POLYTECHNIC UNIVERSITY OF BUCHAREST

Doctoral School of Industrial and Robotic Engineering
Engineering and Management

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ABSTRACT
DOCTORAL THESIS

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Research on quality assurance of the predictive maintenance process in an aircraft maintenance organization

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INTRODUCTION

The evolution of the computer industry, especially the processing power, but also the increase in the volume of data determined by the expansion of the digital universe, along with the development of hardware systems, involves in the short, medium and long term a change in the way we live and the way we produce. quality services and goods. The exponential increase in the volume of information indicates a major change in all industries. In this context in which we are in the digital age, it is essential to find new techniques for collecting and analyzing the huge volume of data available.

In order to meet the current quality requirements, it is necessary to modernize the management activities by combining the theoretical notions of quality management with the benefits offered by artificial intelligence.

A new technological revolution, the fourth, marks the society of today, a society in which the term "connectivity" is the basis of the activities we undertake. Whether we are talking about education, medicine or industry, technology is present and influences these areas in a decisive way. Everything is changing around us, technologies such as artificial intelligence, autonomous vehicles, 3D printing or the Internet of Things are becoming more and more present in everyday life [1].

A specific feature of the fourth industrial revolution is that it changes not only the way people live but also the man himself. At the same time, this industrial revolution will change business models. Everything will be connected to the internet: houses, cars, appliances, equipment, etc. These will be monitored remotely by the manufacturing companies.

In a simplified way, most business models consist of developing a product, marketing it and possibly providing maintenance services. With the development of new technologies in terms of data collection, transfer and interpretation, a new distinct activity will emerge within companies in the near future. Continuous monitoring of products sold while serving the needs of customers will not only be a distinct and well-defined activity within a company, but will become the main source of inspiration in production, maintenance, marketing and sales.

Real-time monitoring of a product provides valuable information about its reliability and how it can be improved, as well as information about customer expectations and needs. By knowing this data, the product can be continuously optimized and adapted to the unique needs specific to each customer. From a marketing perspective, the information collected will help a more targeted sale. The customer will pay only for that product that will meet his needs and the maintenance activity will be predictive.

However, the real revolution is not in the expansion of computer systems but in the way we use and interpret data.

Most companies around the world understand this technological revolution that is looming on the horizon and are investing heavily in this direction and at the same time adapting their business model to keep up with these major changes, which are meant to make our lives better.

The perspective of today's society in the near future leads to a key term that will characterize almost any field, namely the term "complexity". This is the key word I used to refer to when designing this research.

Starting from the field of this doctoral program - Engineering and Management, **the main objective** of this doctoral thesis is the innovation in terms of predictive maintenance activity within an aircraft maintenance organization using machine learning algorithms.

The purpose of the paper is the original contribution to ensuring the traceability of maintenance processes and the identification of defects at an early stage.

The doctoral thesis focuses on how the data resulted from the maintenance process are stored, analyzed and disseminated to all participants of the organization.

In the aviation industry, aircraft are made up of millions of components and sub-components that together make up a system capable of flying. Modern aircraft are true data generators, which will change the way data is stored and the way maintenance is organized for these highly complex technical systems.

In this context, **the thesis proposes** concrete solutions for data management resulting from the maintenance process, so that there is traceability, transparency and predictability.

In addition, this doctoral thesis focuses on predictive maintenance which is superior to preventive maintenance, due to a developed algorithm, which is based on the principle of **artificial neural networks.**

The paper tests and develops a machine learning algorithm capable of identifying a malfunction before it occurs, by analyzing the "big data" generated by aircraft engines.

At the same time, **the inclusion in the field of study** is done by introducing a quality policy at the level of a maintenance organization, which involves adapting, refining and combining the classic concepts of quality management with today's disruptive technologies.

In writing this doctoral thesis, a series of methods and tools were used that constituted the following research methodology:

- research of bibliographic materials in the field
- case studies and comparative analyzes
- simulations and tests
- the development of algorithms was done with the help of the Python programming language and the SKLEARN libraries

Chapter 1

1. The general framework of quality management in the maintenance of technical systems

1.1. The concept of quality

As the industry develops, the concept of quality has gained significant proportions, now becoming an indispensable pillar in the resilience structure of any competitive economic entity.

The need for standardization coupled with the rise of concern for quality, led to the establishment of an international confederation to establish generally valid rules, established by consensus, for various activities.

The International Organization for Standardization (ISO) is a globally recognized non-governmental organization that develops internationally applicable standards.

The standards in the ISO 9000 family refer to the way an organization operates and the definition of the quality management system. In other words, these standards focus on how the processes are organized and not on the final results of an organization. Obviously, the systematization of processes in a company decisively influences the quality of the final product and compliance with customer requirements.

The ISO 9000 [2] family of standards is generic, due to its applicability to any organization regardless of field of activity, size or profit.

Joseph Moses Juran, considered the father of quality management, has revitalized many multinational companies with his concepts that he has launched over time.

It divides quality management into 3 components [3]:

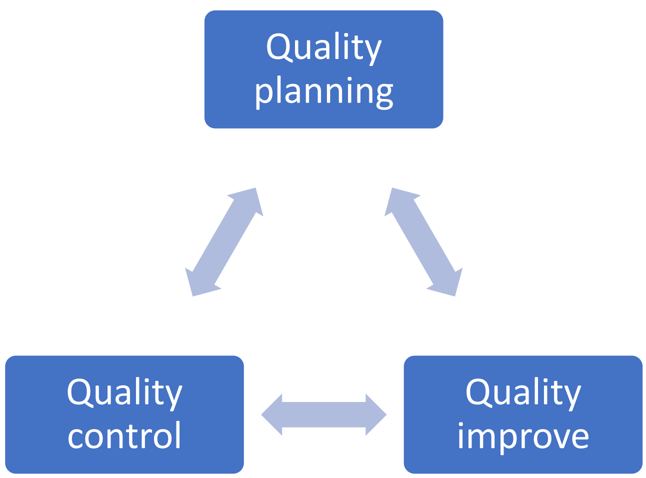

Figure 1.1 Quality components

1.2. Determinarea fiabilității unei aeronave, folosind tehnica lanțurilor Markov

The Markov technique is a statistical model that involves a probabilistic estimation of a future action, given the current state of a variable. Once the probabilities of future actions in each state are defined, a graph of states can be made, which by analogy can be resembled to a tree, due to the branches that form.

