of some activities, different types of aircraft were taken into account, on a full or minimum servicing turaround.

By studying the specific activities of the turaround, we identified that deicing is one of the activities in which its definition in time as the duration of a process is the least studied. There are many studies on how to do this process or on the substances used in relation to the environmental conditions and the materials from which the surfaces of the aircraft are made, but no data have been identified in the literature on the approximation of quantities used in relation to environmental conditions or with deicing time.

This has led to the need to look for answers in this domain and to find mathematical support to identify an amount of deicing / anti-icing fluid that can be estimated based on given working conditions. The importance of this research is defining for those who work in handling companies, offering the possibility to properly manage the fluid resources available to them, over short periods of time, depending on weather conditions and aircraft to be deicing, as well as for longer periods of time, through proper stock management. This chapter highlights many aspects of the deicing process, from the regulatory conditions underlying this process to the resources involved in its deicing process.

The study of deicing in different weather conditions, led to the obtaining of significant statistical data and to the identification of a mathematical form that allows a good approximation of the amount used for deicing, in different concentrations.

The research methodology in this case consisted of:

- collection of statistical data obtained following the deicing on the ground of aircraft with type II fluid;

- calibration of weather information with statistical data provided by specialized institutions;

- modeling these data with the help of linear and nonlinear equations, so that the obtained results increase the accuracy of the values determined by estimating the amount of ADF used.

The usefulness of these equations is beneficial, both in the current activity for a better allocation of the equipment necessary for the service of each aircraft, and for ensuring the continuity of the deicing processes at the company / airport level.

In order to give an even better perspective of this deicing activity, the paper develops in detail each stage of work, with the necessary characteristic times and establishes a mathematical form through which the results obtained as a result of the allocation of resources can be improved.

Based on this model and specific work procedures, a software was developed capable of managing the deicing activity on a dedicated platform. It’s use can lead to outstanding results both for air operators, by shortening the deicing time, and for the handling company by the fact that the available resources are no longer wasted unnecessarily. The development of this software has allowed a better aircraft scheduling to deicing, has led to the reduction of delays caused by improper allocation of equipment and the minimization of their taxi times from the stationary position to the deicing position.

The most important results obtained by using this software are:

- a real-time image of the condition of each aircraft on the platform and the time remaining until the scheduled take-off time;

- a good knowledge of the amount of deicing fluid and water existing in each fluid reservoir from each machine used;

- exact knowledge of the available equipment on the platform;

- estimating the required amount of deicing fluid, depending on the given weather conditions, at an established concentration;

- generation of work reports for each machine used or for each airline.

These are a few aspects of the goal setting shareware that you can use to manage your aircraft's ground clearance.

For a better integration of handling activities in ground operations, a detailed analysis of all specific phases of operation was required, through a systemic approach. This analysis took into account the work of the most important aeronautical agents, identifying their specific activities and how they can be correlated, so as to minimize errors in decision making. From this perspective, the paper addresses a topic of interest, which aims to increase the ability to make decisions at airports (Airport Collaborative Decision Making Implementation - ACDMI) [1], in a way that could provide a complete picture of all activities performed at the airport in real time, through the information used [2].

All these research are components of the airport logistics activity. For a better understanding of logistics, we have developed in Chapter 2 a series of aspects, in which handling plays an important role.

Airport logistics consists in providing all the necessary resources for the development of the characteristic processes, in a way that would allow the entire system to manage the characteristic activities, in order to achieve the transport function.

In the vision of airport logistics, a complex image is developed, consisting of all the characteristic activities having the capacity to manage in real time the needs imposed by the achievement of the proposed goal, that of transporting passengers, goods and mail by air, in safety condition.

Studying the characteristic of the Air Transportation System (ATS) as a systemic representation of the data flow that composes it, we have four main actors:

- the airlines that provide the transport of passengers and / or goods, of the mail, from one point to another;

- airports that provide the necessary support for the mediation of all trade and more;

- Air Traffic Control (ATC) agencies that are responsible for Air Traffic Management (ATM).

- other aeronautical agents who facilitate the transport process by making available to the air operator all the services it needs directly to achieve the proposed purpose (handling, catering, fuel, maintenance companies), but also indirectly through the organizations designated by on the territory of the states to supervise the compliance with the regulatory requirements.

The air transport system is made up of a many factors that generate added value through:

- primary flows: aircraft and their crews;

- secondary flows (support) formed by the processes of: fuel supply, catering, maintenance, handling, etc. [3].

Most of these flows, by their composition or by the interaction between them, are found at the airport. In this sense, the airport can be seen as a system of primary and secondary flows that interact through commercial and procedural mechanisms (there are strictly regulated in this area). Flows, however complex are centered around two key components: airlines and their customers (passengers, shipping companies, and postal services).

CHAPTER I
CURRENT STAGE OF LOGISTICS ACTIVITY AIRPORT

1.1 STATE OF THE ART

Recent concerns regarding air transport activity have led to the identification of tools for modeling and analyzing the performance of airport operations, focusing on the following directions:

- airport capacity and efficient optimization of airport operations;
- validation and evaluation of air traffic management concepts and how they meet current but especially future requirements;
- the development of safety and security standards that better meet current traffic needs, procedures and rules established in an appropriate manner;
- the development of technologies in line with current concerns to meet the development needs of the movement area, the area around the airport and the terminal.

Starting from these aspects, it is necessary to establish an objective in the research activity, namely:

Objective 1: Identify the main research topics in the support activity of airports in the last 20 years.

Among the most significant projects that focused focused on the directions presented above are:

1) "Total Airport Performance and Evaluation" (TAPE) [6], a project aimed at evaluating and validating decision support systems for airport performance and strategic development planning. This project aimed to identify the following issues:

- the integration at strategic and tactical level of the activities specific to the area of maneuver and from the passenger terminal, by using mathematical models that would offer real-time solutions to the problems identified at these airports;
- the development of a new and fast model, in order to analyze the capacity of the movement area and its combination with an analytical one that would offer solutions to the fluidization of the traffic in this space;

Based on these research, a model called "TAPECAP" was created and developed as an essential component of the optimization process in the maneuvering area, combining two other models: *LMI Runway Capacity Model* and *Federal Aviation Administration Airfield Capacity Model* [7].

2) "*Optimization of Airport Systems A + B*" OPTAS A + B [8] is a project that aimed to assess the capacity of the movement area and around the airport using mathematical models to meet the potential capacity, determined by the evolution of European air traffic the future, but also how the airport can be developed to meet current and future needs.

The main problems that were solved in this project included aspects regarding:

- passenger handling (including handling of passengers with reduced mobility - PMR), passenger safety and the design of future terminals that better meet occupational safety and health standards for passengers and companies operating in this area;

- the impact on the environment in the context of the future development of aviation;

- An Advanced Surface Movement Guidance and Control System (A-SMGCS) has been created to provide solutions in the management of airport activities on the surface and to reduce pollutant emissions.

This system was developed and led to the use of tools on the basis of which landing and take-off can be planned, through a movement surface management that has in its composition three by systems:

- Arrival Manager System, AMAN,

- Departure Manager System, DMAN,

- Surface Manager System, SMAN. **[9]**

3) "*Optimization Platform for Airport, including Landside*" (OPAL) [10], [11], [12], this project has been developed as an integrated structure of the movement area (see ICAO Annex 14, page 18, vol. 1, 3-rd ed. of July 1999), with that around the airport, by simulating the characteristic operations independently or acting together, on top of each other. The development of a system to manage the activities around the airport was aimed at correlating these activities, regardless of whether they are carried out in support of passengers or aeronautical agents operating in this area.

4) "*Mantea Airfield Capacity And Delay Model*" (MACAD) [13], [14], is a project that aimed to develop a mathematical model capable of optimally developing airport capacity, focusing on the area of movement.

The model is based on the analysis of runway capacity and the estimation of traffic delays. It considers a number of issues such as:

- scheduling aircraft on landing taking into account slot and landing priority procedures in special cases;

- the rolling of the aircraft on the system of escape routes in a manner that allows their continuous running;

- the parking area, the number of stands or embarkation / disembarkation gates, taking into account their capacity to serve a certain type of aircraft;

- rolling of aircraft on the runway system and alignment at take-off;

- staggering aircraft at take - off, respecting the minimum safety distance expressed in miles or minutes;

- the geometry of the airport and the characteristic operations carried out on it. This establishes the number of stationary positions, the distance between them, their destination;

- the number of runways and the simultaneous operations carried out on them.

5) "*Linking Existing ON ground, ARrival and Departure Operations*" (LEONARDO) [18], the objectives of this project were to demonstrate the feasibility of integrating all tools and technologies related to the management of activities on arrival, departure and turnaaround operations, oriented in support of optimizing the processes around aircraft. This project started as

an integral part of the DAVINCI project, which was developed as an "Operational Concept" meant to integrate all the processes characteristic of the aeronautical agents operating at the studied airport.

6) "*Aviation Policy information Resources based on Observatory Networks*" (APRON) [20], this project was funded by the European Commission and aimed at:

- to identify and validate the main communication dysfunctions that appear at the level of an airport;
- to integrate and harmonize the information collected through the various sources of information;
- to establish a physical link in the communication process between the airport and the different aeronautical agents participating in the air transport process.

In addition to these projects, there have been other developments in various directions, in order to serve as a model for the problems related to the multiple activities at an airport, such as:

- from the range of motion, among the most used simulations are: SIMMOD [21], TAAM [22], LMI Runway Capacity Model [23], FAA Airfield Capacity Model [24], INM, TRIPAC.
- from the area adjacent to the airport, by creating computing platforms such as: POWERSIM, WITNESS-MODA, PAX / BAX and THENA [25].
- from the terminal area, certain computing platforms have been created such as: SLAM.

All this research aimed at optimizing airport activities, at the level of large airports, by creating computing platforms capable of providing solutions.

Most of them, as can be seen, have focused on the movement area by providing data control in a much more rigorous, precise and transparent way to all parties involved.

By the specifics of the activity of each airport, it cannot be said that the problem is over, that all the problems have been solved and that there is a unique model applicable to any airport. This field is constantly evolving, offering new challenges, new problems waiting to be solved.

1.2 PARTIAL CONCLUSIONS

This study aimed to identify several aspects of airport research. Due to the growing concerns in the optimization of airport processes, a series of researches have been identified that have been carried out at European level and aimed at improving airport activity. These projects focused on both the issues raised by the movement area and those in the terminal area or around the airport. All projects aimed at better integrating stakeholders in developing traffic as smoothly as possible, with as few delays as possible and with the ability to make decisions based on real-time data. The synchronization of activities as a whole is the key to success in the future development of airports.

From the analysis made on these researches and applied models [1], [6] - [25], for solving the problems identified at the airport, there are very few elements that would lead to an optimization of the handling activities and even less of those of deicing of aircraft on the ground, given that this process involves a number of human and material resources.

The management of this process would be an important point in the service of aircraft on the ground and the way of cooperation between different aeronautical agents, according to ACDMI (Airport Collaborative Decision Making Implementation). [1]

Objective 1 has been achieved by identifying the main concerns at the major airports in Europe, thus showing the development trend of the concerns in the field.

CHAPTER II
MANAGEMENT OF AIRPORT LOGISTICS ACTIVITY

2.1. A BRIEF HISTORY OF LOGISTICS

The origins of the word "*logistics*" are difficult to determine exactly, but if we take a closer look we will see that over time, over the centuries, it has had different connotations. For example, according to the explanatory dictionary of the Romanian language, this word comes from the Greek language, from "*logistikos*" - which defined a person who knew how to calculate, was qualified in calculations. In Latin, in the time of the great emperors of the Roman Empire, "*logista*" designated an administrative officer in the Roman and Byzantine armies.

Over time, this word "*logistical*" takes on different connotations due to the development of specific military activities. After 1945, logistics appeared as an alternative term for military administration, and after 1948 the three U.S. military services: land, air and naval, agreed on an official definition that included "*the supply and administration of war materials, personnel and equipment*."

After 1960, the concept began to move from the military to the civilian field and began to be used in civilian activities, although it is often seen as a military element of a nation's economy, but also as an economic element of its military operations.

If we were to summarize the definition of this word, in my opinion, logistics represents: *"all the elements that contribute to the supply of raw materials and components, providing the necessary equipment to carry out an activity (training, social assistance, providing support services), in order to achieve products and services".*

Another approach to this definition could be: "*the sum of all the activities undertaken in order to allow the material good to be in the right place, at the right time and at the lowest cost*".

Beyond the historical perspective of this term, it is necessary to define it in the context of aeronautical activities. That is why the aim of this chapter is:

Objective 2: Defining the main elements characteristic of airport logistics processes.

2.2. MANAGEMENT OF AERONAUTICAL ACTIVITIES

The Air Transportation System (ATS) is perhaps, the most complex and largest of all known transportation systems. Along with the maritime one, it integrates a series of agents that intervene in a series of specific activities and whose activity decisively influences the activity of others. Airport Collaborative Decision Making (ACDM) is a concept that seeks to bring together all aeronautical agents, which contribute to the smooth running of activities at an airport. Among the most important aeronautical agents are: air operators, airport operator, handling companies, air traffic control services and others agents involved in the decision-making process based on a real-time exchange of information [28].

An optimization of the planning and use of all the resources involved, at a high level of operation, would lead to a reduction in the propagation of system disturbances, due to delays in various processes and would allow an improvement in the means of operation.

Based on the growing concerns in recent times, related to the optimization of airport activities [3], [4], [6], [8], [9], [10], it would be desirable to create a model that simulate the processes of scale.

The main objective is to integrate all the important processes at an airport taking into account several delay factors and to finally obtain results that express the increase in the efficiency of the airport activity. The evaluation of the degree of efficiency increase can be performed on the basis of indicators, such as the rate of delays or the waiting time to be served.

The problem of organizing and managing specific activities in air transport is not a new one, it is a long-studied problem that knows a lot of research. Research such as ACDM [28] identifies three major actors involved in the air transport system:

- the airport operator;
- air operators, handling companies, support services (police, customs control, emigration, etc.);
- Air Traffic Control (ATC) service providers and the Central Flow Management Unit (CFMU), operated by EUROCONTROL on the basis of ICAO document Doc. 7754, Volume I, Part V.III , paragraph 3);

Other researchers have identified five major categories of actors in the Air Transportation System (ATS).

2.3. ELEMENTS OF AIRPORT LOGISTICS

Studying the main elements of the air transport flow, it is found that those who bring added value to the air transport service are the passengers and / or the transported goods, as well as the aircraft with their crews. In this sense, there are two flows that contribute to the formation of value:

- primary flow: aircraft with their crews;
- the secondary flow (support) formed by the processes: fuel supply, aircraft maintenance, handling, catering, etc.

These two flows together contribute to adding value through the service provided to passengers or to third parties, beneficiaries of the air transport service (freight and / or mail).

2.4. ACTIVITIES CHARACTERISTIC OF TURNAROUND PROCESS

In order to model the scale process, it is necessary to study the elements that compose it and the factors that lead to a high efficiency.

Depending on the specifics of the handling contract or the specifics of the operating services (low-cost carrier - LCC or full service national carrier - FSNC), these services may differ. In order to illustrate the characteristics of these activities, they were presented in the thesis based on the manual "*Aircraft characteristics airport and maintenance planning*", the main services encountered at turnaround with their characteristic times, for different types of aircraft.

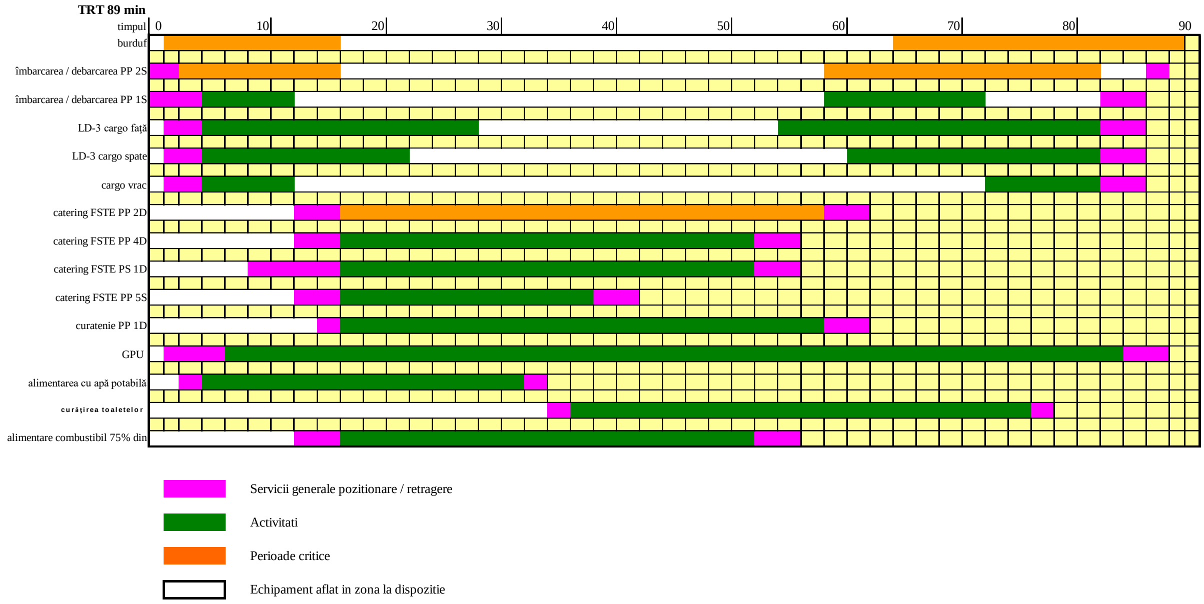

Fig. 2.1 Schedule of boarding / deboarding activities with two floating decks on the A380 - 800 aircraft, with two decks and using the main and upper deck

March 30, 2005 edition and revised November 1, 2012, page 2, figure-5-2-1-991-002-A01

The paper presented in detail each process of scale, with its characteristics, providing a complete picture of everything that means quantity used, time to perform the process, machinery involved and any defining information in this regard. This analysis included the following activities:

- 2.4.1. Loading and unloading luggage,
- 2.4.2. Catering,
- 2.4.3. Aircraft cleaning service,
- 2.4.4. Fuel supply,
- 2.4.5. Water supply and emptying,
- 2.4.6. Boarding and deboarding of passengers,
- 2.4.7. Security check,
- 2.4.8. Deicing / anti-icing on the ground.

2.5 PARTIAL CONCLUSIONS

In this chapter, aspects of the turnaround process have been highlighted by presenting information as detailed in various scientific papers or manuals developed by aircraft manufacturers. The main concern was to show the sequence of operations, the duration and resources involved and the extent to which they can be improved. It is important for any air operator, holder of an AOC (*Air Operator Certificate*), to know all these aspects when performing the GOM (*Ground Operational Manual*), as it essentially contributes to establishing the duration of the turnaround and the quality of services provided on the ground.

Through the analysis performed, we identified a series of constraints determined by:

- the existence of some critical activities, as shown in fig. 2.3 - 2.10 of the thesis, which impose certain restrictions on the succession of ground operations around the aircraft;

- the minimum duration required to carry out certain activities, depending on the configuration of the cabin, the degree of loading of the aircraft and the capacity of the handling company to organize;

- positioning the equipment on the platform for servicing the aircraft.

All these aspects I believe can be improved if there is a continuous concern on the part of all parties involved in carrying out these activities, through a permanent exchange of information on the duration of each process, the position and availability of equipment, the deviation from time. established for the performance of aircraft service processes and other matters necessary for proper management in a minimum of time and at low cost. This can be solved by better integrating information at an airport level, as proposed by Eurocontrol through ACDM [1].

Another aspect identified by the studies carried out in this chapter was the lack of concrete data on the duration and quantities necessary to carry out a deicing process on the studied aircraft. Due to the specificity of this activity, which involves considerable resources of time, equipment, deicing substances, it is necessary to study in detail this process. We must not neglect the financial aspects that arise from all these activities described and which are important for an air operator.

By presenting these aspects, it is considered that **objective 2** of this paper has been achieved, showing which are the main elements that define the logistics activity at the level of an airport and at the same time, it is a step in developing new contributions to improving the turnaround.

CHAPTER III
THE IMPACT OF ACDM ABOUT HANDLING ACTIVITIES

In order to develop the logistics activity at an airport, in accordance with current traffic requirements, it is necessary to achieve a better integration of specific activities through a permanent exchange of data between all aeronautical agents.

In this sense, it is necessary to set objectives in this chapter, so that through the succession of ideas developed to outline a complete picture of how to better manage specific ground activities at an airport.

The objectives of this chapter are:

Objective 3: Define the main ground support processes carried out on an aerodrome;

Objective 4: Establish the main input and output parameters for each process, as well as how they can be correlated, so as to increase the activity on an aerodrome;

Objective 5: Identify characteristic ground and in-flight operation times to increase the accuracy of scheduling ground support activities.