For a better understanding we assume the following situation:

Given a component of a system that can be in two states A and Z:

The probability of transition of the component from state A to state Z derive from the analysis of the system in a determined period and vice versa.[7]

Note:

x – probability of moving from state „A" to state „Z"

y – probability of moving from state „Z" to state „A"

The following graphic representation results::

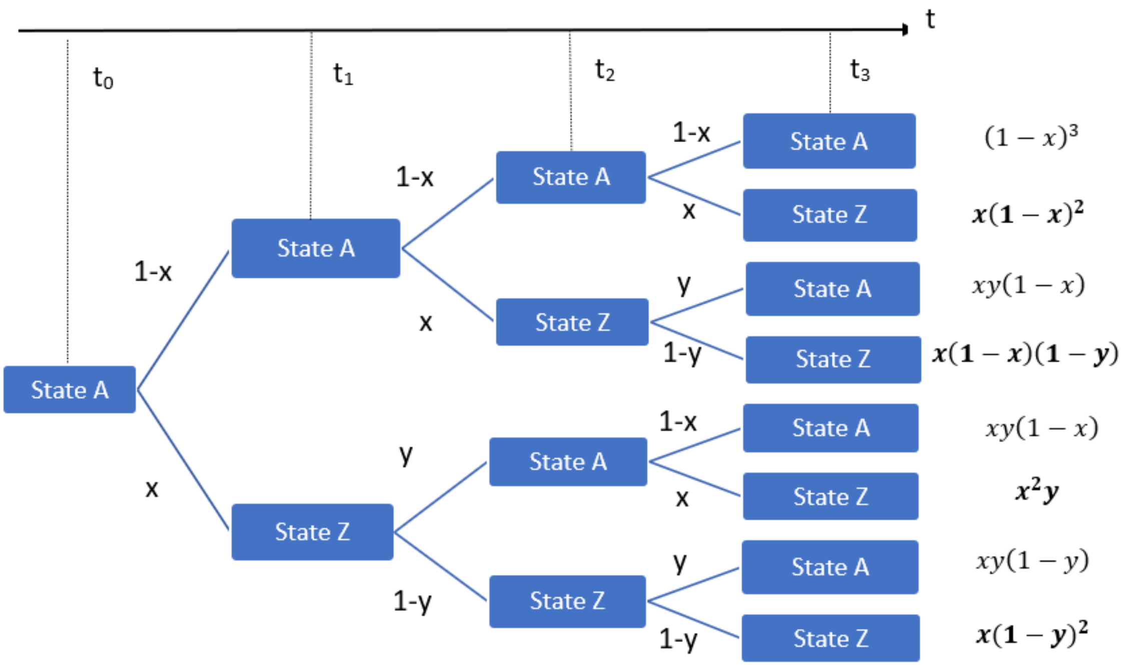

Figure 1.2 Graphic representation of Markov chain [4]

The probability of the system to be in the state „A" at the time t_3 is:

$$P_A = (1-x)^3 + 2xy(1-x) + xy(1-y)$$

The probability of the system to be in the state „Z" at the time t_3 is:

$$P_Z = x(1-x)^2 + x(1-y)(1-x) + x^2y + x(1-y)^2$$

Applying the generalized formula for n states and m iterations results in the same probabilities. So the probability that the system is in one of the "n" (n = 2) states, after "m" (m = 3) iterations according to Markov's theory is:

$$V^0 \cdot P^3 = [1 \quad 0] \begin{bmatrix} 1-x & y \\ x & 1-y \end{bmatrix}^3 = [P_A \; P_Z];$$

Where:

- $[1 \quad 0]$ - is the vector of the initial state. Being in state A, the first element of the vector is 1 and the second 0.
- $\begin{bmatrix} 1-x & y \\ x & 1-y \end{bmatrix}$ - is the transition matrix for the two states.

That being said, the condition of an aircraft or system can be estimated using the Markov chain technique, as follows:

Further, we assume that an aircraft has "n" systems and "m" states:

According to the role of the components and with the minimum equipment list instructions, some conditions in Table 1 may be accepted for flight while others may not be accepted. There are situations in which an aircraft may be able to fly with inoperative systems, by applying the principle of delayed maintenance. A state with one or more inoperative systems can be acceptable. Each system can be "functional" or "failed", as it is presented in the following table:

Tabel 1.1. Aircraft's possible states with two systems

State number	System A	System B	Aircraft's possible state
1	Functional	Functional	Functional
2	Failed	Failed	Failed
3	Functional	Failed	Failed
4	Failed	Functional	Failed

Tabel 1.2. Aircraft's probability to fail and be repaired

	The probability that the system will fail during one Δt:	**The probability that the system will NOT fail during one Δt:**
A	0,1	0,9
B	0,08	0,92
	The probability that the system will be repaired during the same Δt:	**The probability that the system will NOT be repaired during the same Δt:**
A	0,3	0,7
B	0,35	0,65

The probabilities presented in Table 3 were calculated based on the data resulted from the operation of the fuel and hydraulic systems that served a transport aircraft, for the last **12 months**. They are only used to highlight a calculation methodology.

In a real case scenario, these probabilities are calculated using the basic statistical formulas applied to the data generated by the aircraft in a previous period.

Further, applying Markov's technique, the following expression results:

$$V^0 \cdot \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \\ P_{21} & P_{22} & P_{23} & P_{24} \\ P_{31} & P_{32} & P_{33} & P_{34} \\ P_{41} & P_{42} & P_{43} & P_{44} \end{bmatrix}^m$$

P_{ij} is the transition probability of the aircraft during the time interval Δt, to move from state "i" to state "j". It is calculated according to the probabilities in table 1.2.

$P_{11} = 0{,}9 \cdot 0{,}92 = 0{,}828$
$P_{12} = 0{,}1 \cdot 0{,}08 = 0{,}008$
$P_{13} = 0{,}9 \cdot 0{,}08 = 0{,}072$
$P_{14} = 0{,}1 \cdot 0{,}92 = 0{,}092$

$P_{21} = 0{,}3 \cdot 0{,}35 = 0{,}105$
$P_{22} = 0{,}7 \cdot 0{,}65 = 0{,}455$
$P_{23} = 0{,}3 \cdot 0{,}65 = 0{,}195$
$P_{24} = 0{,}7 \cdot 0{,}35 = 0{,}245$

$P_{31} = 0{,}9 \cdot 0{,}35 = 0{,}315$
$P_{32} = 0{,}1 \cdot 0{,}65 = 0{,}065$
$P_{33} = 0{,}9 \cdot 0{,}65 = 0{,}585$
$P_{34} = 0{,}1 \cdot 0{,}3 = 0{,}03$

$P_{41} = 0{,}3 \cdot 0{,}92 = 0{,}276$
$P_{42} = 0{,}7 \cdot 0{,}08 = 0{,}056$
$P_{43} = 0{,}3 \cdot 0{,}08 = 0{,}024$
$P_{44} = 0{,}7 \cdot 0{,}92 = 0{,}644$

The probability that the aircraft to move from state „1" to state „1", during one iteration is:

$$P_{11} = 0{,}828.$$

The probability that the aircraft to move from state „1" to state „2", during one iteration is:

$$P_{12} = 0{,}008.$$
$$\vdots$$

The probability that the aircraft to move from state „4" to state „4", during one iteration is:

$$P_{44} = 0{,}644.$$

The vector of the initial state is $[1 \quad 0 \quad 0 \quad 0]$, given the fact that the aircraft is perfectly functional at the initial moment, which is state 1.