3.1. DEFINITION OF SUPPORT PROCESSES CARRIED OUT ON THE GROUND ON AN AERODROM

In this chapter, a systemic approach was used to define the support processes at an aerodrome, in order to identify all the factors that shape the activity of each organization. In this sense, for each process, from each specific activity, the input parameters, the output parameters and the disturbances that could modify the results of the performed activity were presented in detail. Among the activities analyzed are:

1) Handling, in which the check-in, boarding / deboarding of passengers, loading / unloading of luggage or goods, as well as other services performed on the platform were analyzed.

2) Security and customs service;

3) The airport operator;

4) The air operator, in which the availability of aircraft and crews, aircraft maintenance and crew training were analyzed.

3.2. THE ROLE OF THE HANDLING PROCESS IN THE IMPLEMENTATION OF ACDM

In 1997, at the 14th meeting of the European Civil Aviation Conference (ECAC), held in Conpenhaga, a new air traffic development strategy was established with the aim of "*increasing the ability to control air traffic on the ground and in flight, keeping it at a high level of safety* ".

Airport Collaborative Decision Making (ACDM [28]) - is a concept that aims to optimally solve the problems of air traffic flow, as well as increase its coordination capacity Air Traffic Flow and Capacity Management (ATFCM) at airports, by reducing delays , by improving the ability to predict events and by optimizing the use of resources.

The implementation of such a concept involves a series of positive aspects at the level of an airport, through a better management of the numerous processes that take place on it, but it also brings with it a series of tailor-made costs. In this regard, various activities were analyzed, such as:

- landing and taking off at an airport, with or without ACDM,
- turnaround, taking into account only the handling part,
- runway alignment for take-off,

For all these, the benefits and consequences deriving from the existence or not of the implementation of ACDM at the airport were highlighted.

3.3. THE ROLE OF ACDM IN THE CURRENT CONTEXT OF AVIATION DEVELOPMENT

As this issue has been presented, since the first edition of the Airport CDM Implementation Manual, developed by Eurocontrol [49], it has been a reference point for the management of airport activity. This concept has opened up new ways of collaborating in decision-making, decisions that no longer concern only one entity interested in obtaining results in the performed activity, but all the aeronautical agents that carry out their activity on an airport.

The exchange of information between different aeronautical agents captures the need to develop a system capable of providing solutions to current problems. In this subchapter was presented the exchange of data between:

- the air operator and the handling company;
- airport and air operator or handling company;
- Central Flight Management Unit (CFMU) and Regional Air Traffic Control Centers (APP, TWR) through the Operating Network (AFTN) [51], [52];
- Air Traffic Control Unit (TWR) and Airport [51], [52];

- other service providers (maintenance, catering and fuel).

3.4. BENEFITS OF ACDM IMPLEMENTATION ON HANDLING ACTIVITIES

Of all the aspects presented above, the handling activity has a large part of the benefits of implementing such a system, if certain changes occur at the level of these organizations as well.

The implementation of ACDM would lead to:

- a better organization of the ground activity, through a better knowledge of the estimated block time until arrival (EIBT) for each aircraft served;
- a sustainable use of material and technological resources;
- a balanced workload for each work team;
- a reduction in direct and indirect costs;
- a reduction in costs due to penalties imposed for each minute of delay in the handling process.

3.5 PARTIAL CONCLUSIONS

This chapter sought to capture many aspects of the importance of implementing the concept of ACDM and the impact that the implementation of this concept would have on the airport, but also on other aeronautical agents (airlines, handling companies, fueling companies and others).

This concept is currently being fully implemented at 32 airports in Europe and other major airports should also understand the importance of the benefits of this concept.

The information presented in subchapters 2, 3 and 4 on the implications of the ACDM concept has been achieved in **Objectives 3, 4 and 5** of this chapter.

CHAPTER IV
STUDY ON THE DEICING PROCESS ON AN AERODROM

As we presented in the previous chapter, the deicing process is an important component of the handling activity, from the point of view of the safety of air operations, as well as from the point of view of optimizing the support activities carried out on the aerodrome.

This component of the handling activity was studied taking into account:

- the legal framework for carrying out the deicing activity;
- the factors with an essential role in the development of the process;
- establishing a mathematical relationship to estimate the amount of aircraft deicing fluid (ADF) used in various working hypotheses.

All these aspects are of particular interest both for the handling companies, as service providers and for the airlines, as beneficiaries of these services. Both sides are interested in these issues, as the process involves employing considerable resources, such as:

- technological resources (equipment and deicing fluids),
- human resources for handling companies, and
- financial resources for airlines.

Establishing a coherent policy of the expenses incurred for the development of this process, for any of the parties, presupposes a good knowledge of the deicing and a good management of the expenses for the committed resources.

The purpose of this chapter is:

Objective 6: Establish a mathematical model to identify the amount of ADF / AAF used, depending on the identified influencing factors.

4.1 REGULATORY FRAMEWORK

The deicing / antiicing process, although it takes place only a few months a year, being a seasonal activity depending on the evolution of the weather conditions, still has a major impact on the safety of air operations and on the environment. Due to the length of service time and the costs involved in this activity, it requires a careful analysis of this activity.

From the point of view of regulations, the most important institutions are:

- Society of Automotive Engineers - SAE,
- International Organization for Standardization - ISO,
- Association of European Airlines - AEA.

The study of the regulations specific to this activity is a necessity, meant to improve the activity in relation to the compliance requirements of the authority.

4.2. ESTABLISHING WORKING METHODS

An important role in determining how each deicing / anti-icing process should take place on the ground should be:

- evaluation of the internal potential of the organization, ie the number of equipment (with their technical performance) and human resources (through its work capacity);
- evaluation of the weather conditions in which the activity takes place, both long-term and short-term;
- the type(s) of aircraft(s) serviced and the requirements of the master regarding the minimum expected protection time, "*holdover time*".

All these aspects are evaluated by the management team of the handling company and a work plan is established for each aircraft served. The process can be done in one step or two steps, as the case.

Influence of weather conditions on deicing / antiicing

The weather forecast is one of the most important information in the conduct of aeronautical activities on the ground and in flight, with a significant role in the safety of air operations. Deicing / anti-icing is one of the processes carried out on the ground, which depends very much on the evolution of the weather conditions. The more accurately the weather information is established, the better the deicing / anti-icing decisions.

In order to better understand the influence of weather factors on the deicing operations, a study was conducted at the “Henri Coandă” Bucharest International Airport, regarding the way in which certain factors contribute significantly to obtaining remarkable results, such as:

- ambient temperature;
- surface temperature of the aircraft;
- the thickness of the layer deposited on the surface of the aircraft;

- wind, by direction and intensity;

- ADF concentration.

All of this information affects the amount and type of ADF used.

In order to identify the dependence of these factors on the amount of fluid used, it was proposed to use a linear model in order to evaluate the correlation of the influencing factors with the proposed model.

4.3 THEORETICAL MULTIFACTORYAL LINEAR REGRESSION MODEL, [54]

By establishing the hypothesis that the multifactorial linear model explains the dependence between the amount of deicing or anti-icing fluid used on an aircraft and the independent explanatory variables such as:

- ambient temperature, $\left[{}^{0}C\right]$, x_{1t};
- surface temperature of the aircraft, $\left[{}^{0}C\right]$, x_{2t};
- the thickness of the layer deposited on the surface of the aircraft, $[mm]$, x_{3t};
- wind by its intensity, $[m/s]$, x_{4t},

it seeks to establish a mathematical form with a high degree of correlation of the identified parameters.

The hypotheses for applying this multifactorial linear model are:

- it is accepted that between the quantity of ADF, as an endogenous variable Y_t and the environmental factors, as exogenous variables $x_{1t}, x_{2t}, ...x_{kt}$, there is a linearity relationship disturbed by the error e, determined by the recording of the measurements performed in the analyzed data sample;
- the values recorded for each of the exogenous variables $x_{1t}, x_{2t}, ...x_{kt}$ are not equal to each other, ie it is accepted that the dispersion of each variable is non-zero;
- the variables $x_{1t}, x_{2t}, ...x_{kt}$ are not random, ie if we assume that these recorded values are not altered by observation or recording errors, and the weather conditions allow measurements to be made under similar conditions, then the data collected are repetitive;
- there is no dependency relationship between any two exogenous variables $x_{1t}, x_{2t}, ...x_{kt}$;
- the number of observations made is much higher than the number of chosen exogenous variables;
- errors e_t have zero mean, are independent of each other and are normally distributed.

If we accept that the relation between Y_t and the explanatory variables x_{it} are linear in time, then we can write:

$$\begin{cases} Y_1 = a_0 + a_1 x_{11} + a_2 x_{12} + ... + a_k x_{1k} + e_1 \\ Y_2 = a_0 + a_1 x_{21} + a_2 x_{22} + ... + a_k x_{2k} + e_2 \\ Y_3 = a_0 + a_1 x_{31} + a_2 x_{32} + ... + a_k x_{3k} + e_3 \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ Y_t = a_0 + a_1 x_{t1} + a_2 x_{t2} + ... + a_k x_{tk} + e_t \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ Y_n = a_0 + a_1 x_{n1} + a_2 x_{n2} + ... + a_k x_{nk} + e_n \end{cases} \quad (4.1)$$

Dacă introducem notațiile:

$$\mathbf{Y} = \begin{pmatrix} Y_1 \\ Y_2 \\ Y_3 \\ \dots \\ Y_n \end{pmatrix}, \ \mathbf{X} = \begin{pmatrix} 1 & x_{11} & x_{12} & \dots & x_{1k} \\ 1 & x_{21} & x_{22} & \dots & x_{2k} \\ 1 & x_{31} & x_{32} & \dots & x_{3k} \\ \dots & \dots & \dots & \dots & \dots \\ 1 & x_{n1} & x_{n2} & \dots & x_{nk} \end{pmatrix}, \ \mathbf{A} = \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ \dots \\ a_k \end{pmatrix}, \ \mathbf{e} = \begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ \dots \\ e_n \end{pmatrix} \quad (4.2)$$

Then equation (4.2) can be written as follows:

$$\mathbf{Y} = \mathbf{XA} + \mathbf{e} \quad (4.3)$$

The available data sample will be used to calculate the model parameter estimators. That is, the estimators will be determined $\hat{a}_0, \hat{a}_1, ..., \hat{a}_k$. Then, the values calculated based on the estimator model $\hat{Y}$ of the endogenous variables have a form identical to that of the multiple linear regression equation:

$$\hat{Y} = \hat{a}_0 + \hat{a}_1 x_1 + \hat{a}_2 x_2 + \hat{a}_3 x_3 + ... + \hat{a}_k x_k \quad (4.4)$$

The linear regression equation is a time-dependent variable and in this sense equation (4.4) can be rewritten as follows:

$$\hat{Y}_t = \hat{a}_0 + \hat{a}_1 x_{1t} + \hat{a}_2 x_{2t} + \hat{a}_3 x_{3t} + ... + \hat{a}_k x_{kt} \quad (4.7)$$

The properties of the considered model are:

a) the estimators are linear, ie the explanatory variables x_{it} are not random and have fixed values;

b) the estimators are consistent, ie if the explanatory variables $\hat{a}_i$ have finite and non-zero dispersion, and the value of the estimator a_i tends asymptotically towards the value of the parameter, as the sample size increases;

c) the estimators are of maximum probability;

d) the number of observations is higher than the number of parameters;

e) the errors of the calculation process have a constant dispersion, in any t chosen one (the errors are not heteroskedastic), they are independent and normally distributed.