The probability of the aircraft to be in one of the four states, after 3 iterations (3xΔt) according to Markov's theory is:

$$[1 \quad 0 \quad 0 \quad 0] \cdot \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \\ P_{21} & P_{22} & P_{23} & P_{24} \\ P_{31} & P_{32} & P_{33} & P_{34} \\ P_{41} & P_{42} & P_{43} & P_{44} \end{bmatrix}^3 = [1 \quad 0 \quad 0 \quad 0] \cdot \begin{bmatrix} 0.682 & 0.030 & 0.122 & 0.166 \\ 0.390 & 0.139 & 0.198 & 0.272 \\ 0.530 & 0.066 & 0.270 & 0.124 \\ 0.499 & 0.062 & 0.089 & 0.349 \end{bmatrix}$$
$$= [0.682 \quad 0.03 \quad 0.122 \quad 0.166]$$

1.3. Conclusion

The supremacy in ensuring the quality of a process, whether we are talking about production or maintenance, will be in the hands of those who will have a quality system based on data collection and their interpretation with the help of artificial intelligence.

Applying Markov's methodology results in a vector of states of length "n". Each element of the vector represents the probability that the aircraft will be in each state after a certain time interval.

In the present study, 4 possible states of an aircraft were identified by combining the states of 2 installations (hydraulic installation and fuel installation). The probability vector of the 4 states after 3 iterations was calculated.

With a perspective on the behavior of the aircraft over time, it is possible to achieve an efficient planning of maintenance activities, taking into account the planned missions.

This first chapter outlines a general framework for maintenance management in an aircraft maintenance organization and is a starting point for future research.

Chapter 2

2. Management of large volumes of data in the aeronautical industry - "Big Data"

2.1. Introduction

The notion of "Big Data" is more and more present nowadays. It is a reality that industries are forced to embrace and find the best ways to adapt as quickly as possible, in direct proportion to the rise of this data. This area raises a number of questions about the definition of this concept, how the industry is affected, the principles behind these data, the tools used and last but not least how the aviation industry can benefit from this reality.

This chapter concludes with an innovative solution for storing and managing data resulted from the operation and maintenance of aircraft using Blockchain technology. Given the complexity of this technology, the theoretical notions are applied in a program developed in the Python programming language. It highlights the operating principle of a Blockchain network that records the flight hours, landings and maintenance of an aircraft.

The proposed methodology and technical solution are revolutionizing the aviation industry and opening up new opportunities for companies in the field. The industry revolution is foreshadowed by the revolution of communication, storage and data analysis technologies, as can be understood from the following subchapters.

Big data, or in other words, information of extreme size, diverse and complex, governs any modern organization today. Whether we are talking about employees who produce a lot of data (emails, reports, recordings, social media, etc.) or suppliers and customers who in turn generate various data by the nature of the actions they take, the data is produced throughout the chain. value of a company.

The challenge is to have access to this information, how quickly it is accessed, how it is structured and easy to understand, and how to use computing power to interpret and store it.

2.2. Storage of technical records of an aircraft using Blockchain technology

2.2.1. Introduction

The aim of this paper was to validate the concept of data storage using Blockchain technology in the world of aviation, with an emphasis on improving the traceability of aircraft maintenance activities. It is well known that the aviation industry manages incredibly complex systems, in which failure is not an option. This industry needs Blockchain technology not only for aviation safety reasons, but also to define a new business model, in which airlines can offer customers more trust and more transparency.

At present, passengers who are practically the final customers in the flow of air transport cannot evaluate an airline in terms of maintenance. Improper or incomplete maintenance are prerequisites for an unwanted accident. Moreover, in the event of an air disaster, investigators or audit teams have difficulty understanding how an aircraft has been operated. From a predictive point of view, predictive maintenance models cannot be developed if the data is not really accurate and available. All this can be solved with the implementation of an infrastructure based on Blockchain technology.

In addition to the theoretical explanations, the purpose of this chapter was to highlight the main features of Blockchain technology by developing on a small scale, a decentralized application, using the Python programming language. The program is designed to run on a localhost and store maintenance records and a number of relevant parameters, in the process of tracking the lifespan of an aircraft within a chain of interconnected blocks.

Therefore, the traditional approach to data management is no longer an option for the aviation industry.

2.2.2. Technology description

Blockchain technology was originally developed for the cryptocurrency industry, but it can add value to almost any industry.

Blockchain is a database distributed among members of a private or public network.

There is no central authority responsible for handling the data. Any data transaction is performed based on a protocol, which has been previously accepted by all participants. The result is a digital, secure registry made up of an endless number of interconnected blocks. [5] Each block is linked to the previous one by a cryptographic hash, resulting in a chronologically sorted chain of records. The connection between two consecutive blocks is made due to the fact that each block stores the hash of the previous block. The resulting database is permanent, which means that the data cannot be altered or altered in any way. [6]

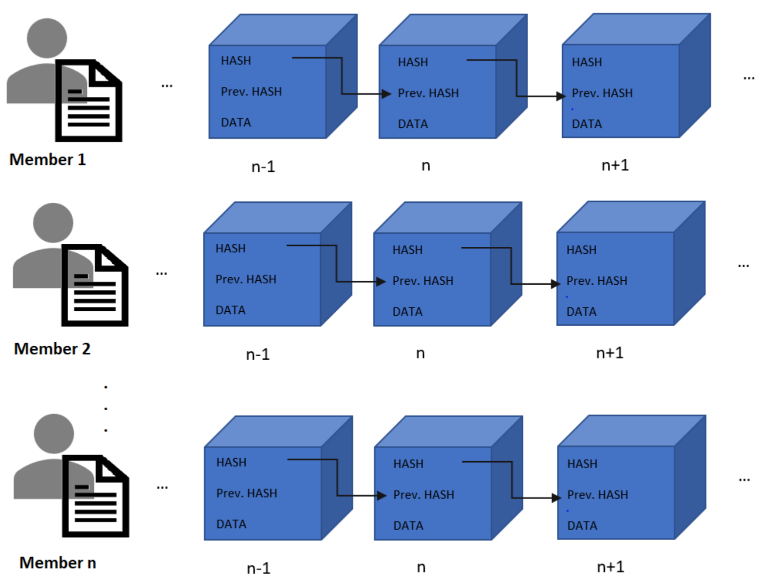

Figure 2.1 Connections between blocks [7]

Basically, the consensus protocol is an algorithm that ensures that the data exchanged within the network is validated by all members.

The concept of Blockchain is about increasing user confidence by creating an accurate and decentralized ledger with multiple layers of security. The digital signature of each block is one of the most important features of a blockchain that involves the use of cryptographic signatures. A hash is like a fingerprint for a digital document. Blockchain technology uses a hashing security algorithm. The most common algorithm of this kind is "SHA256", which is extremely useful because it can generate a unique hash in one direction. This feature means that it is impossible to reverse the cryptographic process and return to the original document.

In addition, SHA256 fulfills the properties of the avalanche effect which states that when changing a single bit in the file to be encrypted, the algorithm will trigger a series of changes, like an avalanche, and the resulting hash will be radically different from the hash of the unchanged document. [8]

Another level of security that makes Blockchain technology so powerful is the concept of "proof of work". [9] Adding a new block to the chain is only possible after a calculation puzzle has been solved. In addition, the validity of the Blockchain system is checked by verifying the correctness of the newly added blocks.