Simplifying calculation hypotheses have been established:

a) a clear distinction was made between the working methods used (one-step or two-step);

b) it has been considered that the temperature and pressure of the ADF or hot water are always the same and do not influence the results obtained;

c) the weather conditions are unchanged during the entire period of deicing / anti-icing process;

d) there is enough liquid in the ADF and water tanks for a complete deicing;

An important role in the evaluation of the factors chosen to express the phenomenon has the coefficient of determination:

$$R^2 = 1 - \frac{\sum_{t=1}^{n} u_t^2}{\sum_{t=1}^{n} \left(Y_t - \overline{Y}\right)^2} \tag{4.8}$$

But every time we introduce a new explanatory variable R^2, its value increases, even if that variable has a low relevance in that model. For this reason, we need to introduce additional criteria that will lead us to establish the veracity of the chosen variable. In this regard, two validation criteria were used:

- Akaike Information Criterion (AIC) [55]:

$$AIC = \frac{1}{n}\left(\sum_{t=1}^{n} u_t^2\right) \cdot e^{\frac{2(k+1)}{n}} \tag{4.9}$$

- and Schwartz Information Criterion (BIC) [55]:

$$SCHWARTZ = \frac{1}{n}\left(\sum_{t=1}^{n} u_t^2\right) \cdot n^{\frac{k+1}{n}} \tag{4.10}$$

4.4 CASE STUDY: A320 AIRCRAFT DEFROST.

The calculations were performed based on statistical data resulting from the deicing process within a handling company.

Following the processing of the collected data and the correlation of this information with that of the Weather Underground site [57], a consistent database was obtained which allowed a study to be carried out on different situations of the deicing process.

4.4.1 Use an ADF / water mixture in a 50/50 ratio

The creation of a representative sample of data allowed the processing and interpretation of the results obtained based on the linear multifactorial model.

Each influencing factor was studied one by one to identify the degree of determination of the estimated function. Then two or three variable couplings were made, following the value of the degree of determination R^2 and whether the chosen factors are relevant for the model used based on the two criteria, Akaike and Schwartz.

Among the results obtained by coupling two, three or four influencing factors are:

1) estimating the model using two variables: ambient temperature - x_{1t}, and wind intensity - x_{4t}. In this case the degree of determination of the phenomenon was 83.60%.

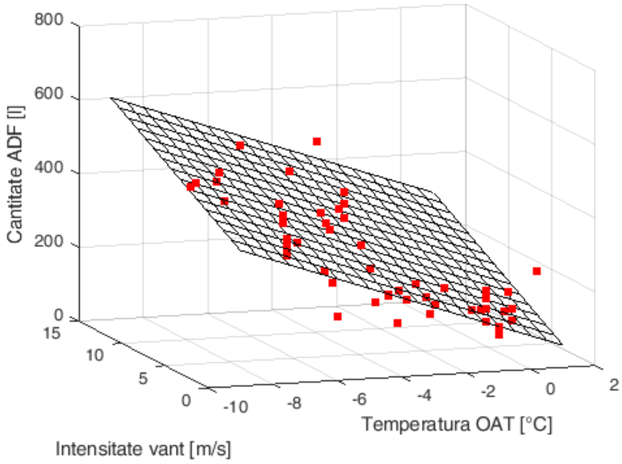

Fig. 4.1 Distribution of the endogenous variable Y_t and the estimated variable $\hat{Y}_t$ based on the linear model, taking into account two variables, x_{1t} and x_{4t}

2) estimating the model using three variables: ambient temperature - x_{1t}, aircraft surface temperature - x_{2t} and wind intensity - x_{4t}. In this case the degree of determination of the phenomenon was 84.73%.

3) model estimation using four variables: ambient temperature - x_{1t}, aircraft surface temperature - x_{2t}, layer thickness deposited on the aircraft surface - x_{4t} and wind intensity - x_{4t}. In this case the degree of determination of the phenomenon was 85.02%.

The linear multifactorial model will have the following mathematical expression for estimating the amount of ADF:

$$\hat{Y}_t = 1.74843 - 22.36838x_{1t} - 11.48540x_{2t} - 9.43115x_{3t} + 11.48856x_{4t} \tag{4.11}$$

By testing the significance of these parameters, it follows that they accept the null hypothesis by applying the *t-Student* distribution:

- $\alpha = 0.08$ for the a_1 parameter, which means a degree of confidence of 99.92%;
- $\alpha = 4.39$ for the a_2 parameter, which means a degree of confidence of 95.61%;
- $\alpha = 29.52$ for the a_3 parameter, which means a degree of confidence of 70.48%;
- $\alpha = 0.001$ for the a_4 parameter, which means a degree of confidence of 99.999%.

This shows that the statistically measured values have strong enough arguments to justify the hypothesis of a link between the identified influencing factors and the endogenous variable Y_t.

By measuring the coefficient of determination R^2 for each variable used or for any coupling of terms, the following results were obtained:

- for 3 influencing factors R^2 it has the following values
0.79052 (x_{1t}, x_{2t}, x_{3t}), 0.84732 (x_{1t}, x_{2t}, x_{4t});

- for 4 influencing factors R^2 it has the value **0.85020** (x_{1t}, x_{2t}, x_{3t} şi x_{4t});

Applying the information criteria Akaike and Schwartz resulted in the following values:

- for 3 influencing factors the resulting values are

- for the variables (x_{1t}, x_{2t}, x_{3t}), $AIC = 4{,}700.49$ şi $SCHWARTZ = 5{,}385.66$,

- for the variables (x_{1t}, x_{2t}, x_{4t}), $AIC = 3{,}425.93$ şi $SCHWARTZ = 3{,}925.31$,

- for 4 influencing factors, (x_{1t}, x_{2t}, x_{3t}, x_{4t}) applying the two criteria is obtained $AIC = 3{,}469.71$ şi $SCHWARTZ = 4{,}113.03$. These have slightly higher values than in the case of three factors which calls into question the veracity of the factor "the thickness of the layer deposited on the surface of the aircraft - x_{3t}. However, as these values are not very high, this result can be considered relevant.

In conclusion, this multifactorial linear model is accepted with a degree of determination of **85.02**% which represents a satisfactory degree of confidence.

4.4.2. Use an ADF / water mixture in a ratio of 75/25

As in the case of defrosting with a 50/50 mixture, the data are analyzed by selecting several exogenous variables one by one.

Among the results obtained by coupling two, three or four influencing factors are:

1) estimating the model using two variables: ambient temperature - x_{1t} and wind intensity - x_{4t}. In this case the degree of determination of the phenomenon was 78.94%.

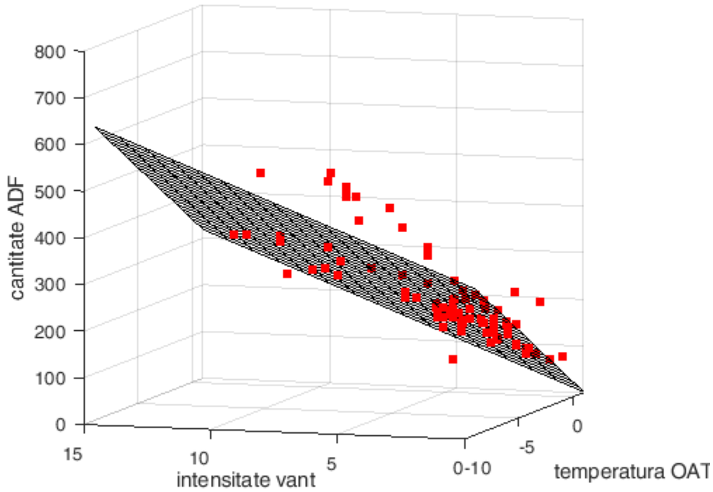

Fig. 4.2 Distribution of the endogenous variable Y_t and the estimated variable $\hat{Y}_t$ based on the linear model, taking into account two variables, x_{1t} and x_{4t}

2) estimating the model using three variables: ambient temperature - x_{1t}, aircraft surface temperature - x_{2t} and wind intensity - x_{4t}. In this case the degree of determination of the phenomenon was 82.62%.

3) model estimation using four variables: ambient temperature - x_{1t}, aircraft surface temperature - x_{2t}, layer thickness deposited on the aircraft surface - x_{3t} and wind intensity - x_{4t}. In this case the degree of determination of the phenomenon was 82.81%. It can be seen that the introduction of variables x_{3t} does not explain the studied phenomenon well enough.

By testing the significance of these parameters it results that he accepts the null hypothesis by applying the *t-Student* distribution:

- $\alpha = 0.00$ for the parameter a_0, which means a degree of confidence of 100%;

- $\alpha = 0.00$ for the parameter a_1, which means a degree of confidence of 100%;

- $\alpha = 0.003$ for the parameter a_2, which means a degree of confidence of 99.997%;

- $\alpha = 30.909$ for the parameter a_3, which means a degree of confidence of 69.091%;

- $\alpha = 0.00$ for the parameter a_4, which means a degree of confidence of 100%.

Consequently, the value of free terms has a high degree of certainty. This shows that the statistically measured values have strong enough arguments to justify the hypothesis of a link between the identified influencing factors and the endogenous variable Y_t.

By measuring the coefficient of determination R^2 for each variable or coupling of exogenous variables, the following results were obtained:

- for 3 influencing factors it has the following values for R^2

0.82623 (x_{1t}, x_{2t}, x_{4t}), 0.49785 (x_{1t}, x_{2t}, x_{3t}) and 0.59984 (x_{2t}, x_{3t}, x_{4t});

- for 4 influencing factors the value for R^2 is 0.82811 ($x_{1t}, x_{2t}, x_{3t}, x_{4t}$);

These values show that as a new factor of influence is added the phenomenon is better explained. Of course, it is important to assess whether the newly introduced factor is relevant. In this regard, the Akaike and Schwartz information criteria were applied. The results for three and four influencing factors were:

- for 3 influencing factors the values resulting from applying these criteria are

- for the variables (x_{1t}, x_{2t}, x_{3t}), $AIC = 6{,}679.13$ and $SCHWARTZ = 7{,}407.98$,

- for the variables (x_{2t}, x_{3t}, x_{4t}), $AIC = 5{,}322.46$ and $SCHWARTZ = 5{,}903.26$,

- for the variables (x_{1t}, x_{2t}, x_{4t}), $AIC = 2{,}311.26$ and $SCHWARTZ = 2{,}563.47$,

- for 4 influencing factors, (x_{1t}, x_{2t}, x_{3t}, x_{4t}) applying the two criteria is obtained $AIC = 2{,}332.09$ and $SCHWARTZ = 2{,}654.42$.

Analyzing these results, based on the two criteria Akaike and Schwartz, but also on the coefficient of determination, it is observed that we have the best coupling of exogenous variables at (x_{1t}, x_{2t}, x_{4t}).

In conclusion, the linear multifactorial model will have the following mathematical expression for estimating the amount of ADF:

$$\hat{Y}_t = 94.11382 - 43.18059 x_{1t} + +11.46316 x_{2t} + 23.55635 x_{4t} \tag{4.12}$$

This model has an accepted degree of certainty of 82.62%.

4.4.3. Use of an AAF in a ratio of 100/0

As with deicing, the use of an anti-icing fluid (AAF), a fluid in which water is not used, requires the determination of a mathematical expression that estimates the amount of AAF required for good protection of the aircraft, taking into account the same influencing factors as in previous cases.

Among the results obtained by coupling two or three influencing factors are:

1) estimating the model using two variables: - ambient temperature - x_{1t} and the surface temperature of the aircraft - x_{2t}. In this case, the degree of determination of the phenomenon was 3.25%.

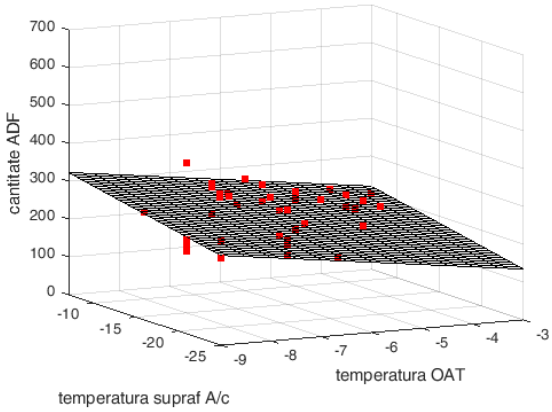

Fig. 4.3 Distribution of the endogenous variable Y_t and the estimated variable $\hat{Y}_t$ based on the linear model, taking into account two variables, x_{1t} şi x_{2t}

2) estimating the model using three variables: - ambient temperature - x_{1t} and the surface temperature of the aircraft - x_{2t} and wind intensity - x_{4t} does not improve the results obtained on the degree of determination. This is also 3.25%.

In conclusion, this three-factor linear model, based on three factors of influence, cannot be used because it has a degree of determination of 3.25%, totally unsatisfactory and other factors of influence should be identified or a non-linear model applied.

4.4.4. Use a nonlinear model to estimate the amount of ADF at a mixture of 50/50

Taking into account different factors and coupling two by two, it was observed that the best results were obtained with the variables: ambient temperature - x_{1t} and wind intensity - x_{4t}. The estimated variable was determined for a polynomial of order 2, 3 and 4, for each combination of factors, from which the polynomial of order 4 was noted, for which a value of the square root and its normalized value was obtained by:

$$RMSE = 36.5718, \; NRMSE\,1 = 0.0731, \; NRMSE\,2 = 0.1246$$

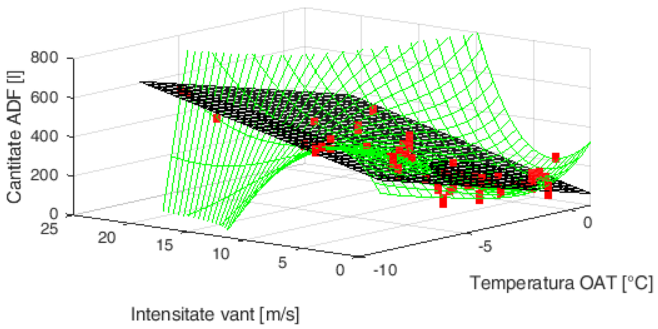

Fig. 4.4 Distribution of the endogenous variable Y_t and the estimated variable $\hat{Y}_t$ based on the linear model, taking into account two variables, x_{1t} şi x_{4t}

Of all the variables analyzed, the coupling between x_{1t} and x_{4t} provided the best degree of determination of the coefficients used, of **93.23**%. The estimation function can be expressed in the form:

$$\hat{Y}_t = 209.7535 + 82.7483x_{1t} - 38.1216x_{4t} + 27.4451x_{1t}^2 + 4.1736x_{4t}^2 - 21.4214x_{1t}x_{4t} + \\ + 3.0651x_{1t}^3 + 0.5421x_{4t}^3 + 2.1558x_{1t}x_{4t}^2 - 0.6467x_{1t}^2x_{4t} + 0.1292x_{1t}^4 - 0.0077x_{4t}^4 \quad (4.13)$$

4.4.5. Use a nonlinear model to estimate the amount of ADF at a mixture of 75/25

As in the previous point, two factors were coupled and it was observed that the best results were with the variables: ambient temperature - x_{1t} and wind intensity - x_{4t}. Interesting results were obtained for both a 3rd order and a 4th order polynomial.

The value of the average error of the quadratic root and its normalization for a 3rd order polynomial is:

$RMSE = 43.8026$, $NRMSE1 = 0.0768$, $NRMSE2 = 0.1712$

- with a degree of determination of the equation of order 3 of 84.39%
- and with a form of the equation of order 3 of the type:

$$\hat{Y}_t = 6.5174 - 83.1819x_{1t} + 23.0469x_{4t} - 14.9129x_{1t}^2 - 0.0865x_{4t}^2 + 2.4386x_{1t}x_{4t} - \\ - 0.9943x_{1t}^3 + 0.0570x_{4t}^3 + 0.2745x_{1t}x_{4t}^2 + 0.6820x_{1t}^2x_{4t}$$

Whereas, the value of the average error of the quadratic root and its normalized one, for a polynomial of order 4 is:

$RMSE = 42.8925$, $NRMSE1 = 0.0753$, $NRMSE2 = 0.1677$

- with a degree of determination of the equation of order 4 of 85.03%
- and with a form of the equation of order 4 of the type:

$$\hat{Y}_t = 85.9049 + 10.9511x_{1t} + 5.2424x_{4t} + 21.062x_{1t}^2 + 7.5522x_{4t}^2 + 2.4763x_{1t}x_{4t} + \\ + 4.2625x_{1t}^3 - 0.82415x_{4t}^3 + 0.15122x_{1t}x_{4t}^2 + 0.52102x_{1t}^2x_{4t} + 0.26261x_{1t}^4 + 0.02567x_{4t}^4 .$$

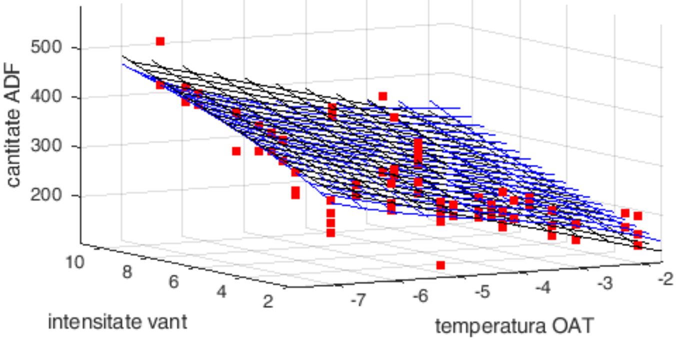

Fig. 4.5 Distribution of the endogenous variable Y_t and the estimated variable $\hat{Y}_t$ based on the linear and nonlinear model of order 3, taking into account two variables x_{1t} and x_{4t}

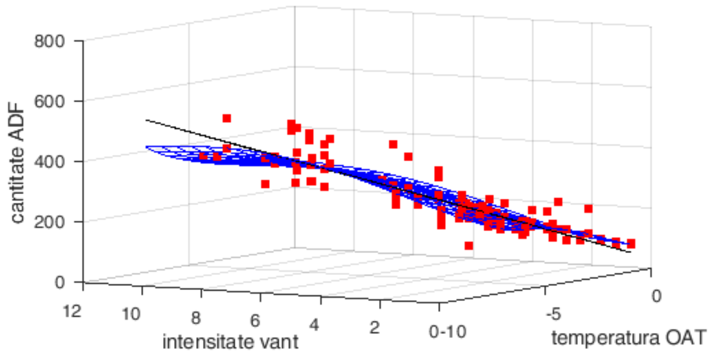

Fig. 4.6 Distribution of the endogenous variable Y_t and the estimated variable $\hat{Y}_t$ based on the linear and nonlinear model of order 4, taking into account two variables, x_{1t} și x_{4t}

Taking into account the distribution of statistical points and the form of the estimating variable, it can be said that the mathematical form of the 4th order polynomial is a satisfactory one, having a degree of determination of the coefficients used of **85.03**%. The estimation function can be expressed in the form:

$$\hat{Y}_t = 85.9049 + 10.9511x_{1t} + 5.2424x_{4t} + 21.062x_{1t}^2 + 7.5522x_{4t}^2 + 2.4763x_{1t}x_{4t} + \\ + 4.2625x_{1t}^3 - 0.82415x_{4t}^3 + 0.15122x_{1t}x_{4t}^2 + 0.52102x_{1t}^2x_{4t} + 0.26261x_{1t}^4 + 0.02567x_{4t}^4 \quad (4.14)$$

4.4.6. Utilizarea unui model neliniar pentru a estima cantitatea de AAF la un amestec de 100 / 0

As in previous cases, the analysis of the behavior of different factors was continued, where for the variables: ambient temperature - x_{1t} and wind intensity - x_{4t}, an average error of the square root and its normalization was obtained for a 3rd order polynomial of:

$RMSE = 22.8383$, $NRMSE\,1 = 0.1038$, $NRMSE\,2 = 0.0947$

- with a degree of determination of the 3rd order equation of 75.23%
- and with a form of the equation of order 3 of the type:

$$\hat{Y}_t = 950.3125 + 421.8442x_{1t} - 16.331x_{4t} + 65.5423x_{1t}^2 - 5.8282x_{4t}^2 - 24.4923x_{1t}x_{4t} + \\ + 2.819x_{1t}^3 + 0.03342x_{4t}^3 - 0.70774x_{1t}x_{4t}^2 - 2.9833x_{1t}^2x_{4t},$$