2.2.3. Dezvoltarea unei aplicații blockchain - folosind limbajul de programare Python

The methodology for creating a blockchain application involves going through the following steps:

1. The first one was to set up the Python development environment using Spyder software, available through Anaconda platform
2. The second step was to organize the file structure composed of:
   a. Three python files – one script for each node that corresponds to the parties involved in the network. Each script is different from the other only through the port on which the application is running;
   b. A json file with a list of node addresses;
   c. A json file with five key elements (“FlightHours”, “Landings”, “AircraftEfficiencyStatus”, “StartMaintenanceTask”, “EndMaintenanceTask”) that will be required every time an aircraft event will be registered in the blockchain. The current software was developed for two aircraft events:
      i. Flight event which means an aircraft has just completed a flight and some relevant information of its life cycle are available to be added in the blockchain;
      ii. Maintenance event which means that an aircraft has just started or ended a maintenance task.
3. Next step was Developing the main script that has the following structure:
   a. Importing necessary libraries
   b. Building a blockchain class
   c. Creating a web application
   d. Decentralizing the Blockchain
   e. Running the application and results

2.3. Conclusion

This chapter introduces an innovative way to store and use aviation maintenance records using Blockchain technology. At the same time, the impact of Blockchain technology on the organizations involved was analyzed. The concept was also demonstrated through a web application that highlights the main features of this technology. In addition, the program includes a practical situation and creates a starting point for an application that can be used on a global scale. In other words, the developed program, supported by the theoretical notions presented, represents a step forward towards the realization of a viable and applicable product in the aeronautical industry.

Moreover, the choice to implement Blockchain technology can give passengers the opportunity to evaluate an airline in terms of fleet maintenance.

The storage and structuring of aircraft operation and maintenance data, all embedded in a decentralized network such as Blockchain, will enable the development of innovative new concepts.

Predictive maintenance and pattern identification to support aviation safety decisions will fully benefit from the way data is stored in the Blockchain.

In this context, the accuracy of prediction techniques will increase rapidly, which will fuel the entire industry to the next level of quality.

Chapter 3

3. The influence of the human factor in aircraft maintenance activity. Cumulative interpretation of data using machine learning algorithms

3.1. Introduction

The classic approach to preventing and eliminating aircraft maintenance risks has shown its limitations over time. Given the fact that the aircraft is an extremely complex technical system, and its proper functioning can make the difference between life and death for tens or even hundreds of people, quality assurance of maintenance processes is mandatory.

Given that machine learning algorithms are increasingly used in big data analysis and produce remarkable results that could not have been achieved with the help of classical statistical analysis, this chapter aims to highlight the usefulness of these algorithms in data analysis. 3456 air accidents from 2000 to 2020 registered in the ASRS (Aviation Safety Reporting System).

At the same time, the study analyzed in another 4967 aviation accidents from the same period which were based on the human factor, the correspondence between the type of human error and the flight stage in which the aircraft were. All these aviation accidents had in common the final result of the destruction of the aircraft or the need to carry out repairs. The data was provided by the American National Aviation Safety Data Analysis Center.

In aviation, the principle that "Failure is not an option" is well known both at the operational level and at the management level. Aviation safety means a constant concern for the improvement of all activities that make up or support, directly or indirectly, the flight activity.

3.2. Case study on the performance of machine learning algorithms

3.2.1. Introduction

Whether we are talking about piloting errors or technical problems resulting from poor maintenance, it is well known that 80% of aviation incidents are caused by the human factor [10]. Thus, experts in the field are constantly looking to identify new solutions to improve aviation safety and ways to prevent human error. In these times dominated by innovation, technology is an important asset in optimizing maintenance, aircraft operation and even the investigation of aviation accidents, with unprecedented results so far.

Understanding the past to improve the future is a fundamental mindset that can be applied to all branches of the aviation industry.

All information related to an aircraft, generated over time, can be included in a database so that it can be analyzed in order to develop predictive maintenance suggestions. The same approach can be applied in the analysis of evidence and reports generated after an aeronautical incident. The investigation of an aeronautical incident involves hundreds of hours of collective work and examination of evidence.

This study aims to identify a new tool to improve the process of investigating aviation incidents caused by human error. The use of artificial intelligence in the investigation process to automatically process the accumulation of evidence and resulted reports, will reveal the root cause of an incident. Accelerating an investigation means huge benefits for all parties involved.

In this regard, prototype software has been developed to highlight the power of artificial intelligence in aviation accident investigation. Using machine learning algorithms, a program was trained with data to develop an application capable of automatically determining the root cause of an accident based on statements provided by witnesses.

All data was extracted from the U.S. Aviation Safety Reporting System (ASRS) database for incidents involving the destruction of aircraft or maintenance between 2000 and 2020.

It should be noted that this application does not only refer to the automation of a stage in the investigation of air accidents, but rather sets new standards in the aviation industry with the help of artificial intelligence.

The aerospace industry, like many other industries, has changed due to automation and digitalization as an integral part of the new industrial revolution. The need to reduce human factor involvement has led to the development of many applications such as additive manufacturing, augmented reality, intelligent software and accurate data prediction tools.

3.2.2. Automation of the stage of determining the main cause of an aeronautical incident

Therefore, after an incident or plane crash, the investigators gather in several series descriptive statements and reports to understand what were the causes of the event.

The automation of the browsing stage and the analysis of the text describing an incident consists in the realization of a program, which has as input data the descriptive text of the aeronautical incident and as output data the class to which it belongs.

The purpose of the program is to process all existing statements and reports simultaneously, to understand them and to provide the main cause of the aviation incident, in less than 1 second. The realization of this program involves the training of an algorithm with as many incidents from the past as we know about the outcome, so that the program learns and is able to classify a new event.

The study continues with the second stage, in which 3455 incidents from the period 2000-2020 [11] are randomly extracted from the same database, which were based on both human errors and other factors (conditions of environment, erroneous procedures, technical failures, etc.).

The accidents that had as main cause the human factor are marked with “1” and the others with “0”. We get a ".csv" file with 2 columns:

- the cause of the event (1/0)
- description of the incident in text form

Tabel 3.1 Final results of the algorithms used

	Support vector machine	Naive Bayes	Random Forest
Accuracy	**0.7997**	**0.7777**	**0.7986**

3.3. Conclusion

The influence of the human factor in the management of aeronautical or maintenance activities is particularly important. Understanding the influence of the human factor is also necessary in elucidating the investigation of an aeronautical catastrophe. Current technological tools can help us simplify certain tasks in a process.

The application presented in this chapter does not only refer to the automation of a stage in an aircraft accident investigation, but rather sets new standards in the aviation industry by using artificial intelligence techniques.

At the same time, in this chapter, the main machine learning algorithms with their advantages and disadvantages have been analyzed. These can be extremely useful depending on the data set to be processed and the performance goals.