Whereas, the value of the mean error of the quadratic root and its normalized one, for a polynomial of order 4 was:

$RMSE = 22.6183$, $NRMSE\,1 = 0.1028$, $NRMSE\,2 = 0.0938$

- with a degree of determination of the 4th order equation of 75.70%
- and with a form of the equation of order 4 of the type:

$$\hat{Y}_t = 1814.5373 + 1065.6323x_{1t} + 8.2734x_{4t} + 233.2361x_{1t}^2 - 7.9666x_{4t}^2 - 19.8646x_{1t}x_{4t} + \\ + 21.3204x_{1t}^3 + 0.1866x_{4t}^3 - 0.7262x_{1t}x_{4t}^2 - 2.6364x_{1t}^2x_{4t} + 0.7334x_{1t}^4 - 0.0037x_{4t}^4,$$

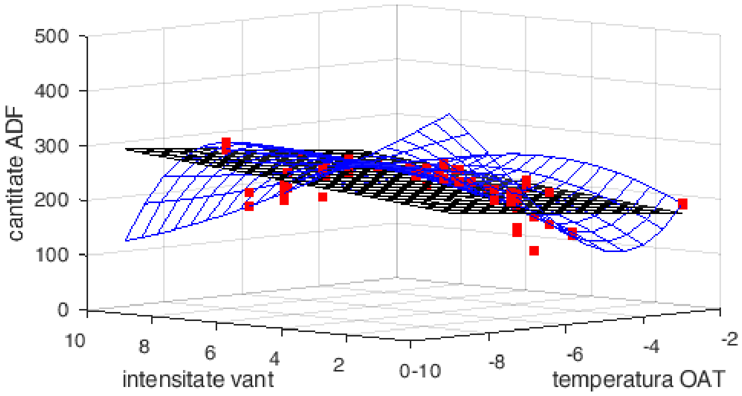

Fig. 4.7 Distribution of the endogenous variable Y_t and the estimated variable $\hat{Y}_t$ based on the linear and nonlinear model of order 3, taking into account two variables, x_{1t} şi x_{4t}

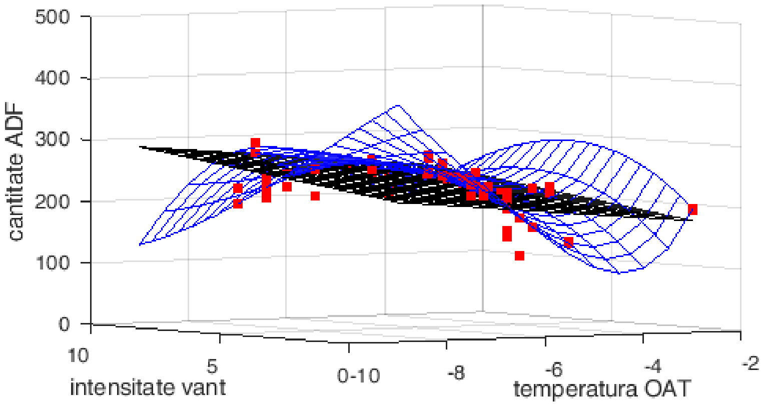

Fig. 4.8 Distribution of the endogenous variable Y_t and the estimated variable $\hat{Y}_t$ based on the linear and nonlinear model of order 4, taking into account two variables, x_{1t} şi x_{4t}

The differences are not significant between the two polynomials, but we can say that the mathematical form of the 4th order polynomial is better than the 3rd order one. The degree of determination of the coefficients used is **75.70**%. The estimation function can be expressed as:

$$\hat{Y}_t = 1814.5373 + 1065.6323x_{1t} + 8.2734x_{4t} + 233.2361x_{1t}^2 - 7.9666x_{4t}^2 - 19.8646x_{1t}x_{4t} + \\ + 21.3204x_{1t}^3 + 0.1866x_{4t}^3 - 0.7262x_{1t}x_{4t}^2 - 2.6364x_{1t}^2x_{4t} + 0.7334x_{1t}^4 - 0.0037x_{4t}^4 \quad (4.15)$$

4.5 PARTIAL CONCLUSIONS

Based on the research performed on representative data samples for each type of concentration studied, the following were observed:

- the accuracy of the data collected from the deicing / anti-icing processes on the ground, is particularly important in validating the results obtained with these models. The degree of determination is strongly influenced by the number of statistical data and the accuracy of the recorded values;

- there are factors with a significant weight in the modeling of the physical phenomenon, such as: ambient temperature - x_{1t}, the surface temperature of the aircraft - x_{2t} and the intensity of the wind - x_{4t} but there are also factors that although have a slightly lower weight, we must still take them into account. in modeling the phenomenon;

- it was observed that in case of an ADF / water concentration, of 50/50 a degree of correlation of 93.28% was reached, while at a concentration of 75/25 a degree of correlation of 85.03% is reached. This shows that the dependence phenomenon studied on the basis of the four factors does not have a linear variation, but rather a nonlinear one.

- in the case of anti-icing and the use of a non-linear model, the degree of correlation is 75.7%. The two influencing factors, the ambient temperature and the wind intensity, played an important role in obtaining this result. This is natural if we consider the FAA's recommendations for deicing / anti-icing of aircraft.

- a factor that was not taken into account in this model is the experience of the deicing team. This can significantly affect the results obtained if the team used does not have relevant experience in this field.

The importance of this process could lead to significant savings if the deicing activity were better organized in the following sense:

- better training of work teams to limit ADF losses unnecessarily;

- establishing the required amount of deicing / anti-icing fluid for at least 24 hours in advance, depending on the operating schedule of the companies served, the types of de-iced aircraft and the estimated weather conditions for the next working period;

- establishing a working scenario to ensure the necessary equipment and people for the activity established on that day. This organization would eliminate deadlines caused by machine performance, number of machines available and service personnel.

CHAPTER V
OPTIMIZATION OF THE DEICING PROCESS

Introduction

The aim of this chapter was to reduce aircraft delays as a result of the deicing process by reducing service times. It is an issue of optimization with multiple restrictions, given certain constraints that seek to define the process as effective and for the benefit of all parties involved.

The purpose of this chapter was:

Objective 7: Optimize the deicing process through a function with multiple constraints.

5.1. PROCESS MANAGEMENT

The deicing activity must be seen from at least two perspectives: one of the airlines and other that of the handling companies.

The optimization process must take into account the following aspects:

- aircraft type (dimensional constraints);
- the degree of contamination of the aircraft surfaces;
- weather conditions and type of deicing agent used;
- time left until the set time of departure, (Standard Time Departure - STD);
- the number of successive passes made by the deicing machine;

- the number of equipment used in the process;

- the amount of water and deicing agent available in the tanks;

- the heating time of the water and the deicing agent, up to the optimum operating temperature.

The mathematical formulation of the pursued problem consists in the elaboration of an objective function of the deicing process, in order to minimize the delays of the aircraft, as well as to minimize the movement interval of the equipment, from the stationary position to the working position. [58]

In order to establish an objective function, we must first establish certain conditions:

- positioning the service equipment as close as possible to the deicing area;

- moving the machine on the moving surface of the airport, from the stationary position to the working position on the same road. [59]

There are airports that do not benefit from platforms dedicated to the deicing process, and in this respect we must establish rules of travel minimizing the repositioning time.

$$\sum_{s=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\Delta t_{s,h}(K_k,t_i)-\sum_{h=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\Delta t_{h,p}(K_k,t_{i+1})=0 \quad (5.1)$$

For a staggering of the machines in service, it is necessary to establish a condition for their allocation only after the completion of the previous activity. This condition is expressed by the relation:

$$ARDT_{i-1}(K_k)<ARDT_i(K_k) \quad (5.2)$$

In order for this process to be properly managed, a good knowledge of the water, ADF and fuel reserves of each machine after the deicing is required.

Another issue we need to address is the estimated time to complete the deicing process and from which the aircraft is ready to leave the deicing position, and the crew may apply for taxiing permission from offshore position (Target Off- block Time - TOBT). This time must be combined with the operator's Standard Take Off Time (ATOT) and the estimated taxi time (*Standard Taxi Time* - STT).

To address all of these issues, we need to consider the following:

- the time proposed for the start of the deicing process is not always the same as the one established according to the management program of the current activities on the platform;

- taxi time is not a constant;

- the deicing time depends on the weather conditions;

- the technological performance of the equipment used and the human performance of the service personnel [60].

Depending on the available resources (equipment and deicing fluids) the number of equipment participating in the deicing process is determined:

$$ARDT_i+\frac{\sum_{s=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\min\left(\Delta t_{s,h}(K_k,t_i)\right),\Delta ts_{k,h}(t_i)}{n}+\max\left(f_i(p,FU,A/c,x_{it},n)(1+\zeta)\right)\le TED_i \quad (5.3)$$

We can say that a defrosting process is optimized $TED_i<STD_i$ if otherwise we will have to allocate a cost function that will penalize the outdated time. In order to comply with the allocated slots and not to interfere with the operation of the aircraft, an additional time restriction is required in the allocation of equipment during operation:

$$TED_i \leq STD_i - AWTT_i \tag{5.4}$$

At least two rules can be established to properly manage this process:

- "*first come, first served*", is a generally valid rule;

- "*according to custom airline*", used as a second rule intended to resolve situations when the first rule is not sufficient.