Chapter 4

4. Monitoring the "health" of technical systems in the aviation industry using artificial neural networks

4.1. Introduction

The Fourth Industrial Revolution [12] opens up new horizons for the way technical systems are managed and administered, regardless of the category to which they belong. As presented in previous chapters, the 4.0 industrial revolution is characterized on the one hand by the interconnection of digital, biological and physical worlds, as well as the development of new technologies such as artificial intelligence, cloud computing, robotics, 3D printing, the Internet of Things and advanced wireless technologies.

The previous chapter demonstrated the use of machine learning algorithms in the analysis of aviation accidents. In the case of air transport, the safety of the passenger is determined by the way in which the technical system (aircraft) operates. Traditional techniques for ensuring the quality of repair / inspection processes are outdated in an industry governed by data, sensors and digital infrastructures that create a new, intangible and seemingly invisible world.

That being said, this chapter focuses on the development of a methodology for the use of aircraft data and the development of innovative software tools for monitoring the technical condition of a system, with the possibility of predicting failures. Finally, the testing and validation of these instruments will be done on a set of real data, collected over time from the engines of a transport aircraft, manufactured after the year 2000.

At the same time, the final results will be supported by other analyzes on various data sets, downloaded from NASA's public portal.

4.2. Aircraft "health" monitoring systems

These days, every modern aircraft is equipped with a so-called aircraft health assessment system to monitor unforeseen events and to reduce unscheduled maintenance and disruption of aeronautical activities.

The word “health” is usually associated with the condition of a biological organism, while the word “monitoring” involves a series of actions to verify and record the behavior of an entity both quantitatively and qualitatively. Therefore, a "health monitoring system" has the same purpose as the intuitive case of a human body. A real-time aircraft health monitoring system can detect, classify and predict failure in time, leading to predictive maintenance with low costs and much longer overall life. In principle, such a system is based on a network of sensors, communication channels and computational resources for analyzing relevant data.

4.3. Development of an artificial neural network to predict a major failure for a number of turbojet engines

4.3.1. Initiation of the algorithm

The data set chosen for this study was downloaded from the NASA portal [13] and consists of 22,631 recordings of 100 turbojet engines of the same type, monitored until they fail. The database used monitors the degradation process through 24 sensors specific to the analyzed engines:

The purpose of the algorithm to be presented below is to identify a different, abnormal behavior characterized by the operation of the 24 sensors, before the failure occurs. Thus, for this study we divided the operating periods of the engines into two areas:

- critical operating area calculated as the last 15% of the operating period - marked with **"0";**

normal operating area, the rest of the range - marked with **"1";**

Therefore in the end the algorithm has to label a given set of 24 sensors, as belonging to one of the 2 ranges.

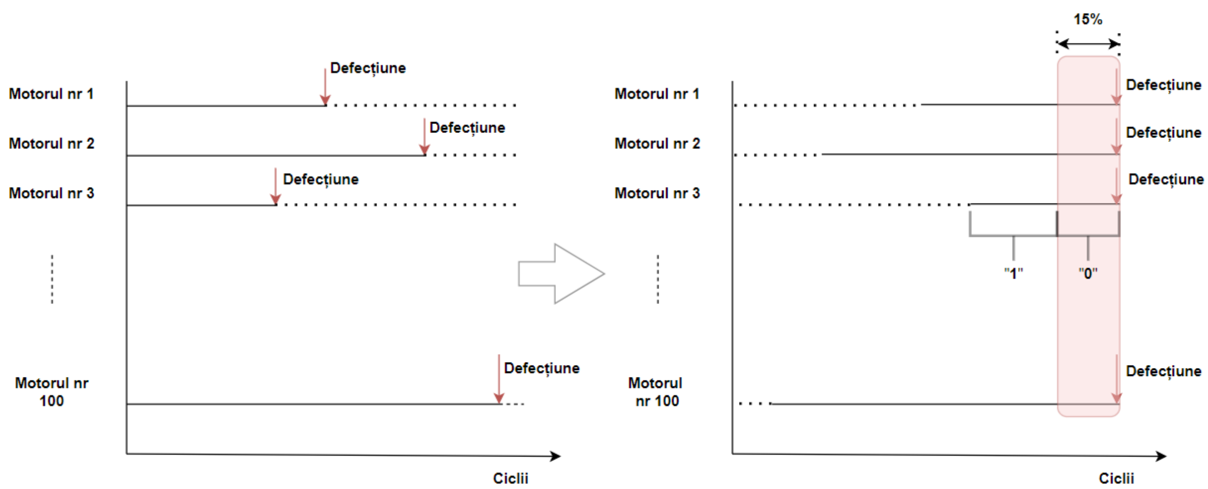

Figure 4.1 The evolution of the 100 engines over time

That being said, the result is an **X-array** that encompasses the values of the sensors of the 100 engines. For each operating cycle there is a binary value (0/1) depending on the range to which it belongs. As we presented above, if the set of sensors corresponds to a cycle in the last 15% of the engine life then we will have the value 0. Considering these working hypotheses, the **vector Y** also results.

The back propagation process is represented in antithesis to the forward propagation process as follows:

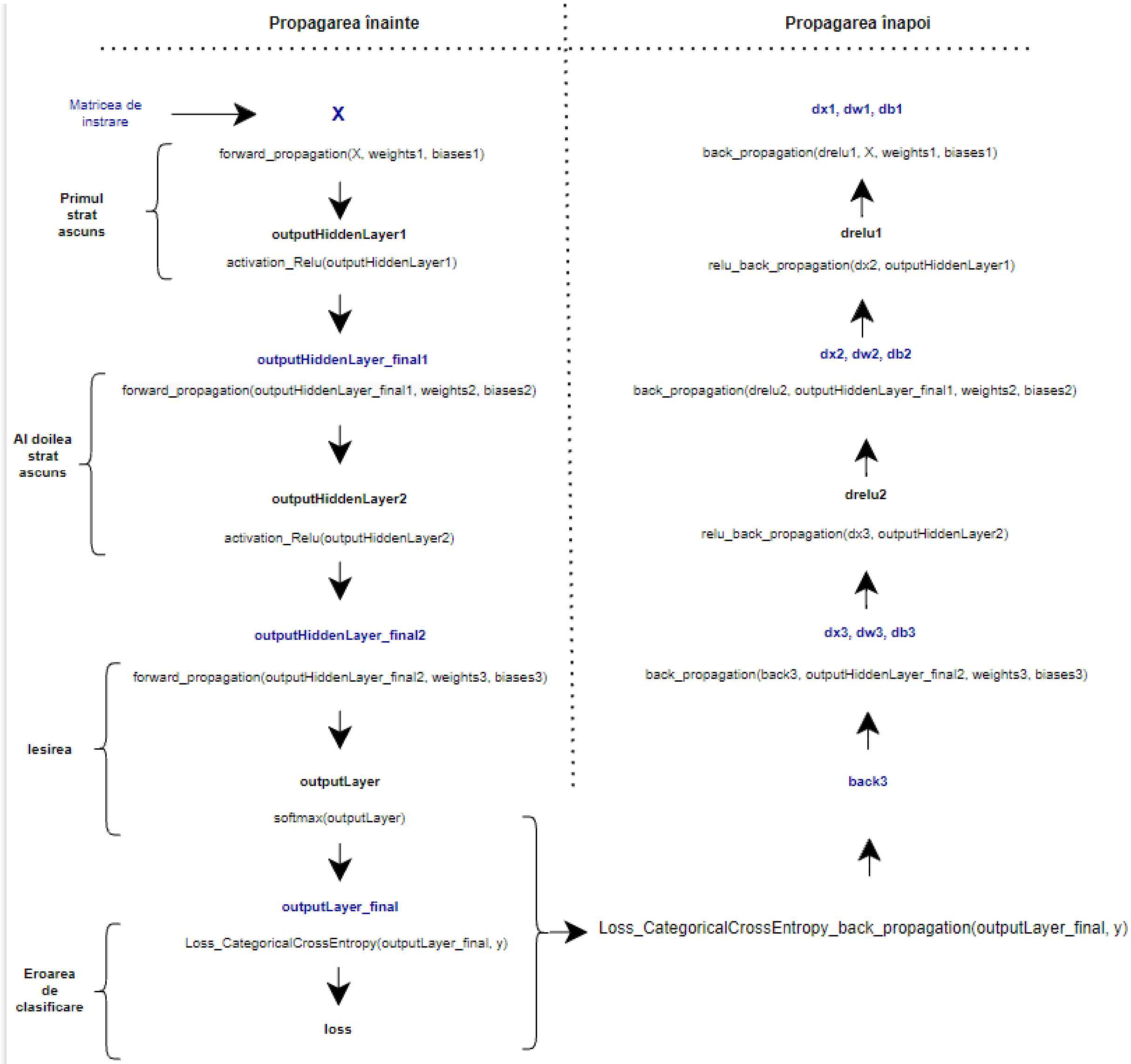

Figure 4.2 Forward propagation vs back propagation

4.3.2. The optimization step with the help of SGD (Stochastic Gradient Descent) with Momentum

Momentum is an extension of the SGD optimization algorithm that makes it easy to exceed the local minimum to reach the global minimum.

In this situation the optimization process consists in updating the parameters over the **150 epochs** using the formulas specific to the SGD algorithm [12] with a moment of **0.9**:

Results:

Epoch:0**, Accuracy:** 0.738**, Classification error** 0.693**, Learning rate:** 0.900

Epoch:1**, Accuracy:** 0.848**, Classification error** 0.524**, Learning rate:** 0.900

Epoch:2**, Accuracy:** 0.848**, Classification error** 0.429**, Learning rate:** 0.891

Epoch:3**, Accuracy:** 0.848**, Classification error** 0.453**, Learning rate:** 0.882

Epoch:4**, Accuracy:** 0.848**, Classification error** 0.512**, Learning rate:** 0.874

Epoch:5**, Accuracy:** 0.848**, Classification error** 0.559**, Learning rate:** 0.865

Epoch:6**, Accuracy:** 0.848**, Classification error** 0.578**, Learning rate:** 0.857

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Epoch:148**, Accuracy:** 0.965**, Classification error** 0.080**, Learning rate:** 0.364

Epoch:149, **Accuracy:** 0.965**, Classification error** 0.080**, Learning rate:** 0.363

Epoch:150**, Accuracy:** 0.965**, Classification error** 0.080**, Learning rate:** 0.361

Time: 0:00:24.723129

In conclusion, it can be seen that at this stage of optimization the value of the classification error, respectively the value of the accuracy stabilizes much faster than in the case of SGD without momentum.

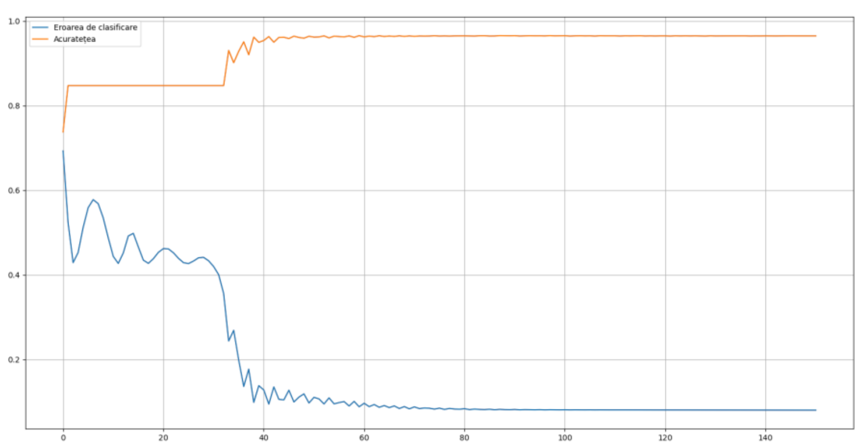

Figure 4.25 Classification error and accuracy at the end of the 150 epochs

4.4. Conclusion

Given the complexity of the technological arsenal that equips today's aircraft, it is obvious that the efficient monitoring of the behavior of a technical system can be done only by analyzing the data generated by it.

Data from technical systems and interpretive solutions turn preventive maintenance into a traditional and even inefficient approach if it is predominant over predictive maintenance.

It therefore reiterates the idea that traditional techniques for ensuring the quality of repair / inspection processes are outdated in an industry governed by data, sensors and digital infrastructures that create a new, intangible and seemingly invisible world.

The prediction algorithm developed is based on the principle of operation of neural networks and is design for binary classification situations. It can differentiate between normal and abnormal behavior.

The performance of a prediction algorithm based on neural networks is due to the correlations and connections it can make over a large data set. The higher the amount, the more optimized the algorithm becomes and the more efficient it becomes. Basically, this type of algorithm mimics the human brain by its ability to adapt over time. These performances cannot be achieved by human technical expertise nor by classical algorithms with predefined rules.

Chapter 5

5. Interoperability of the actors involved in the maintenance activity - maintenance management computer system

5.1. Introduction

Ensuring the quality of the maintenance process in the digital age / Big Data involves, without a doubt, a specialized application adapted to the technical systems involved. In the aeronautical industry, the planning and monitoring of maintenance in an efficient way is done only through an IT system, well integrated within the organizational culture.

This chapter outlines a new quality policy in an aircraft maintenance organization in the context of the new industrial revolution. This doctoral thesis concludes with the validation of the neural network algorithm developed previously and with the conceptual development of an innovative application for the management of aeronautical product maintenance.

The innovative character of this computer system is given primarily by the use of Blockchain technology and the integration of the neural network algorithm in order to make predictive maintenance suggestions.

In addition, this chapter presents a method of concretizing the research activity in this thesis in a computer product synchronized with the requirements of the software market in Romania. The viability of the product and its economic efficiency will be demonstrated through a business plan.

The implementation of a maintenance management system is part of the digitalization strategy of an aeronautical company.