Another condition that must be established in the allocation of deicing machines in a new process is that the machines must not be allowed to participate in a new process until the previous process in which they took part has been completed.

$$\max(TED_i) + f_0(t_i) - Mnx_{s,h}(K_k, q_{\max}) \leq \min(ARDT_{i+1}) \tag{5.5}$$

Unfortunately, equations (5.4) and (5.5) are not enough to guarantee the efficiency of the processes and then a new condition is imposed, based on a criterion of minimum available resources (water and ADF) in the machines participating in the process:

$$\min\left((1+\varepsilon)q_{ADF\,estim}\right) < q_{ADF\ real}(K_k), \quad \min\left((1+\varepsilon)q_{apa_{estim}}\right) < q_{apa\ real}(K_k) \tag{5.6}$$

In conclusion, from equations (5.3), (5.4) and (5.6) it results that it is important to know how long each process will take, under what conditions we can perform it, but even more important is to know when it will be completed! For this reason, the time at which a deicing process can be considered completed is:

$$\begin{aligned} TED_i &= \min(ARDT_i) + \frac{\sum_{s=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R} \min\left(\Delta t_{s,h}(K_k, t_i)\right), \Delta ts_{k,h}(t_i)}{n} + \\ &+ \max\left(f_i(p, FU, A/c, x_{it}, n)(1+\zeta)\right) \\ daca \quad & \min(ARDT_i) + \frac{\sum_{s=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R} \min\left(\Delta t_{s,h}(K_k, t_i)\right), \Delta ts_{k,h}(t_i)}{n} + \\ &+ \max\left(f_i(p, FU, A/c, x_{it}, n)(1+\zeta)\right) \geq STD_i \end{aligned} \tag{5.7}$$

and

$$\begin{aligned} TED_i = STD_i\,,\ daca \quad & \min(ARDT_i) + \frac{\sum_{s=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R} \min\left(\Delta t_{s,h}(K_k, t_i)\right), \Delta ts_{k,h}(t_i)}{n} + \\ &+ \max\left(f_i(p, FU, A/c, x_{it}, n)(1+\zeta)\right) < STD_i \end{aligned} \tag{5.8}$$

The objective function has the following form:

$$\min \sum_{i=0}^{R} \left(a \cdot TED_i + \frac{1}{b} \Delta t_{s,h}(K_k, t_i) \right) \tag{5.9}$$

5.2. SIMULATION OBTAINED ON THE BASIS OF THE NON - LINEAR MODEL

In order to simulate the deicing activity at an airport, it is necessary to consider some important aspects such as:

- the desire of the airlines to carry out the deicing process in the shortest possible time;

- the desire of the handling agents to reduce the costs with the immobilized resources;

- the airport aims at a strict coordination of the movements of equipment and aircraft on the platform;

- the evolution of weather conditions is slow over time.

In order to improve the deicing process on the LROP, it is recommended to create a single deicing platform, which will also allow a good collection of the residues resulting from this process. In this regard, a study was conducted on the activity of operation, deicing at the airport level and legislative restrictions at national and international level and an article was published in a review. [59]

In order to support all the operators involved and in line with the proposed airport development strategy for the next period, we should redefine the deicing positions at this airport. This aircraft deicing platform must be designed to meet both the airport's operational needs and its environmental standards. [64], [65], [66]

In this regard, it is proposed that the deicing position be chosen at the entrance on the "N" and "G" runways with the following advantages:

- significant reduction $\Delta t_{s,h}(t_i)$ by positioning the equipment near this position dedicated for deicing;

- the residues resulting from the deicing process can be collected through a network. This reduces the pollution of the soil and subsoil (groundwater) with glycol residues. It is possible, through a collection and separation process, to reuse this glycol-based mixture;

- 2 or 3 machines can be used for a defrost with a significant reduction $\Delta ts_{k,h}(t_i) = 0$.

- taxi time is reduced as a result of the release of aircraft runways. The amount of polluants emitted into the atmosphere is reduced as a result of the combustion phenomena that occur when the aircraft is run in taxi-out mode. There is a growing concern at European level to reduce the amount of HC, NOx, SO2, CO, CO2 emitted. [68]

The development of software to minimize the service life of air operators has been the main concern of this subchapter. The software interface allows you to view the scheduled flights from that day, but also to introduce new flights for that day. Also consider all aspects of this chapter, using Matlab object-oriented programming. The stored information can be exported to Excel for further processing in the form of periodic activity reports.

Using this interface is a solution for managing the deicing process, through the rational use of the resources involved, but also through a better coordination of specific activities in a way that reduces risks and uncertainties. At an airport with a platform dedicated to this process and with high traffic, in severe weather conditions, it is very important that the deicing schedule is a coordinated and controlled process down to the smallest detail. Uncertainty or lack of adequate information such as:

- position of deicing equipment on the platform,

- the amount of ADF or water available in each machine,

- the time left until take-off or many other information, become vulnerabilities of a system that can inevitably lead to the occurrence of operational events. [69]

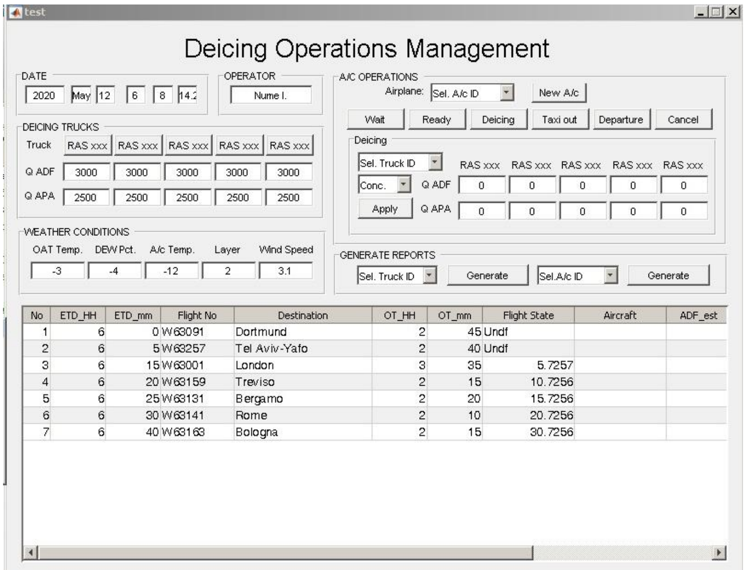

Fig. 5.1.a Deicing process management software interface

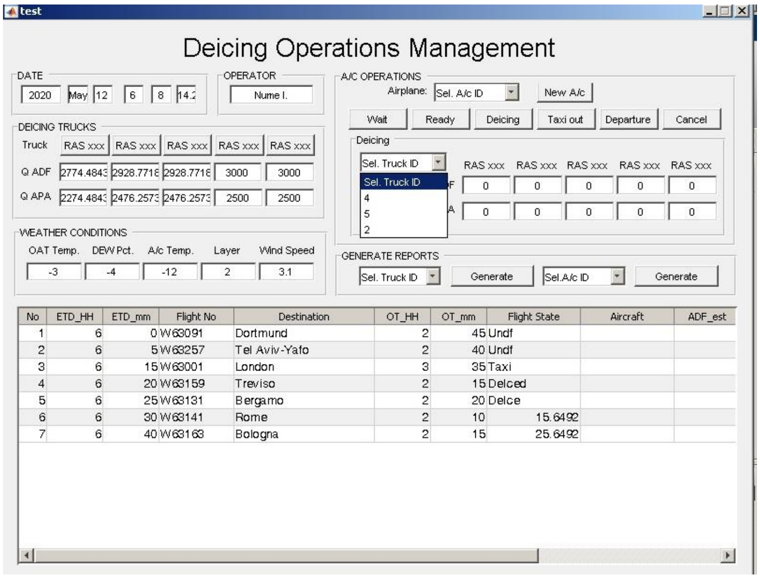

Fig. 5.1.b Deicing process management software interface

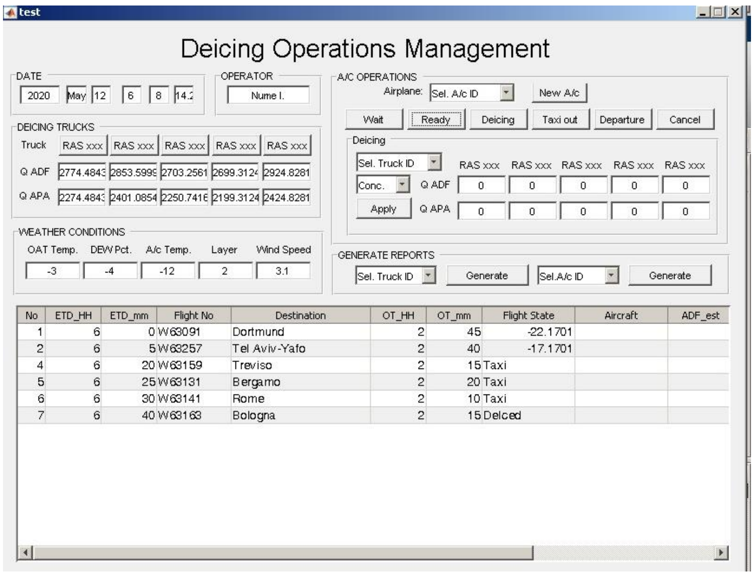

Fig. 5.1.c Deicing process management software interface

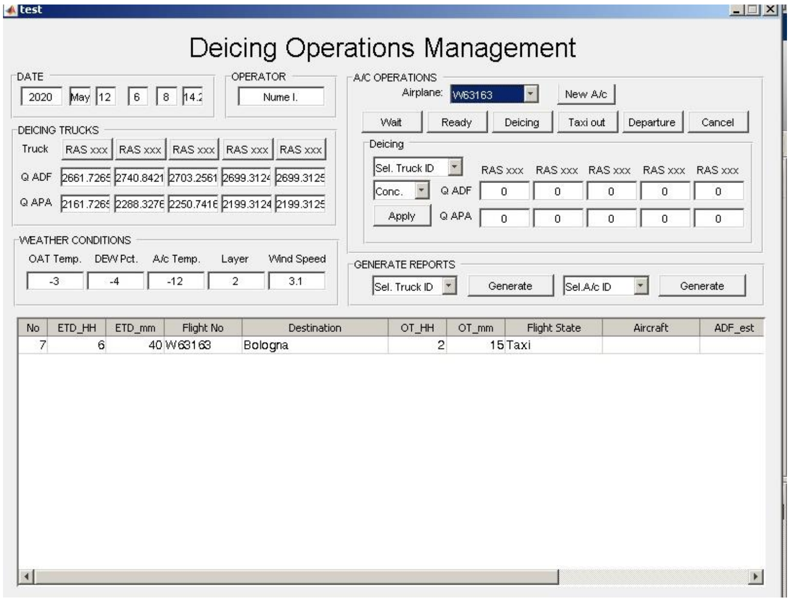

Fig. 5.1.d Deicing process management software interface

This interface aims to visualize multiple states of the aircraft, starting from the specific operating schedule of the airport. A first feature of this is the flexibility with which to choose the aircraft from the listed program "nrFlight" = [F] or the possibility of introducing a new aircraft (charter flight) "New" = [N]. The list can be updated with the option "Refresh" = [R].

If you want to pick up an aircraft from the list of the airport operating schedule, then all you have to do is specify the current flight number from the displayed list and enter [F]. In this sense, no. position of the aircraft from the currently displayed list and choose the status of the aircraft, which can be expressed by:

- Waiting - other activities are carried out around the aircraft;

- The aircraft has completed all turnaround processes and is in the standby position ready to begin deicing (Ready).

- after the end of the deicing, the continuity of the deposited layer and its thickness are verified, when the process is considered closed, the state “DeIced” = [I] is assigned. Theoretically, the aircraft should start taxi out if it receives approval from TWR.