According to the specialized documentation “Computerized maintenance management system”, - C.M.M.S. are software solutions for monitoring, planning and execution
maintenance activities of a technical system.

The main advantages of implementing a CMMS are [14]:

- ensures the traceability of technical operations
- facilitates the connection of several entities in a common ecosystem
- gives users a clear view of the processes
- equipment efficiency analysis

5.2. “Blockchain” module

From the user's point of view, the blockchain module will be a portal to the maintenance history of managed aircraft with various sorting and search elements. These will be displayed as "blocks" and will demonstrate the aircraft's compliance with the maintenance schedule.

The first step is to initialize an inspection as can be seen in the application frontend in figure 5.1:

Figure 5.1 Initialize periodic inspection

Furthermore, the technical team performs the technical inspection, during which time in the computer system this operation is pending - "in progress." After performing the maintenance operations, the head of the technical team will formalize the completion of the operations in the computer application. As can be seen in the figure below, this is the time when the data is sent to the database and their fingerprint in a distributed blockchain register.

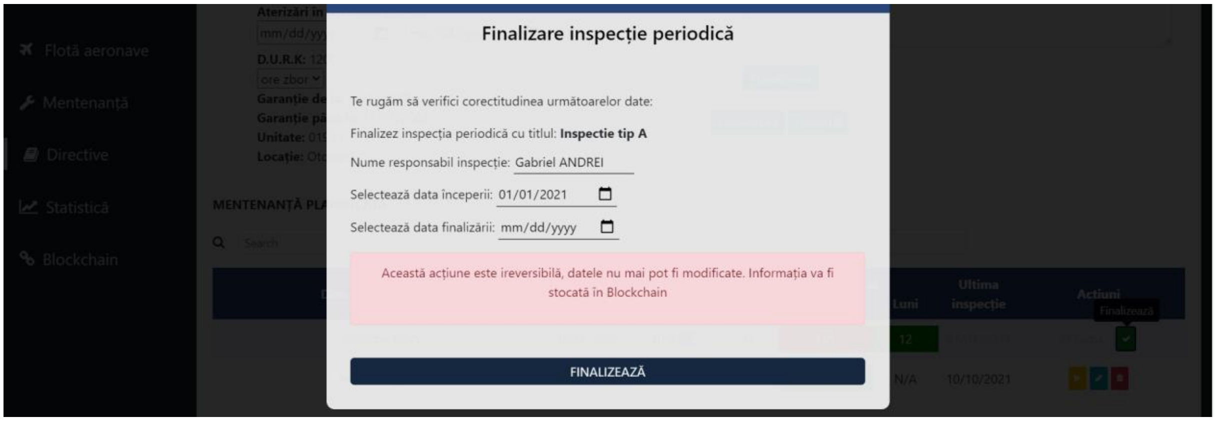

Figure 5.2 Completion of periodic inspection

In the case of a decentralized application (DApp) [15], things work differently because instead of connecting directly to a server, it will also connect to a Blockchain network [16]. However, for the reasons set out above, this study proposes a hybrid application that uses both traditional and blockchain databases.

5.3. Conclusion

Standardization, automation, efficiency, monitoring and sorting are fundamental principles in quality management which, at present, can only be put into practice throughout a digital environment adapted to contemporary operational requirements.

Ensuring the quality of the maintenance process through digitization will significantly increase aviation safety.

The IT system, configured as described in this study, is a key pillar in the quality policy of a modern organization that understands the usefulness of big data and the need for trust from the perspective of customers, shareholders or suppliers.

Chapter 6

6. The economic opportunity of the computer system based on Blockchain technology and machine learning algorithms

6.1. Summary of the business idea

The company aims to develop custom software for computerized maintenance management system (CMMS) to optimize the operations of monitoring, planning and execution of maintenance activities. Systems of this type are useful both in the maintenance area and in the production area because with their help the traceability of the technical operations within the company is ensured. CMMS systems are found in oil and gas production, electricity generation, construction, transportation and other industries where physical infrastructure is important. At the same time, the

IT system allows the connection of several entities / compartments in a common private ecosystem, which allows users to have a clear visibility on the processes within the company.

In the perspective of the industrial revolution 4.0 that can be seen on the horizon, characterized by intelligent devices interconnected by means of sensors, a high potential for CMMS systems is estimated.

6.2. Description of the proposed business

The field of activity of the applicant is defined according to code 6207 - “Custom software development activities (customer oriented software)” with emphasis on CMMS / ERP solutions (in Computerized maintenance management system / Enterprise Resource Planning) with storage of data in a Blockchain protocol.

The main advantages of this business model are the high quality of the resulting products at a relatively low price compared to industry competitors, which together with the possibility of storing and auditing data in a Blockchain protocol, will differentiate the company from others. suppliers of similar products.

6.3. Profit and Loss Account Forecast

According to the business plan, sales are expected starting with the fifth month of activity. As a result of the advertising carried out according to the marketing plan, we expect to reach the level of 2/3 of the products sold per month.

In this context, sales for the first year of operation will be as follows:

- Basic license – 1 product in the first month of sales:39200 lei
- Basic license – 2 products in the second and third month of sales: 78400 x 2 = **156800 lei**
- Basic license – 3 products in months 4,5 and 6 sales: 117600 x 3 = **352800 lei**
- Basic license – 2 products in the last month of sales (December): **78400 lei**

Total: 627200 lei

Tabelul 6.1 Profit and Loss Account Forecast

		AN 1 (12 luni)
1	**REVENUE RELATED TO TURNOVER (REVENUE FROM THE SALE OF FINISHED GOODS AND REVENUE FROM SERVICES RENDERED)**	627,200.00
2	Other operating revenues	-
	OPERATING INCOME – TOTAL (RD.1+2)	**627,200.00**

1	Salaries (including employer contributions)	371,252.00
2	Depreciation and amortization expenses	9,000.00
3	Rents, royalties	24,200.00
4	Utilities (electricity, heat, water, communications)	5,434.00
5	Office running costs (consumables)	4,250.00
6	Advertising, marketing expenses	91,000.00
7	Insurance	0.00
8	Expenditures related to the acquisition of specialized services necessary for the operation, expenses with services provided by third parties	32,800.00
9	Notary fees and translations	2,000.00
10	Inventory items and furniture	8,050.00
11	Other business operating expenses	18,500.00
	TOTAL EXPENSES (RD. 1 la 11)	**551,652.00**
	PROFIT OR LOSS FROM OPERATION	75.548,00
	FINANCIAL REVENUE - TOTAL	-
	FINANCIAL EXPENDITURE - TOTAL	-
	FINANCIAL PROFIT OR LOSS	-
	TOTAL INCOME	627.200,00
	TOTAL EXPENSES	551.652,00
	GROSS PROFIT OR LOSS:	75.548,00
	Profit / income tax	6.272,00
	NET PROFIT OR LOSS:	**69.276,00**

6.4. Conclusion

The quality management of a process / product involves new methodologies adapted to the available technological tools. We live in a time when the volume of data **is growing exponentially** regardless of the name of the industry. The performance of devices, which are either a goal or a means in a production / maintenance activity, also involves a large amount of data. Some companies are aware of the **“BigData”** phenomenon and optimize their work process by capitalizing on their data within the organization. Therefore, the proposed business targets medium and large companies that want to centralize all their data in a single platform but paradoxically in a decentralized way.

Chapter 7

7. General conclusions and future research directions

7.1. General conclusions

This doctoral dissertation focuses on the aeronautical industry at a time when a new industrial revolution is in full swing. The research aims to define a general framework by implementing a quality policy focused on the use of big data. From general to particular, this research proposes concrete solutions to identify the failures of a technical system at an early stage, with the help of artificial intelligence.

That being said, the following conclusions are drawn:

- *Chapter 1*
  - The aeronautical industry is constantly expanding, resulting in the need to use new methods of data storage and interpretation. Quality assurance of maintenance processes is dependent on the use of state-of-the-art technologies
  - Identifying critical components is a first step in developing a predictive maintenance plan to maintain increased reliability.
  - Knowing the operating history of an aircraft and the role of critical systems / components in maintaining flight availability, the state of operation can be determined after a certain number of flight hours using the Markov chain technique.

- *Chapter 2*
  - In the field of aviation, the amount of data is growing exponentially, and the details can make the difference between a safe flight and an unsafe flight. Blockchain technology is an innovative solution for the aviation industry and will revolutionize the way maintenance and traceability of aircraft are ensured.
  - Implementing a Blockchain solution may seem difficult to implement, but the benefits are important for both companies and manufacturers, as well as for passengers. Given that the number of new aircraft flying is growing exponentially, the need for confidence is an ongoing goal.
  - Companies that understand the benefits of a Blockchain solution will have better tracking and evidence of their processes, improve their business, and become more reliable for their customers. As a result, the number of safety incidents will decrease, while revenues will increase considerably.

- *Chapter 3*
  - In this chapter we have analyzed the main machine learning algorithms with their advantages and disadvantages. These can be extremely useful depending on the data set to be processed and the performance goals.
  - The traditional processing of statements and evidence resulting from an investigation is obsolete given the available technological tools. In general, an aviation incident has two main possible causes: human error or technical failure.
  - Classifying an aeronautical incident, at an early stage of the investigation, would not only save time and money in the economy of an investigation but would eliminate subjectivism and allow investigators to focus on details and solutions to avoid a new similar event.

- *Chapter 4*
  - The Big Data phenomenon introduces in the behavior management of a technical system a failure prediction capability clearly superior to a human technical expertise. Machine learning algorithms have the ability to solve the main problem in fault management, namely their identification.
  - At present, identifying the underlying causes of a malfunction is not a priority for this branch of artificial intelligence. From an economic point of view, it is more important for an airline operator to prevent a malfunction than to understand its causes..

- *Chapter 5*
  - The quality management system of an aircraft maintenance organization, proposed in this research activity, focuses on the principle of interoperability. This is implemented through a maintenance management computer system, available to all participants involved in planning and monitoring the maintenance flow.
  - Given the context of the fourth industrial revolution, the proposed IT system ensures an innovative management of sensitive data, generated by the maintenance and operation of aircraft. This is done thanks to Blockchain technology.
  - The computer system uses the artificial neural network algorithm, presented in Chapter 4, in order to identify potential failures in the propulsion systems of the managed aircraft.

- *Chapter 6*
  - This chapter highlights the economic opportunity of the previously proposed software solution. The implementation of a maintenance management IT system, capable of providing a unique level of authenticity to maintenance traceability is an innovative approach and absolutely necessary for the digital society in which we live.
  - Economically, this software product can be a successful business model due to the demand in the local and international market and the innovative nature it brings.

- In addition, the organization of the IT system on modules allows the development of the application in established "low-code" platforms. This approach brings a higher financial return due to low development costs without compromising quality.
- Following the business plan presented in this chapter, the entrepreneur pays off his investment and makes a profit from the first year of activity.

7.2. Contribuții originale

1. Following the analysis of bibliographic materials both in the field of quality management and in the field of aeronautics and machine learning, we performed a comparative analysis of traditional techniques to improve a process, in order to extrapolate on a maintenance flow.
2. Starting from the fundamental reliability analyzes of a technical system, we developed a predictive maintenance model using Markov chains. The result is a statistical model that estimates the technical condition of an aircraft's installations after a certain number of iterations (hours of operation).
3. A new method of certification of maintenance activity in a digital ecosystem has been introduced using Blockchain technology. To this end, an application for the development of aircraft-specific maintenance inspections has been developed, simulating a decentralized network of three virtual entities under the governance of a Blockchain protocol.
4. Following a case study, conducted in an aircraft maintenance organization, in conjunction with the principles of human factors in the literature, I conducted a risk analysis that may lead to the unavailability of an aircraft. This analysis resulted in the need to implement a management strategy based on data analysis.
5. In this regard, we performed a comparative analysis of four regression algorithms and four clarification algorithms by testing on various data sets.
6. Following the analysis of the eight machine learning algorithms, we selected three of them to create an algorithm capable of analyzing text-type evidence, resulting from an aeronautical incident, in order to predict the underlying cause of that event.
7. Also, from the perspective of risk management in the aviation industry, we analyzed a database of aviation incidents from 2000-2020 in order to identify the human factors that contributed to the event, in each flight stage of an aircraft.
8. We built an artificial neural network algorithm to identify potential failures of a turbojet engine at an early stage. This algorithm was trained and tested on a database composed of the operating parameters of 100 turbojet engines.
9. We developed a prototype of a web application for aircraft maintenance management, an application that ensures the authenticity of maintenance processes using Blockchain technology and makes predictions based on data stored using the algorithm developed.

10. We have developed a business plan to demonstrate the economic viability of the developed web application.
11. We have proposed a quality policy for an aircraft maintenance organization specific to the current technological context..

7.3. Direcții viitoare de cercetare

Blockchain technology and the concept of decentralized applications together with machine learning algorithms are constantly evolving. These technologies are constantly evolving, offering new opportunities for research and innovation.

In this context, as a future direction of research, the deepening and realization of a digital certification system for maintenance and repair activities integrated in a Blockchain and IPFS protocol, is a main objective.

In order to ensure the authenticity of the maintenance and repair activities, a digital certificate issuance service can be created, which will be connected to a C.M.M.S. To this end, certain components need to be refined and adapted to operational requirements:

- creation of a web authentication web3, specific for access to a maintenance management application
- solving the limitation of storage space by integrating the IPFS protocol
- simplifying user-application interactions

On the other hand, another future direction of research is to deepen and optimize the algorithms of artificial neural networks to assess the degree of wear of the technical systems of an aircraft.

7.4. Synthesis of published articles

The doctoral student has published **11 scientific papers** in the field of engineering and management, all of which were developed during his doctoral studies, of which **6 as first author and 5 as co-author**, as follows:

- 6 (eight) articles / studies published in ISI listed journals;
- 5 (three) articles / studies published in BDI listed journals;

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