- the start of taxi taxiing is identified by "Taxi out" = [T], while it is registered in the system for each aircraft until it is aligned to the position, at the head of the runway and receives the approval for takeoff;

- the "Dep" status = [D] is received after the aircraft has reached v_2 (ATOT), through the ACARS-OFF system.

The interface is built in such a way as to allow the issuance of activity reports for each machine participating in the process, showing the amount of ADF and water consumed over time.

Through this software development, we tried to capture as many elements of the deicing process as possible and make it as easy as possible to make decisions in the deicing process, so that the results obtained bring a significant improvement to this activity.

5.3 PARTIAL CONCLUSIONS

The aim of this chapter was to identify solutions that would reduce the delay time of aircraft for deicing and at the same time reduce the travel time of the machines from the stationary position to the service position.

Through the realized program, certain constraints were established that allowed to solve the problem with partial restrictions, in order to offer an optimal solution according to the imposed variations.

During the testing phase of the program, certain aspects were observed that led to detailed research on issues such as:

1) Allocation of the completion times of the turaround process according to an established scenario. As defined in the scenario, there were no situations in which two or more aircraft completed the turnaround process simultaneously and required all deicing.

This has allowed for simplified management of the problem, which does not rule out the possibility that this may actually happen. In such a situation, prioritization rules in addition to those established are required.

2) The cases in which we have only one machine available have not been studied well enough, especially in collaboration with other restrictions.

3) The studied issue was exemplified on a single type of aircraft. If we introduced various types of aircraft into the unknown problem, the problem would diversify, which reality does not exclude.

4) No pre-deicing conditions were imposed in this study. This is practiced for aircraft staying overnight at the airport and severe weather conditions are announced. In order to prevent significant ice from settling on the surface of the aircraft overnight, some handling operators prefer to deicing the aircraft as soon as the passengers and baggage have been unloaded. This does not accumulate significant ice deposits on the surface of the aircraft and also shortens the deicing process of the aircraft at the scheduled time of takeoff.

Objective 7 "*Optimizing the deicing process through a function with multiple constraints*" was achieved by creating a program in Mathlab capable of providing solutions to solve the given problem and also record the results obtained.

Personal contribution

Chapter IV aimed to achieve objective 6 "*Establish a mathematical model to identify the amount of ADF / AAF used, depending on the influencing factors identified*."

In order to understand the deicing process, the specific regulations underlying the development of this activity, developed by various international organizations, were identified and summarized. It is important that everything we do in aviation is in accordance with the specific regulations, and deicing occupies a special position in this regard.

After describing the deicing activity itself, it was very important for the author to identify some influencing factors of this activity, which through their analysis should lead to obtaining a composition law that can provide a more accurate determination of the amount of ADF, used in relation to the factors listed.

Using statistical data from aircraft deicing, Romanian Airport Services sorted the data, validated the ambient temperature information with information from specific sites, and then tested the relevant factors in relation to the requirements of using a linear model multifactorial [52], and finally the results were refined using a nonlinear model, with four influencing factors:

- ambient temperature, x_{1t},
- the surface temperature of the aircraft, x_{2t},
- the thickness of the layer deposited on the surface of the aircraft, x_{3t} and
- wind intensity, x_{4t}.

The development of these models represents a personal and original contribution that led to the obtaining of results with a degree of correlation of the information of:

a) in the case of deicing with a concentration of 50/50 and the use of a multifactorial linear model, the degree of determination of the estimated quantity based on the estimation function is 85.02% while in the case of using a nonlinear model it reaches **93.2**% ;

b) in the case of deicing with a concentration of 75/25 and the use of a multifactorial linear model, the degree of determination of the estimated quantity is 82.62%, while in the case of the use of a nonlinear model it reaches **85.03**%;

c) in the case of deicing with a concentration of 100/0 and the use of a multifactorial linear model, the degree of determination of the estimated quantity is 3.25%, while in the case of the use of a nonlinear model it reaches **75.70**%.

Through these mathematical expressions, a solution was offered to a problem of interest, both for the handling companies and for the airports where this process is carried out.

For an airport, as an integral part of this process by providing a specific deicing platform, it is useful to know the estimated quantity and duration in order to properly size this platform. It's sizing is done taking into account the following aspects:

- configuration of tracks and tracks;
- the evolution of the weather conditions and especially of the above parameters shown, by their average and minimum value, recorded for each day of the year. Of course, this requires a consistent database, but also useful for both the deicing process and the expansion of the movement surface (according to the provisions of ICAO Doc. 9157 - Aerodrome Design Manual, Part 1 Runways)
- the operating schedule of the aircraft at the studied airport and its future evolution;
- the types of aircraft operating at this airport and the safety limits imposed between two neighboring aircraft, both laterally and longitudinally (see ICAO Doc. 9157 - Aerodrome Design Manual, Part 2 Taxiways, Aprons and Holding Bays, Fourth Edition - 2005, Chapter 3.6)
- the capacity of the rainwater drainage system, as well as the deicing liquid resulting from the deicing of the aircraft. Against this, there are a number of legislative provisions on environmental protection, an issue studied and published in an article [59].

For airlines, this determination of the required amount of type II deicing fluid provides a good perspective on its ability to identify the likely costs of this activity, as well as the length of the process itself. This is a much more important issue for air operators than the cost of deicing fluid, as companies are more concerned with adhering to the operating schedule of each aircraft than with the price of deicing fluid. It is a matter of managing operational resources and meeting flight schedules, with multiple implications for crews and passengers.

For the handling companies involved in this process, it is a matter of resource management, as presented in Chapter 5.

In the process of processing the statistical data that were the basis for determining the necessary ADF / AAF, it was observed that for certain sets of numerical data, the resulting values have certain peculiarities when the temperature of the outside environment drops below -20^{0}C and we have a freezing rain phenomen. The slope of the curve is large, which induces a peculiarity in approximating its values. As the freezing rain phenomena are quite rare in our country and are generally short episodes in time, these data have been isolated. Moreover, it is necessary to have a large volume of data when processing numerical values, in order to reduce the estimation error.

The research conducted in this chapter resulted in the publication of an article [59] "*Considerations on ground aircraft deicing and sustainable airport development*", in Revista de Chimie, vol. 2/2019, Bucharest. In this way, we sought to highlight the information resulting from scientific research, outlining personal concerns, but also those of specialists in the field, interested in a rational use of deicing / anti-icing fluids, as well as environmental protection issues.

The solutions offered in the published paper, but also in the thesis, offer an alternative to the sustainable exploitation of the airport environment in accordance with the specific regulations in the field. [64], [65], [66]

The results obtained and presented in this chapter consider that these objectives have been achieved and that the possibility of future development using various deicing fluids is offered.

Chapter V came as a natural continuation of the research started in this paper and not only, offering a mathematical model and a software application that would allow a real improvement of the defrosting activity, through a rigorous control of the processes.

The objective behind this chapter was:

Objective 7 "*Optimize the defrost process through a function with multiple constraints*".

Starting from an idea published by Anna Norin and others [3], a calculation process was developed taking into account all the elements underlying the deicing process at an airport. For the author, in this paper, it was very important to capture the whole deicing process in the smallest detail, showing which elements need to be identified in a calculation process so that those who use the software choose the most good for the airline operator, but also for the handling company or airport.

Original contribution

The development of an adequate software for the processing of the data related to the deicing, was another preoccupation of this paper, bringing at the same time an element of originality of the paper.

With this application, the defrost activity can be managed much more easily, regardless of whether it is performed on a dedicated platform, as desired or in position.

The development of this application was based on the following principles:

- simplicity in use;
- flexibility in entering and obtaining data;
- first come first served;

This program has two main protagonists: the air operator and the handling company. From this perspective, restrictions have been built and the whole part of the calculation, presented in Chapter 5, has been developed, taking into account all the aspects considered useful in managing this problem.

As the resources involved in this issue are generally finite, it was considered useful to focus on the following resources:

- human resources - the persons involved in deicing;
- technological resource - represented by the available equipment used for deicing.
- the amount of deicing liquid and water in each deicing machine.
- time resource available up to scheduled departure time.

All these aspects are taken into account when deicing an aircraft, in order to obtain the best results, first of all for the air operator, as the main beneficiary of this program, and then if possible, for the handling company.

Taking into account the second principle underlying the development of this program, we have determined that each aircraft included in the processing list has a certain status:

- Wait, Ready, Deicing, Taxi out, Departure and Cancel.

Practically all the states through which an aircraft passes from its position to the stand and until it takes off have been defined. This allows strict control over aircraft on the platform in operation and to be deicing.

In the proper management of the activity it was considered that depending on the given situation, the coordinating agent of the deicing activity on the platform or from the aircraft (in case the deicing is done in position) to determine how many machines it needs to deicing. Of course it is a dose of subjectivism, but we are based on a rational decision based on knowledge and experience.

The software provides an estimate of the need for deicing fluid and water, but in the end, at the end of the process, the actual quantities consumed on each participating machine are entered. This allows work reports to be obtained on each aircraft / company and on each deicing machine participating in the process.

Basically we have a real-time image of the consumption of water and deicing fluid, on each aircraft and equipment used, which leads to a better coordination and training of the resources used, but also a control of the resources used every day or week. . These are three of the basic principles of management. And if we look at the problem in terms of an activity that can be planned as shown in Chapter IV, by the fact that we can assess future needs with some important data of this process, we can discuss a more efficient organization of this activity.

The software is seen as an application that can be extended and adapted to any airport, depending on the specifics of the operation and deicing activity.

Proposals for future developments

The structure of the paper and the multitude of problems analyzed show some proposals that I consider as interesting as those presented:

1) In Chapter IV we analyzed how a dependency relationship can be established between the four factors considered and the amount of ADF used to deicing the aircraft. This analysis was performed for a single type of ADF, type II. He is interested in continuing this study with other deicing fluids, such as type I or type IV.

2) If a deicing type (ADF) and another anti-icing type (AAF) were used during the deicing process, it would be interesting to determine which type is most suitable for each stage, both in terms of of the holdover time as well as in terms of the minimum quantities used.

3) In Chapter V, through the software interface used, it was not possible to capture all the particular aspects that can be encountered in the deicing process. It would therefore be useful to continue its expansion in the following directions of development:

- the deicing process at the airport is performed on a dedicated platform where several handling companies operate. Each of them serves certain air operators. The problem is to organize this process so that each handling company can honor its service contracts (deicing), without the aircraft being delayed from the established operating schedule;

- the deicing should be done under restricted conditions of temperature, commissioning time and to offer real solutions and at low costs.

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